El acceso a las representaciones abstractas durante el reconocimiento visual de palabras y la lectura

Facultad de Psicología

Programa de Doctorado en Lectura y Comprensión

Tesis Doctoral

Valencia, Julio 2018

Presentada por:

Ana Marcet Herranz

Dirigida por:

Manuel Perea Lara

ÍNDICE

1. INTRODUCCIÓN 11

2. OBJETIVOS GENERALES DE LA INVESTIGACIÓN 15

3. INTRODUCCIÓN A LAS PUBLICACIONES 17

3.1 Lectura y poblaciones especiales (colectivos con diversidad funcional) 17

3.2 Similitud visual y entradas léxicas abstractas 18

3.3 Aplicaciones prácticas: Educación y marketing.. 21

4. PUBLICACIONES 23

4.1 Why braille reading is important and how to study it 23

4.2 Buscando las claves de la lectura en personas sordas 33

4.3 Is nevtral NEUTRAL? Visual similarity effects in the early phases of written-word recognition 39

4.4 Tracking the time course of letter visual-similarity effects during word recognition: A masked priming ERP investigation 51

4.5 Visual letter similarity effects during sentence reading: Evidence from the boundary technique ... 87

4.6 Can I order a burger at rnacdonalds.com? Visual similarity effects of multi-letter combinations at the early stages of word recognition 115

4.7 Are you taking the fastest route to the RESTAURANT? The role of the usual letter-case configuration of words in lexical decision.. 133

4.8 Can letter position encoding be modified by visual perceptual elements?.......................... 147

4.9 ¿Pueden los juegos mejorar la habilidad lectora? 167

4.10 ¿Comprarías ropa de DOLCE & BANANA? Similitud visual y percepción de marcas 173

5. CONCLUSIONES... 179

5.1 Efectos de similitud visual 179

5.2 Repercusión para los modelos teóricos de identificación de palabras y lectura 184

5.3 Aplicaciones prácticas 185

6. REFERENCIAS 189

Listado de publicaciones presentadas en esta tesis doctoral e índices de calidad del año 2017 en Scopus, JCR y Latindex

Marcet, A., Jiménez, M. y Perea, M. (2016). Why braille reading is important and how to study it. *Culture and Education, 28*, 811–825. doi:10.1080/11356405.2016.1230295
(Scopus: Q1 [Cultural Studies]; JCR: Factor de impacto 0.719)

Marcet, A., Vergara-Martínez, M. y Perea, M. (2016). Buscando las claves de la lectura en personas sordas. *Ciencia Cognitiva, 10:2*, 36–39.
(Índice Latindex = 33)

Marcet, A. y Perea, M. (2017). Is nevtral NEUTRAL? Visual similarity effects in the early phases of written-word recognition. *Psychonomic Bulletin and Review, 24*, 1180–1185. doi:10.3758/s13423-016-1180-9
(Scopus: Q1 [Experimental and Cognitive Psychology]; JCR: Factor de impacto 3.092)

Gutiérrez-Sigut, E., Marcet*, A. y Perea, M. (2018). Tracking the time course of letter visual-similarity effects during word recognition: A masked priming ERP investigation. Bajo revision en la revista *Cognitive, Affective, and Behavioral Neuroscience.*
(Scopus: Q1 [Cognitive Neuroscience]; JCR: Factor de impacto 2.565)
*Igual contribución de los tres autores, como se indica en el artículo.

Marcet, A. y Perea, M. (2018b). Visual letter similarity effects during sentence reading: Evidence from the boundary technique Bajo revision en la revista *Acta Psychologica*.
(Scopus: Q1 [Developmental and Educational Psychology]; JCR: Factor de impacto 1.862)

Marcet, A. y Perea, M. (2018a). Can I order a burger at rnacdonalds.com? Visual similarity effects of multi-letter combinations at the early stages of word recognition. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 44*, 699–706. doi:10.1037/xlm0000477
(Scopus: Q1 [Experimental and Cognitive Psychology]; JCR: Factor de impacto 2.319)

Perea, M., Marcet*, A. y Vergara-Martínez, M. (2018). Are you taking the fastest route to the RESTAURANT? The role of the usual letter-case configuration of words in lexical decision. *Experimental Psychology*, 65, 98–104. doi:10.1027/1618-3169/a000391

(Scopus: Q2 [Experimental and Cognitive Psychology]; JCR: Factor de impacto 1.206)

*Igual contribución de los tres autores, como se indica en el artículo.

Marcet, A., Perea, M., Baciero, A. y Gomez, A. (2018). Can letter position encoding be modified by visual perceptual elements? *Quarterly Journal of Experimental Psychology*. doi: 10.1177/1747021818789876

(Scopus: Q1 [Psychology (Miscelaneous]; JCR: Factor de impacto 2.129)

Marcet, A. y Perea, M. (2017). ¿Pueden los juegos mejorar la habilidad lectora? *Ciencia Cognitiva, 11*, 26–29.

(Índice Latindex = 33)

Marcet, A. y Perea, M. (2017). ¿Comprarías ropa de DOLCE & BANANA? Similitud visual y percepción de marcas. *Ciencia Cognitiva, 11*:3, 67–70.

(Índice Latindex = 33)

El Dr. Manuel Perea Lara, Catedrático de Universidad de la Universitat de València,

DECLARA:

Que el trabajo titulado *El acceso a las representaciones abstractas durante el reconocimiento visual de palabras y la lectura*, que presenta Ana Marcet Herranz para la obtención del título de doctora, se ha realizado bajo mi dirección y tutoría cumple todos los requisitos para poder optar a su lectura como Tesis Doctoral en la Universitat de València.

Y para que así conste y tenga los efectos oportunos, firmo el presente documento.

Manuel Perea

Valencia, 16 de julio de 2018

Para la realización de la Tesis Doctoral, la investigadora Ana Marcet Herranz ha disfrutado de:

- Una ayuda para contratos predoctorales para la formación de doctores contemplada en el Subprograma Estatal de Formación, del Programa Estatal de Promoción del Talento y su Empleabilidad, en el marco del Plan Estatal de Investigación Científica y Técnica e Innovación (BES-2015-07414).

En este periodo y para difundir el trabajo de investigación recogido en esta Tesis Doctoral, la investigadora Ana Marcet Herranz ha obtenido:

- Una beca de la Psychonomic Society (*Graduate Student Travel Award*) en el año 2016.

- Una Beca de la Sociedad Experimental de Psicología Experimental (SEPEX) para la Difusión de Trabajos de Investigación. Convocatoria 2017-2018.

1. INTRODUCCIÓN

Según la vigesimotercera edición del Diccionario de la Lengua Española (Real Academia Española, 2014), leer es "pasar la vista por lo escrito o impreso comprendiendo la significación de los caracteres empleados" (p. 1321). A pesar de la aparente sencillez de la definición anterior, sabemos que la lectura implica procesos cognitivos muy complejos que requieren, a diferencia del lenguaje hablado, una instrucción específica para su adquisición. Tradicionalmente la lectura se entendía como un proceso ascendente centrado principalmente en la descodificación de las letras que conforman las palabras (Orton, 1937). Pero desde los años 70 la psicolingüística ha puesto de manifiesto la importancia de los conocimientos previos del lector para la correcta comprensión del texto. Es decir, la lectura ya no se entiende como un proceso meramente perceptivo abajo-arriba, sino que se considera un proceso activo en el cual se requieren experiencias previas que, a partir de la información del texto, permitan construir nuevos conocimientos (Carreiras, 1997; Solé, 1987).

Pero, ¿por qué es importante aprender a leer? Desde un punto de vista educativo, leer nos acerca al conocimiento, a través de la lectura podemos aprender conceptos nuevos y descubrir campos de sabiduría sin la necesidad de tener a un experto a nuestro lado. En un contexto social la lectura nos acerca a los demás, nos permite comunicarnos sin estar cerca ni utilizar la voz, entender el mundo que nos rodea, nos sirve para guiarnos, saber dónde nos encontramos y hacia dónde ir. En definitiva, la lectura es esencial para desarrollarnos como personas, aprender y vivir en una sociedad altamente alfabetizada que utiliza más los textos escritos para comunicarse que el cara a cara. Un ejemplo de ello es la utilización de la mensajería instantánea a través del teléfono. En la actualidad es más habitual enviar mensajes escritos que hablando por voz a través de nuestros teléfonos móviles.

Tan importante es aprender a leer como saber cómo funciona dicho proceso. Cuando leemos, tienen lugar, en pocos cientos de milisegundos, una compleja serie de procesos cognitivos que involucran cómputos a nivel perceptivo, ortográfico, fonológico, morfológico, sintáctico y semántico, que han sido analizados en las últimas décadas, tanto en lectores expertos como en el ámbito del desarrollo lector (véase

Rayner, Pollatsek, Ashby y Clifton, 2012, para una revisión reciente de la psicología de la lectura). Una persona adulta automatiza la lectura comprensiva gracias al dominio y la práctica que tiene de ella; ejecuta de manera inconsciente todos los mecanismos necesarios para una lectura eficaz, desde las operaciones más básicas como identificar las letras hasta las más complejas como es asociar a una situación determinada, el significado que tienen las palabras que leemos.

A pesar de que para leer de forma eficiente es necesario ejecutar una larga serie de procesos, en esta tesis nos centraremos principalmente en el reconocimiento de palabras a la hora de abordar la lectura. El reconocimiento de palabras es un tema fundamental en la psicología cognitiva y la psicolingüística (Balota, Yap, y Cortese, 2006; Besner y Humphreys, 1991). Primeramente, para conocer los diferentes niveles y códigos de análisis en el procesamiento del lenguaje, la atención y memoria (por ejemplo, véase Craik y Lockhart, 1972), ya que las palabras son unidades mínimas, relativamente bien definidas que pueden ser analizadas en muchos niveles diferentes: características visuales, letras, fonemas, morfemas y significado, entre otros. Y por otra parte, la investigación sobre el reconocimiento de palabras también ha sido central en el desarrollo de teorías sobre procesos automáticos y atencionales (por ejemplo, Healy y Drewnowski, 1983; LaBerge y Samuels, 1974; Neely, 1977), así como en la investigación sobre el desarrollo de los procesos básicos de reconocimiento de palabras que han dado lugar a un buen número de modelos computacionales (véase Gomez, 2012, para una revisión).

La lectura implica un proceso en el que intervienen varios componentes que deben funcionar adecuadamente. Pero, ¿cuáles son dichos componentes? La psicolingüística ha intentado examinar cuáles son esos componentes a través de la observación y el comportamiento de los lectores a la hora de realizar diferentes tareas relacionadas con la lectura. Para llevar a cabo las diferentes tareas es necesario contar con una serie de técnicas científicas para evaluar los correlatos fisiológicos y neuronales que subyacen, que expliquen el comportamiento de los lectores. Como resultado de estas investigaciones, el procesamiento lector se puede dividir en cuatro niveles que incluyen componentes cognitivos específicos (Cuetos, 1990):

- Procesamiento perceptivo (Identificación de letras: ortografía y fonología)
- Procesamiento léxico (Reconocimiento visual de palabras)

- Procesamiento sintáctico (Entender la estructura a través de reglas)
- Procesamiento semántico (Extraer el mensaje)

La existencia de estos procesos se hace patente cuando existe una dificultad que afecta a un proceso y no a otro. Esto ocurre en diferentes colectivos como pueden ser las personas sordas o las personas ciegas. En cuanto a la lectura en personas sordas, sabemos que hacen un uso efectivo de la información proveniente de la forma visual de las palabras porque su grado de conciencia fonológica es menor que en sus iguales oyentes, lo que repercute en su habilidad lectora (Herrera y Defior, 2005). El caso de las personas ciegas es diferente. Ellos tienen otro sistema para la lecto-escritura: el braille. Esto implica que el proceso lector va a ser diferente al de las personas videntes puesto que la lectura en tinta y la lectura en braille utilizan canales diferentes (la vista y el tacto).

A través de la psicología cognitiva y la neurociencia cognitiva es posible separar los componentes implicados en cada nivel y poder así comprender las dificultades que puedan observarse en algunos lectores. Gracias a esto se puede identificar el nivel donde se encuentra la dificultad y trabajar para poder desarrollar las diferentes competencias que implica cada nivel. En este trabajo nos centraremos en los procesos tempranos del procesamiento de la lectura: el acceso a unidades abstractas en el reconocimiento de palabras.

Un supuesto compartido en los modelos de reconocimiento visual de palabras y lectura es que, a pesar de las diversas fuentes/estilos/caja en que se presentan las palabras escritas (v.g., mesa, mEsA, MESA, o mesa), todas estas instancias activan de manera similar las neuronas (o detectores) responsables del concepto “mesa”. A modo de ilustración, en la Figura 1 se indican dos descripciones neurales (no implementadas) publicados por Grainger, Rey y Dufau (2008) y Dehaene, Cohen, Sigman y Vinckier (2005). Como se aprecia en ambos paneles, se asume un nivel neural de detectores de letras abstractas que se activan ante la presencia de las distintas instancias de una letra, dentro en ambos casos de un modelo de corte jerárquico.

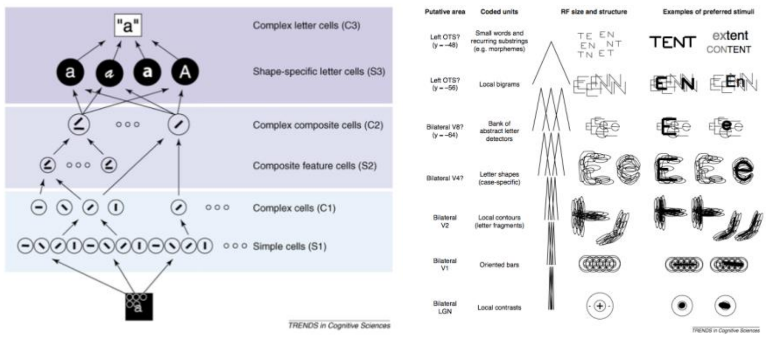


Figura 1. Modelos neurales de reconocimiento de letras/palabras de Grainger et al. (2008) (iquierda) y Dehaene et al. (2005) (derecha).

Si bien existe evidencia de que en adultos, la activación léxica es abstracta e independiente de la apariencia física de las palabras y las letras (Bowers, Vigliocco y Haan, 1998; ver también Carreiras, Perea, Gil-López, Abu Mallouh y Salillas, 2013; Carreiras, Perea y Abu Mallouh, 2012), también lo es que el sistema visual adulto es sensible a características subléxicas de las palabras como la frecuencia (New y Grainger, 2011) y la posición de las letras en la palabra (Acha y Perea, 2010; Ktori y Pitchford, 2008). Un sistema visual adulto eficiente debería por tanto ser capaz de activar representaciones léxicas abstractas, siendo hasta cierto punto insensible a las características físicas de la palabra escrita y sus componentes. Ello no obsta, como se apreciará en varios de los experimentos de esta tesis doctoral, que la similitud visual y la familiaridad de la forma de la palabra juegan un papel modulador en los primeros momentos de la identificación de palabras.

2. OBJETIVOS GENERALES DE LA INVESTIGACIÓN

El principal objetivo de mi tesis doctoral es el análisis de los efectos de similitud visual de letras, tanto en los primeros momentos del reconocimiento visual de palabras, como durante la lectura. Esto se analizará desde una perspectiva conductual (tiempos de reacción), mediante la investigación de seguimiento ocular durante la lectura de frases (en las que la palabra-test sería presentada en la parafóvea), así como empleando un registro de la actividad electrofisiológica (mediante el registro de potenciales relacionados con el evento [PRE]), de manera que se pueda determinar con mayor precisión el curso temporal de los mismos.

Esto quiere decir que no estudiamos qué es lo perceptivo, sino cómo y cuándo se llega de lo perceptivo a lo abstracto y los factores que lo modulan. Para ello, hemos realizado una serie de experimentos en este contexto que pueden tener importantes repercusiones para los modelos teóricos de reconocimiento visual de palabras. Dichos investigaciones engloban a su vez diversos colectivos (personas con ceguera y personas sordas) y ámbitos de la sociedad (educación y marketing).

3. INTRODUCCIÓN A LAS PUBLICACIONES

Seguidamente, se ofrece una panorámica de los diferentes artículos de los que se compone esta tesis doctoral—cada uno de los cuales corresponde a un artículo de investigación, agrupados en categorías.

3.1 Lectura y poblaciones especiales (colectivos con diversidad funcional)

Como se ha indicado anteriormente, poder leer fluidamente requiere el funcionamiento adecuado de varios componentes que trabajan conjuntamente en el proceso lector. Pero, ¿qué pasa cuando falla uno de ellos? Necesariamente se verá afectada alguna función lectora, algún proceso concreto dentro de todo el transcurso desde que vemos la palabra hasta que accedemos a su significado. En los artículos uno y dos nos centraremos en cómo se comporta el sistema perceptivo de las personas sordas y con ceguera durante el proceso lector.

En el artículo 1, se realiza una revisión de los procedimientos para analizar la lectura, con especial atención a la lectura en braille, mediante la comparación con la lectura en tinta. Se presta particular atención en los métodos para poder medir la lectura en braille, desde métodos conductuales a aquellos propios de la neurociencia cognitiva. La realización de esta revisión me permitió tener de primera mano una panorámica de las cuestiones y procedimientos necesarios para la investigación en lectura, tanto en braille como en tinta.

En el artículo 2, se realiza una revisión de la literatura sobre activación fonológica y lectura en personas sordas, así como de sus implicaciones educativas. El origen de dicho artículo fue originalmente un trabajo previo de corte experimental para el que obtuve una beca de iniciación a la investigación en la Universitat de València y en el que examinamos el papel de la información abstracta de las letras en la lectura en personas sordas (Perea, Marcet y Vergara-Martínez, 2016b). En dicho experimento se realizó una tarea de decisión léxica utilizando la técnica del *priming* enmascarado que consiste en presentar, por un periodo breve de tiempo (33-50ms) un estímulo-señal o *prime*. Después del *prime* aparece la palabra-test (o *target*) que los sujetos ven en mayúscula y a la que deben contestar si se trata de una palabra real o no. En lectores oyentes, se observa una ventaja de las letras con las misma caja que con caja diferente en pseudopalabras (GEDA-GEDA < geda-GEDA), cosa que no ocurre en las palabras, donde la identidad nominal produce tiempos de respuesta similares a la identidad física (REAL-REAL = real-REAL) posiblemente a la falta de retroalimentación de los niveles superiores como es la información fonológico-léxica (Jacobs, Ferrand y Grainger, 1995; Perea, Jiménez y Gomez, 2014; Vergara-Martínez, Gomez, Jiménez y Perea, 2014). Este trabajo llevado a cabo con personas sordas reveló que para ellas, la identidad física disfrutaba de una ventaja de procesamiento sobre la identidad nominal no sólo en pseudopalabras, sino también en palabras (GEDA-GEDA < geda-GEDA; REAL-REAL < real-REAL). Esto sugiere la existencia de diferencias fundamentales en las primeras etapas del reconocimiento visual de la palabra de los lectores sordos y oyentes, posiblemente relacionadas con la cantidad de retroalimentación de los niveles superiores de información. A partir de estos hallazgos, realizamos una revisión del tema que examinó si la diferencia que existe a nivel lector entre oyentes y sordos por la dificultad que tienen las personas sordas al no acceder rápidamente a la información fonológica que anula las diferencias físicas entre palabras. A su vez, se acentuó la importancia que tiene la intervención educativa para poder desarrollar una correspondencia más estable entre las letras y sus sonidos en este colectivo, ya que las personas sordas no tienen dificultades en cuanto a la ortografía, pero sí tienen déficits en el procesamiento fonológico.

3.2 Similitud visual y entradas léxicas abstractas

A través de diferentes tareas/técnicas como la decisión léxica, el registro de movimientos oculares durante la lectura y el registro de potenciales relacionados con el evento se han hallado claves importantes de cómo funciona nuestro sistema de reconocimiento visual de palabras. Para poder analizar los procesos más tempranos y automáticos, así como los asociados a la actividad semántica, en los artículos comprendidos entre el tres y el siete se han realizado diversos experimentos utilizando diferentes manipulaciones de similitud visual y varias técnicas (conductual: *priming* enmascarado y presentación individual; movimientos oculares; potenciales relacionados con el evento).

En el artículo tercero, hemos estudiado conductualmente la relación de similitud de un estímulo-señal con la palabra-test empleando la tarea de decisión léxica con la técnica de *priming* enmascarado, seleccionando palabras que contenían letras que son visualmente similares a otros letras (p.e., i-j y u-v, como en frito o neutral; véase Simpson et al., 2012, para una base de similitud visual de letras). Los resultados mostraron menores tiempos de identificación de palabras cuando la palabra-test estaba precedida por una pseudopalabra visualmente similar (frjto-FRITO) que cuando estaba precedida por una pseudopalabra visualmente diferente (frgto-FRITO). Además, los tiempos de reacción para frjto-FRITO fueron sólo ligeramente más lentos que los de la condición de identidad (frito-FRITO). Estos resultados muestran que en los primeros momentos de procesamiento foveal, existe cierto grado de incertidumbre en el código ortográfico para aquellas letras que son visualmente similares a otras.

En el artículo cuarto, el objetivo fue examinar los correlatos electrofisiológicos de los efectos de la similitud visual de las letras que hasta ahora se limitaba a los experimentos conductuales. Llevamos a cabo un experimento de *priming* enmascarado en el que medimos las respuestas de PREs a palabras precedidas por un prime de identidad (dentista-DENTISTA), uno visualmente similar (dentjsta-DENTISTA) o uno visualmente disimilar (dentgsta-DENTISTA), con el objetivo de rastrear el curso del tiempo de los efectos de la similitud visual de letras durante el procesamiento de texto.

En el artículo quinto, se examinaron los efectos de similitud visual de las letras no con palabras presentadas aisladamente (como en el artículo tercero y cuarto), sino durante la lectura de frases. En concreto, exploramos el papel de la similitud visual de las letras en el procesamiento parafoveal durante la lectura de oraciones. Para ello, examinamos las duraciones de las fijaciones oculares de los participantes durante la lectura de oraciones usando presentaciones parafoveales de estímulos visualmente similares (frjto para la palabra frito) o visualmente diferentes (frgto-frito), junto con una condición de identidad (frito-frito). Para ello, utilizamos la técnica del límite (*boundary technique*) de Rayner (1975).

En el artículo sexto empleamos una manipulación novedosa de la similitud visual: no ya entre dos letras individuales (u-v o i-j) sino con combinaciones de letras (rn-m; cl-d). A esta combinación de letras la llamaremos homoglifos. Una palabra escrita a partir de homoglifos por combinación de letras, pude ser fácilmente leída como si estuviera bien escrita (p. ej., docurnento), en particular en los primeros momentos de procesamiento. Esto quiere decir que nuestro sistema perceptivo puede ser fácilmente preso de confusión a causa de esta manipulación. Lógicamente, un elemento importante para minimizar los efectos de similitud de los homoglifos por combinación de letras durante el reconocimiento de palabras es aumentar el espaciado entre caracteres.

En el artículo séptimo, nos ocupamos de los procesos de similitud visual no ya a nivel de letras, sino a nivel de la forma habitual de las palabras. Para ello, seleccionamos palabras que normalmente se presentan en mayúsculas (p.ej., RESTAURANTE, FARMACIA) y palabras que normalmente se presentan en minúsculas (p.ej., molécula, columna). Estas palabras fueron presentadas en un experimento de decisión léxica bien en su caja habitual (RESTAURANTE, molécula) o no (restaurante, MOLÉCULA).

Finalmente, en el artículo octavo se analizan los efectos de similitud visual no a través de la identidad de las letras o de la forma de las palabras, sino a través del orden en que se presentan las letras (p.e., CHOLOCATE puede ser fácilmente confundible con CHOCOLATE; véase Perea, Marcet, y Gomez, 2015, para una breve revisión). En concreto, se examinó si el efecto de transposición de letras en pseudopalabras (p.e., CHOLOCATE vs. el control CHOTONATE) con la tarea de decisión léxica podía estar modulado por características viso-perceptivas como el color o el tipo de presentación (serial vs. paralela).

3.3 Aplicaciones prácticas: Educación y marketing

Los trabajos descritos en los apartados anteriores no tienen únicamente relevancia teórica para los modelos de reconocimiento de palabras y la lectura. Creemos importante ir más allá de la teoría y examinar las posibles implicaciones prácticas de nuestros trabajos. Por ello, además de los artículos relacionados con el campo teórico, también se han realizado artículos de aplicación práctica.

El artículo 9 se centra en el ámbito de la educación. Sabemos de la importancia que tienen las actividades lúdicas en la motivación de los alumnos a la hora de asimilar nuevos conocimientos. Pero, ¿pueden los juegos modular las destrezas que utilizamos a la hora de leer un texto? Una primera aproximación viene de los trabajos de psicología básica que señalan que un déficit en atención visual puede ser causante de la dislexia (Franceschini, Gori, Ruffino, Viola, Molteni y Facoetti, 2013). Si esto es así, el entrenamiento en videojuegos puede mejorar la atención visual y, consiguientemente puede ser empleado para tratar la dislexia. Una segunda aproximación es mediante un juego de mesa como es el Scrabble, que puede ser utilizado para mejorar las habilidades lectoras, ya que modula la forma en la que procesamos las palabras escritas porque puede reorganizar funcionalmente las redes cerebrales encargadas del procesamiento lingüístico (Protzner y col., 2015).

Finalmente, el artículo décimo se centra en las aplicaciones de nuestras investigaciones en las marcas comerciales y el marketing. El marketing es una parte fundamental a la hora de fundar y dirigir una empresa. A través de diferentes estrategias de marketing una marca puede ser fácilmente reconocible entre otras muchas marcas de la competencia. Pero no todo son ventajas, al ser propietario de una marca conocida estás sujeto a sufrir innumerables imitaciones de su producto. Lo mismo pasa con dominios de página web, que pueden ser confundidos por páginas web fraudulentas con las consecuencia de que los usuarios de dichas páginas puedan ser víctimas de *phishing* debido a que nuestro sistema perceptivo tiene dificultades para discriminar correctamente las direcciones web originales de aquellas compuestas por palabras con letras visualmente similares (p.ej., www.rnicrosoft.com).

4. PUBLICACIONES

4.1 Why braille reading is important and how to study it

Abstract

Despite its relevance in theoretical and practical terms, braille reading has received little attention from researchers. Awareness of the pros and cons of the different procedures used to examine braille reading is needed to facilitate the realization of systematic studies and to improve teaching methods in braille reading. This study provides a critical examination of braille reading methods and highlights key points for future studies on tactile reading.

Keywords: reading; braille; cognitive processes; word recognition

Resumen

A pesar de su interés en términos teóricos y aplicados, la lectura en braille ha recibido poca atención por parte de los investigadores. Para facilitar la realización de investigaciones sistemáticas y poder mejorar los métodos de enseñanza de la lectura en braille, es necesario conocer los pros y los contras de los procedimientos empleados para el registro de la lectura en braille. En el presente trabajo, se examinan críticamente los métodos de lectura en braille y se indican claves para futuros trabajos sobre lectura en la modalidad táctil.

Palabras clave: lectura; braille; procesos cognitivos; reconocimiento de palabras

There is no need to emphasize the importance that reading has in the daily lives of all people in all spheres. Consequently, numerous studies have examined the cognitive processes that underlie reading, not only in normal adult readers, but also focusing on the processes of learning to read and the difficulties involved in such processes (see Rayner, Pollatsek, Ashby, & Clifton, 2012, for a review of the psychology of reading). While the great majority of studies that discuss reading have focused on sighted reading, a different modality exists which, although given much less attention in the literature, is particularly relevant from both a theoretical and practical viewpoint: tactile reading using braille.

The braille system, designed by Louis Braille in 1825, is based on a grid of six tactile dots presented in two parallel columns of three dots each. The combination of these six tactile dots signifies a specific letter (e.g., the letter *r* is written ⠗). The use of this system not only provides blind or partially sighted people with a tool for reading and writing, but also allows them to access information, education and culture. Since braille texts in paper format are difficult to manage, device such as 'braille displays' have been developed, which usually consist of 40 cells where the information is presented in braille, and which is then updated on the subsequent (or previous) lines.

Examining the cognitive processes that underlie braille reading may help us to establish the best conditions for learning to read, as well as the mechanisms that help to promote fluent reading. As Legge, Madison, and Mansfield (1999) showed, the age at which a person learns to read braille is a predictor of reading speed. This can lead to improvements in teaching/learning methods both for children and adults who are blind or partially sighted. At the same time, this can also provide visually impaired people with a unique opportunity to integrate into society and to develop their skills to their full potential. The reader of braille is not only able to read written texts, but also to read information in braille in different services (e.g., lifts, maps, signs) and to read information on products (food, medicines). In order for braille reading to be efficient, not only does it need to be learned, but it also needs to be practised. While resources such as audio books are important, in some cases they may also limit the literacy skills of blind people or the partially sighted; whether as a result of children's eagerness to be the same as their peers, or due to the difficulties that older people who have lost their sight experience when trying to learn braille, the percentage of blind people who read braille is on the decrease. In order to promote good levels of proficiency in braille reading, the braille teaching methods based on haptic perception (Spanish Braille Commission, 2015) are in need of modernization, bearing in mind that a high level of braille reading in visually impaired people is associated with higher levels of education and better economic positions (Ryles, 1996).

To carry out systematic studies on braille reading, it is important to obtain measurements that enable us to infer the cognitive processes underlying reading processes. The aim of this study is to carry out a critical analysis of the current methods used to examine braille reading, in such a way that this may serve as a guide for further studies.

While reading braille, readers have to carry out the following operations (Hughes, 2011): (1) decode the dot patterns (perceptive processing) by activating representations of the letters in the cerebral cortex; (2) access the meaning (linguistic processing); and (3) coordinate the movement of the fingers with the perceptive and linguistic processing. In the literature on ocular movements (eyetracking), accepted and validated ocular motor measures exist, which are obtained on the basis of ocular fixation, the range of saccadic movement, regressions and reading speed (see Rayner et al., 2012). Studies on the motor component of braille reading have shown the existence of fundamental differences between visual and tactile modalities (see Hughes, McClelland, & Henare, 2014). Firstly, while the saccadic movements activated when reading 'print' are ballistic, when reading braille, the fingers move across the text from left to right, letter by letter, thus allowing the reader to detect the dots and extract the tactile information. Secondly, while 'print' readers extract visual information through ocular fixation, for braille readers, interruptions to the movement of their fingers means a loss in information collection. Thirdly, while eye regressions are ballistic, benefitting from parafoveal processing (i.e., of the words close to the fixation point), regressions in tactile reading may stop at any moment and do not share the same characteristics for processing neighbouring words. Finally, and in fourth place, reading speed (which is to say the number of words per minute) is approximately three times quicker in the visual modality than the tactile one.

The high level of scientific production related to sight reading has resulted in the development of mathematical models (e.g., E-Z Reader model: Reichle, Pollatsek, Fisher, & Rayner, 1998). In relation to braille, more studies are needed to be able to develop mathematical models. Reading braille involves greater complexities given that readers may use both hands (and sometimes various fingers) in a synchronized way while reading (Mousty & Bertelson, 1985).

The first experimental study on tactile reading was carried out at the beginning of the last century (Bürklen, 1917/1932). Since then, and especially over the last 30 years, braille reading has been studied using different techniques. The next section provides a description of the procedures used to examine braille reading. This is followed by a critical analysis of the pros and cons of each of the techniques described.

1.1 Braille reading measurement methods

In order to systematize the presentation of the different techniques used to examine braille reading, we first provide a description of the chronometric techniques used to identify words. Secondly, we describe the procedures followed by the fingers when reading sentences or text in braille. Thirdly, we show how cognitive neuroscience techniques can be applied to braille reading.

1.1.1 Chronometric techniques for identifying words in braille

The simplest way to examine braille reading is to use chronometric tasks to check word recognition, in a similar way to sighted reading. Paradigmatic examples of this are: (1) lexical decision tasks (i.e., decide if a string of letters is a word or not; e.g., Perea, García-Chamorro, Martín-Suesta, & Gómez, 2012); (2) semantic categorization tasks (i.e., decide if the word presented forms part of a specific category; e.g., decide if the word is masculine or feminine; Bertelson, Mousty, & Radeau, 1992); and (3) pronunciation tasks (Bertelson et al., 1992).

Word recognition experiments in braille are carried out as follows: in the first instance, a group of words are selected in accordance with one or more independent variables (e.g., frequency of use), and then the reaction time and accuracy of responses are recorded as dependent variables. To do this, a braille display needs to be connected to a computer using the appropriate software. For each experimental test, first of all a sign is marked on the braille display to represent the fixation point; after this, a word (or pseudoword) is presented and the computer chronometer is started simultaneously. If the task is one of classification (lexical or categorization decision), the participant uses the hand not used for reading to press a button for 'yes' and another for 'no', as quickly and accurately as possible. If the task is one of pronunciation, the time between the presentation of the word and the commencement of the verbal response is calculated. As an example of a classification task, it is worth highlighting the lexical decision experiment carried out by Perea et al. (2012). In this experiment, the encoding processes used to order the letters in words in tactile reading (braille) and in sighted reading were examined. The pseudowords used in this experiment were created by transposing two letters (*CHOLOCATE*), or by replacing two letters (*CHOTONATE*).

In the visual modality, reaction time and error percentages were substantially greater in the pseudowords created by transposing two letters (*CHOLOCATE*) than in the pseudowords created by replacing letters (*CHOTONATE*), in line with previous studies (Perea & Lupker, 2004). In the tactile modality, the results showed that braille readers were as quick and accurate with both types of pseudowords (*CHOLOCATE = CHOTONATE*). This result is consistent with models that assume that the effects of transposing letters occur in an early stage of visual processing more than in an orthographic stage common to both modalities (the overlap model:

Gomez, Ratcliff, & Perea, 2008).

1.1.2 Procedures for monitoring braille reading

An extremely informative way of studying the intricacies of the cognitive processes involved in reading is to analyse them in real time. In the case of 'print' reading, techniques for tracking ocular movement have enabled a detailed analysis of ocular movement patterns during reading (Rayner et al., 2012). It is clear that a parallel technique is required to be able to track finger movements in order to provide a detailed study of braille reading.

Four types of procedures for tracking finger movement in braille reading are presented below.

Use of a device attached to the fingers. The first known method used to track hand movements when reading braille consisted of attaching a pen-like instrument to the index finger of the reader, whose finger movements then left a trace on the paper (Bürklen, 1917/1932). A basic weakness of this method was that, apart from being uncomfortable for the reader, it could also interfere with fluency in the reading of sentences. Subsequently, Noblet, Ridelaire, and Sylin (1985) developed a method for tracking hand movements in which a light emitting diode was attached to both of the reader's index fingers, with its flashes being recorded using a camera. A third option, used by Hughes (2011), involved attaching a digitizer to the reader's finger, which enabled details to be recorded on speed and acceleration when reading sentences.

Use of video cameras. A procedure used since the 1980s is the recording of finger movements using video cameras. Mousty and Bertelson (1985) designed an experiment using two video cameras. While participants read a text in braille which was positioned on the table, one of the cameras recorded the hand movements made from left to right, while the other recorded finger movements. In addition, a clock was placed on the table which was also recorded by both cameras during the reading, thus enabling the synchronization of both cameras. Although this procedure helps to measure reading speed, the analysis of the data can be costly and timeconsuming. Variations to the method have been proposed using one single camera. Specifically, Miller (1997) used a camera underneath a transparent surface on which was placed a transparent sheet of plastic with embossed letters.

Use of movement trackers (Wii™). Aranyanak and Reilly (2013) designed a sophisticated method in which LEDs were attached to readers' index fingers and an infra-red camera was then used (that of Nintendo Wii™ Wiimote devices) to track finger movements when sliding them across the braille display.

Use of an active braille display. A recent option, introduced by Perea, Jiménez, Martín-Suesta, and Gómez (2015), consists of using the braille display not only as a device for extracting data, but also as a device for recording which letter/s is/are being read. 'Active' braille displays are available on the market that record the position (place and time) of the finger while reading a sentence in braille. In other words, the braille display is connected to a computer that presents the sentences and, at the same time, also collects information on finger movements.

1.1.3 Cognitive neuroscience procedures

A particularly interesting option that has recently become available is the examination of cerebral correlates in braille reading. For this procedure, cognitive neuroscience techniques can be used offering excellent spatial resolution (e.g., functional magnetic resonance) and temporal resolution (e.g., event-related potential). In the first case, participants are required to read texts within the scanner, with the blood flow in different areas of the brain being recorded. Few studies are available in this area, although the experiment carried out by Reich, Szwed, Cohen, and Amedi (2011) is worth highlighting. Reich et al. observed that brain areas associated with the 'orthographic lexical processes' activated when reading braille in the congenitally blind are very similar to the processes activated with sighted reading. With regard to the study of event-related potential, research has focused on the study of attentional and auditory processes and not on reading as such.

1.2 Discussion

The previous section has provided an outline of the methods used to carry out systematic studies on braille reading. While these studies have clear implications in relation to word recognition and reading models (e.g., by dissociating what is specific to sensorial modalities and what is common to both modalities [visual vs. tactile]), they also have considerable practical implications. It is essential that visually impaired children be taught to read braille from an early age if they are to access information in the same way as their sighted peers, in such a way as to provide them with the 'key' to knowledge. Awareness of the pros and cons of each of the experimental techniques used to explore cognitive processes during reading is needed in order to be able to study braille reading processes in a systematic way.

Firstly, we examine the chronometric tasks. These techniques, which are extremely easy to use, offer relevant data on underlying cognitive processes and, in fact, many theoretical models related to word recognition in sighted reading have been developed in the context of lexical and pronunciation decision tasks with isolated words (e.g., the dual-route cascaded model: Coltheart, Rastle, Perry, Ziegler, & Langdon, 2001). Nevertheless, these techniques do present some limitations: (1) words are presented in an isolated way, when in fact they tend to be presented in sentences or in text when reading; (2) only one data point is obtained at the end of the processing: response time.

The second family of procedures is constituted by methods used to monitor braille reading. Undoubtedly, these procedures provide a more 'ecological' reading context, enabling measurements to be taken not only of reading speed, but also of other variables such as acceleration and regressions during reading, among others. The limitations of these procedures tend to be more extrinsic than intrinsic: the devices used are expensive and the data analysis process laborious. 'Active' braille displays undoubtedly provide the simplest case, given that it is the device itself that is used to collect the dependent variables. A limitation of active braille displays is that they only allow the use of one hand (one finger) while tracking the reading. To some extent, this could make the reading process less natural since most braille readers use both index fingers while reading. Devices which are attached to the fingers (e.g., digitizers) may also result in less natural reading processes. Ideally, the most preferable option is the use of video cameras. Nowadays, optoelectronic systems are available, such as Optotrak 3D, that enable the analysis and evaluation of finger movement, and can thus be used for braille reading in a more sophisticated way than in the procedures designed by Mousty and Bertelson (1985).

Finally, techniques emerging from cognitive neuroscience (e.g., functional magnetic resonance) may help to complement previous techniques, particularly when the aim of the research is to ascertain the neural correlates of braille reading, and to compare them with reading processes in sighted reading (see Reich et al., 2011; also see Abboud, Maidenbaum, Dehaene, & Amedi, 2015). The study of reading processes in blind people (or of cognitive processes in general) using cognitive neuroscience techniques may help not only to improve techniques for learning to read, but also to attend to important questions regarding brain plasticity. In fact, the brain is able to adapt to blindness, creating new connections that compensate for the sensorial lack and allow the person to acquire a highly efficient reading system based on touch (see Hannan, 2006).

In summary, studies on braille reading can provide extremely interesting information on the reading process that will also help to improve methods for teaching and learning to read; which should in turn ensure the inclusion and normalization of the learning of braille reading within the classroom and the motivation of blind students. This will help to increase literacy levels among this sector of the population, with all the social advantages that this entails (Ryles, 1996). Moreover, such studies will also help teachers meet the needs of such students in an adequate way, helping them develop their skills to their maximum potential, as well as integrating fully into society (e.g., see the recommendations of the Comisión Braille Española, 2015).

4.2 Buscando las claves de la lectura en personas sordas

Resumen

En este trabajo examinamos los procesos de reconocimiento visual de palabras en una población que muestra generalmente un bajo nivel lector: las personas sordas prelocutivas. Si bien investigaciones recientes han mostrado que las personas sordas hacen uso efectivo de la información proveniente de la forma visual de las palabras, no lo hacen de su sonido. Por tanto, en la intervención educativa, sería conveniente que los profesionales que trabajaran con personas sordas emplearan procedimientos que les permitieran desarrollar una correspondencia más estable entre las letras y sus sonidos.

Palabras clave: lectura; sordera; lenguaje; educación

De acuerdo con la Comisión para la Detección Precoz de la Sordera, aproximadamente uno de cada mil niños en España nace con sordera profunda. Gracias a la inclusión que existe actualmente en nuestras escuelas, niños sordos y oyentes comparten aula, y es en el ámbito de la lecto-escritura donde la gran mayoría de los niños sordos encuentra más dificultades. Es bien conocida la alta relación entre el nivel lector y la capacidad de identificar y utilizar los elementos constituyentes del habla (conciencia fonológica) (Herrera y Defior, 2005). En el caso de los niños sordos, debido a su falta de audición, su grado de conciencia fonológica es menor que en sus iguales oyentes, lo que repercute en su habilidad lectora. Dadas las ventajas que proporciona un buen nivel lector en la sociedad actual, es crucial desarrollar procedimientos que mejoren tanto el proceso de aprendizaje de la lectura como la comprensión lectora de las personas sordas a lo largo de su vida. Para ello, es imprescindible conocer los procesos cognitivos que difieren entre personas sordas y oyentes durante la lectura, en particular respecto al papel de la forma visual de las letras que forman las palabras (ortografía) y su sonido (fonología).

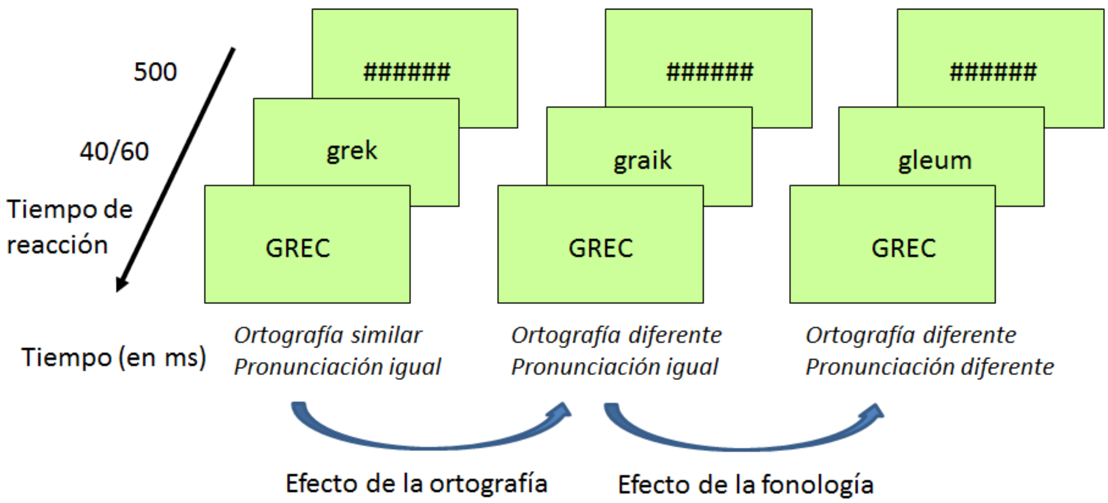


Figura 1. Condiciones de los estímulos-señal y estímulos-test en el experimento de Bélanger et al. (2012). Obsérvese que la palabra francesa *GREC* se pronuncia /gʀɛk/, al igual que los estímulos-señal *grek* y *graik*. La pronunciación de *gleum* es /gløm/.

Para examinar conjuntamente los efectos de la ortografía y la fonología durante el reconocimiento visual de palabras, Bélanger, Baum y Mayberry (2012) realizaron un experimento de decisión léxica (esto es, decidir si una cadena de letras forma una palabra real o no) en el que participaron personas sordas prelocutivas y oyentes. A continuación nos centraremos en las cadenas que sí formaban palabras reales, a las que llamaremos “palabras-test”, ya que nos interesa evaluar la calidad de su procesamiento. Cada palabra-test iba precedida brevemente por otra cadena de letras, que llamaremos “señal”. La manipulación clave en el experimento era el tipo de relación que existía entre la señal y la palabra-test. Había tres tipos de relación (véase la Figura 1): 1) una condición en la que la señal y la palabra-test se pronunciaban de la misma manera y se escribían de forma parecida; 2) una condición en la que la señal y la palabra-test se pronunciaban de la misma manera, pero se escribían de forma diferente; y 3) una condición en la que la señal y la palabra-test no se parecían ni en su pronunciación ni en su escritura. Si la persona es capaz de procesar la información ortográfica de la señal, es de esperar que esto le ayude a leer la palabra-test más rápidamente en la condición 1 que en la 2 (efecto de la ortografía). Si además, la información fonológica de la señal ayuda a leer la palabra-test, esto conllevará un beneficio de la condición 2 sobre la condición 3 (efecto de la fonología). Este estudio desveló que tanto las personas sordas como los oyentes se benefician cuando la señal y la palabra-test se escriben de manera similar (condición 1 más rápida que condición 2), pero sólo los oyentes se benefician cuando la señal y la palabra-test comparten únicamente el sonido (condición 2 más rápida que condición 3). Por lo tanto, los oyentes y las personas sordas se apoyan en la forma visual de las palabras al leer, pero solamente los oyentes se benefician de su sonido (véase Bélanger, Mayberry y Rayner, 2013, para evidencia similar durante la lectura de frases).

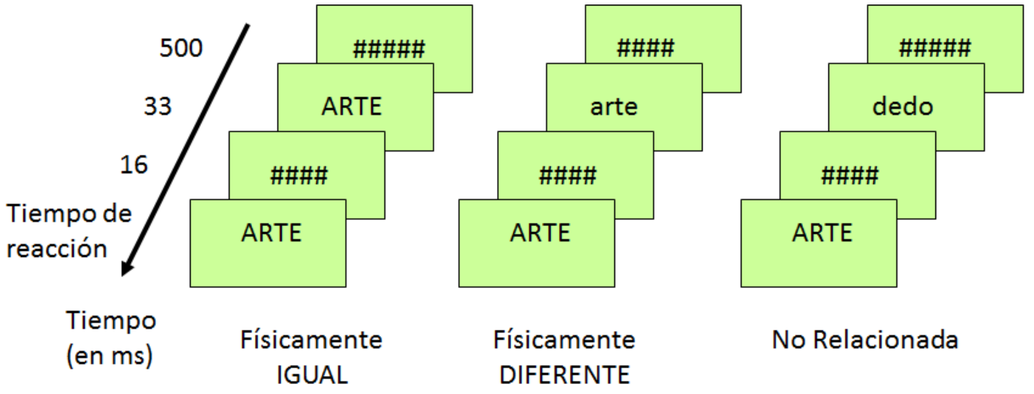


Figura 2. Condiciones de los estímulos-señal y estímulos-test en el experimento de decisión léxica de Perea, Marcet y Vergara-Martínez (2016).

Este déficit en el uso de la información fonológica de las palabras ha sido confirmado recientemente en un estudio de nuestro laboratorio. Se sabe que, en lectores oyentes, el tiempo en reconocer una palabra-test como “ARTE” es igual de rápido cuando va precedida brevemente por la señal “ARTE” (una señal físicamente igual) como por la señal “arte” (igual pronunciación, pero forma visual diferente; Jacobs et al., 1995; véase Vergara-Martínez, Gomez, Jiménez y Perea, 2015, para evidencia electrofisiológica). Esto ocurre incluso para palabras que, pronunciándose igual, se escriben en una grafía diferente, lo que sugiere que este efecto tiene una naturaleza fonológica (Pylkkänen y Okano, 2010). Perea, Marcet y Vergara-Martínez (2016b) estudiaron este efecto en personas sordas prelocutivas (véase la Figura 2). Los resultados mostraron que las personas sordas se benefician menos que los oyentes al leer la palabra-test cuando va precedida de una señal que suena igual, pero visualmente es diferente (arte-ARTE), que cuando la señal es idéntica (ARTE-ARTE; véase la Figura 3). Estos resultados vuelven a mostrar diferencias entre lectores sordos y oyentes, posiblemente porque las personas sordas no acceden rápidamente a la información fonológica que anula las diferencias físicas entre palabras.

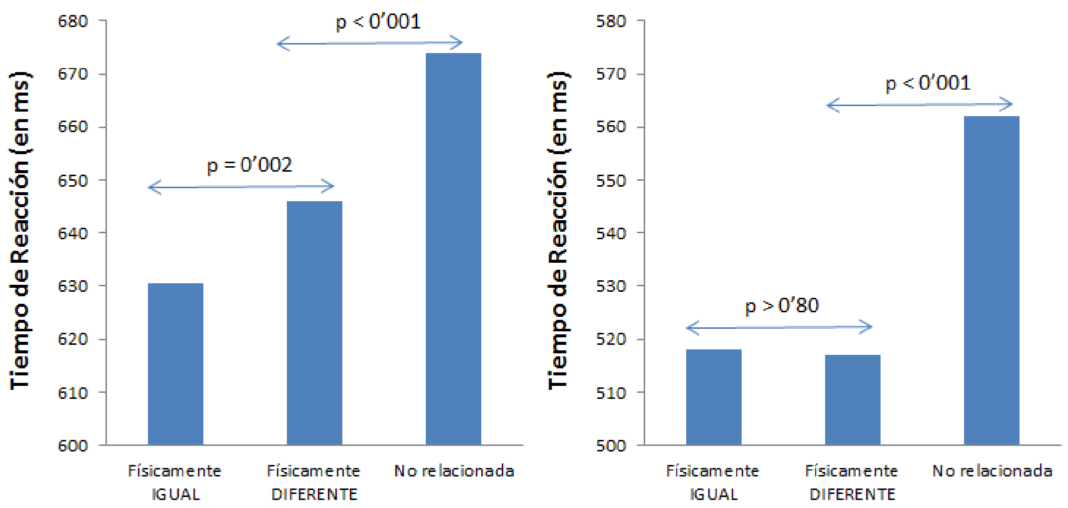


Figura 3. Tiempos de reacción promedio de cada una de las condiciones en el experimento de Perea et al. (2016) con personas sordas adultas (izquierda) y en el experimento paralelo de Perea, Jiménez y Gomez (2015) con personas oyentes adultas (derecha).

En definitiva, en los últimos años ha habido un creciente interés en el estudio de los procesos de lectura en personas sordas. Estas investigaciones han mostrado que las personas sordas no tienen dificultades en cuanto a la ortografía, pero sí tienen déficits en el procesamiento fonológico. Para poder desarrollar una correspondencia adecuada en la relación entre letras y sonidos durante el aprendizaje de la lectura, una posible estrategia es trabajar con diferentes modalidades de intervención como el sistema dactilológico, la lectura labial o la propia producción del habla (véase Lederberg, Schick y Spencer, 2013, para una revisión).

4.3 Is nevtral NEUTRAL? Visual similarity effects in the early phases of written-word recognition

Abstract

For simplicity, contemporary models of written-word recognition and reading have unspecified feature/letter levels—they predict that the visually similar substituted-letter nonword PEQPLE is as effective at activating the word PEOPLE as the visually dissimilar substituted-letter nonword PEYPLE. Previous empirical evidence on the effects of visual similarly across letters during written-word recognition is scarce and non-conclusive. To examine whether visual similarity across letters plays a role early in word processing, we conducted two masked priming lexical decision experiments (stimulus-onset asynchrony = 50 ms). The substituted-letter primes were visually very similar to the target letters (u/v in Experiment 1 and i/j in Experiment 2; e.g., nevtral-NEUTRAL). For comparison purposes, we included an identity prime condition (neutral-NEUTRAL) and a dissimilar-letter prime condition (neztral-NEUTRAL). Results showed that the similar-letter prime condition produced faster word identification times than the dissimilar-letter prime condition. We discuss how models of written-word recognition should be amended to capture visual similarity effects across letters.

Key words: visual similarity; masked priming; lexical access

Contemporary models of written-word recognition and reading in the Roman alphabet share the assumption that lexical access takes place on the basis of case-invariant abstract letter representations which are attained early in processing (Grainger, Dufau, & Ziegler, 2016). For simplicity's sake, these models assume a minimal/null role of visual similarity across letters in lexical access. Using the default parameters in the interactive activation model (Rumelhart & McClelland, 1982) and its successors (e.g., spatial coding model, Davis, 2010), the visually similar substituted-letter prime PEQPLE is as effective at activating the word PEOPLE as the visually dissimilar substituted-letter prime PEYPLE (i.e., each condition yielded 60 processing cycles in masked priming lexical decision using Davis', 2010, simulator)—note that O and Q share all features but one at the feature-letter level (-), whereas O and Y do not share any features (-). Likewise, other leading models posit that all letters are equally confusable (Bayesian reader model, Norris, 2006; Rationale model of eye movements in reading, Bicknell & Levy, 2010) so they would also predict similar word identification times for PEQPLE-PEOPLE and PEYPLE-PEOPLE.

Nonetheless, if we assume that it takes time for the cognitive system to encode letter identity (or letter position), visual similarity across letters should have an impact in the early phases of word processing. Clearly, if PEQPLE-PEOPLE produces faster word recognition times than PEYPLE-PEOPLE, modelers should make an effort to develop in greater depth the underpinnings of the links between the feature and letter levels (i.e., this finding could be used as a benchmark for what is there to simulate). An analogy with letter position coding is relevant here: the slot-coding schemes in the interactive activation model and the Bayesian reader were admittedly oversimplifications (see Rumelhart & McClelland, 1982, p. 89; Norris, 2006, p. 346). The literature on letter transposition effects in the past decades ruled out these schemes and led to more sophisticated accounts of letter position coding (e.g., spatial coding model: Davis, 2010; noisy Bayesian reader model: Norris, Kinoshita, & van Casteren, 2010).

Visual similarity effects have been reported with letter-like digits and letter-like symbols with the masked priming technique. For example, Perea, Duñabeitia, and Carreiras (2008) found that lexical decision times for a target word like MATERIAL were faster when preceded by a visually similar digit prime (M473RI4L; i.e., a prime that included letter-like digits such as 4 = A, 3 = E or 7 =T) or a visually similar symbol prime (e.g., M∆T€R!∆L) than when preceded by a control prime (M568RI2L or M□T%R?□L) (see Kinoshita & Lagoutaris, 2010; Lien, Allen, & Martin, 2014, for converging evidence). Furthermore, visually similar digit/symbol primes were nearly as facilitative as identity primes (Perea et al., 2008).

As visual similarity with letter-like digits/symbols plays a role early during written-word identification, one would expect a parallel effect with visually similar substituted-letter primes. Indeed, a number of experiments on letter identification have obtained effects of visual similarity (e.g., the letters B and R are more confusable than B and G; for review, see Mueller & Weidemann, 2012). However, the empirical evidence in the word recognition literature is scarce and non-conclusive. In a single-presentation lexical decision task, Perea and Panadero (2014) found more "word" responses to viotin-type nonwords (i.e., one-letter different nonwords that looked visually similar to their base word [violin]) than to viocin-type nonwords in individuals with dyslexia, but the effect did not occur in normally reading individuals. To study in detail the effects of visual similarity early in processing, masked priming is a better option than a single-presentation paradigm. Kinoshita, Robidoux, Mills, and Norris (2013) conducted a masked priming lexical decision experiment in which a target word (e.g., abandon) could be preceded by: a) a visually similar digit prime (484NDON; 4 is visually similar to A and 8 is visually similar to B); b) a visually dissimilar digit prime (676NDON); c) a visually similar letter prime (HRHNDON; H is visually similar to A and R is visually similar to B); or d) a visually dissimilar letter prime (DWDNDON)—they also included an identity priming condition (ABANDON) and an unrelated condition (PRODUCT). As in prior research, they found faster word identification times for 484NDON-abandon than for 676NDON-abandon—the word identification times for 484NDON-abandon were nearly the same as those for ABANDON-abandon. But the critical finding was that they failed to find a significant difference between HRHNDON-abandon and DWDNDON-abandon.

To explain the null visual similarity effect for substituted-letter primes, Kinoshita et al. (2013) suggested that "the letter representations A and H may be connected by a bidirectional inhibitory link, such that the activation of one drives down the activation of the other" (p. 828) However, a closer look at the priming effects reported by Kinoshita et al. (2013) reveals an 8-ms advantage of HRHNDON-abandon over DWDNDON-abandon (p = .0982)—there were only 20 items/condition (N=37; 740 data points in each cell). In a recent simulation study, Stevens and Brysbaert (2016) claimed: "a properly powered experiment requires at least 1,600 word observations per condition for the orthographic priming study". Thus, it may be premature to conclude that visual similarity across letters does not play a role early in word processing.

The goal of the current masked priming lexical decision experiments was to examine whether visual similarity across letters plays a role in the early phases of written-word recognition using a large number of data points per condition (2160; 80 items/condition; N=27 in each experiment). Each target word was briefly preceded by: a) a lowercase identity prime; b) a visually similar substituted-letter prime; or c) a visually dissimilar substituted-letter prime. In Experiment 1, we used two critical letters ("u" and "v") that had a high degree of estimated visual similarity: 4.93 in a 1-7 Likert scale (Simpson, Mousikou, Montoya, & Defior, 2012) (e.g., neutral-NEUTRAL vs. nevtral-NEUTRAL vs. neztral-NEUTRAL). Experiment 2 was designed to replicate Experiment 1 with a different set of words; furthermore, the critical letters ("i" and "j") had an even greater degree of visual similarity (5.17 out of 7; Simpson et al., 2012).

The predictions are clear. If each letter only activates its own representation early in word processing, possibly via bidirectional inhibitory links across letters (e.g., the letter "j", but not "i" or "o", would activate the abstract representation of "j"), one would expect a similar advantage of the identity condition over both the visually similar and visually dissimilar letter conditions. This outcome would not require any major modifications in contemporary models of written-word recognition. Alternatively, if visual letter similarity plays a role in the early phases of written-word recognition (e.g., the letter "j", and to some degree the visually similar letter "i", would activate the abstract representation of "j"), one would expect an advantage of the visually similar letter condition over the visually dissimilar letter condition. This result would require more elaborated accounts of the feature/letter levels in models of written-word recognition.

Experiment 1

Method

Participants

The participants were 27 undergraduate students from the Universitat de València. All of them were native speakers of Spanish with normal/corrected-to-normal vision. Written informed consent was obtained from all participants.

Materials

We selected two hundred and forty Spanish words from the EsPal subtitle database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras 2013). The average average Zipf frequency was 3.67 (range: 1.71-5.91), the average number of letters was 7.5 (range: 5-11), and the average Levenshtein distance (OLD20) was 2.1 (range: 1.2-4.3). All words had the letters "u" or "v" in an internal position (e.g., NEUTRAL; CAVERNA [cavern]). Target words were presented in capital letters and were preceded by: a) an identity prime in lowercase (identity condition; neutral-NEUTRAL; caverna-CAVERNA); b) a nonword prime in lowercase in which the letter u/v from the base word was replaced by v/u (visually similar letter prime condition; nevtral-NEUTRAL; cauerna-CAVERNA); or c) a nonword prime in lowercase in which the letter u/v from the base word was replaced by a visually dissimilar letter—each keeping a neutral form [i.e., letters with no ascenders/descenders] and the same consonant/vowel status as the visually similar letter prime (visually dissimilar letter prime condition; neztral-NEUTRAL; caoerna-CAVERNA). Likewise, we created 240 nonwords, with the same length as words, using Wuggy (Keeulers & Brysbaert, 2010). All nonwords had the letter "u" or "v" in an internal position (e.g., CARCURA; OLCLIVO) and the same prime-target manipulation as that for the words (i.e., an identity condition, a visually similar letter prime condition, and a visually dissimilar letter prime condition). To counterbalance the prime-target pairs across conditions, we created three lists in a Latin square manner. The words/nonwords are available at http://www.uv.es/amarhe5/VisSim.pdf

Procedure

Participants were tested individually in a silent room. We used DMDX to present the stimuli and register the responses (Forster & Forster, 2003). Participants were informed that, in each trial, they would be presented with a letter string that could form (or not) a word in Spanish. Their task was to press, as quickly and as accurately as possible, the key for "sí" [yes] or "no". The sequence of each trial was as follows: 1) a pattern mask composed of a series of #'s was presented in the center of a CRT screen for 500 ms (the length of the mask was the same as the length of the prime/target); 2) a prime stimulus (in lowercase) replaced the mask in the same spatial location for 50 ms; and 3) a target (in uppercase) replaced the prime in the same spatial location until the participant responded (or 2 sec had elapsed). All stimuli were presented in a fixed-width font (14-pt Consolas). Stimulus presentation was randomized for each participant. Sixteen practice trials preceded the 240 experimental trials. The whole session lasted for approximately 18-20 minutes.

Results and Discussion

Error responses (6.0% for words; 3.6% for nonwords) and correct response times (RTs) shorter than 250 ms (0.0% of the data) were omitted from the latency analyses. The mean RTs for correct responses and accuracy are displayed in Table 1. As in the Kinoshita et al. (2013) experiment, we focused on the word targets—note that masked form priming effects for nonwords tend to be unreliable.

Table 1. Mean lexical decision times (in ms) and accuracy (in parentheses) for words and nonwords in Experiment 1

	Identity	Similar letter	Dissimilar letter
Words	603 (.971)	613 (.968)	624 (.954)
Nonwords	720 (.932)	722 (.944)	726 (.943)

To examine the effect of type of prime (identity [ID], similar letter [SIM], dissimilar letter [DIS]), we conducted linear mixed-effects models using the lme4 and lmerTest R packages. Because of the positive skew of the RT data, we employed −1000/RT (instead of raw RT) as the dependent variable in the latency analyses. There were 6247 observations. We coded the levels of type of prime so that the model would test the two comparisons of interest (i.e., SIM vs. DIS and ID vs. SIM). The model included random intercepts for subjects and items as well as the by-subject and by-items random slopes for type of prime (i.e., the maximal random effects structure). The analyses on the accuracy data were modeled using the glmer function in R (lme4 package), where the accuracy data were coded as binary values (1 = correct, 0 = incorrect).[1]

The statistical analyses of the word identification times showed an 11-ms advantage of the SIM priming condition over the DIS priming condition (613 vs. 624 ms, respectively), t = 2.83, p = .005. In addition, there was a significant 10-ms advantage of the ID priming condition over the SIM priming condition, t = -2.53, p = .012.

The statistical analyses of the accuracy showed higher accuracy in the SIM priming condition than in the DIS priming condition (0.968 vs. .953, respectively), z = -2.45, p = .014, whereas there were no differences in accuracy between the ID and SIM priming conditions (0.971 vs. 0.968, respectively), $|z| < 1$.

The results are straightforward: we found a significant 11-ms advantage of the SIM condition over the DIS condition—this effect was virtually the same for u→v and v u→v substitutions.

This finding suggests that visual similarity across letters does play a role in the early phases of written-word recognition. To reach firmer conclusions, it is important to replicate the experiment with another set of stimuli and critical letters. To that end, we designed Experiment 2. This experiment was parallel to Experiment 1 except that we employed the letters i/j instead of the letters u/v as the visually similar letters.

[1] In both experiments, the pattern of significant effects was the same in standard ANOVAs in which the means were aggregated over items/subjects.

Experiment 2

Method

Participants

Twenty-seven students from the same population as in Experiment 1 took part in the experiment. None of them had participated in Experiment 1.

Materials

We obtained a set of 240 Spanish words from the EsPal subtitle database (Duchon et al., 2013). The average Zipf frequency was 4.08 (range: 3.33-5.50), the average number of letters was 7.6 (range: 5-11), and the average Levenshtein distance was 2.2 (range: 1.3-4.3). All words had the letters “i” or “j” in an internal position (e.g., DENTISTA [dentist]; PASAJERO [passenger]). For each target word, we created three primes: 1) an identity prime (dentista-DENTISTA; pasajero-PASAJERO); 2) a visually similar letter prime (dentjsta-DENTISTA; pasaiero-PASAJERO); 3) a visually dissimilar letter prime (dentgsta-DENTISTA; pasauero-PASAJERO). We also created 240 nonwords in the same manner as in Experiment 1. All nonwords had the letter “i” or “j” in an internal position (e.g., BESTINDA; MOMAJERA). The manipulation for the nonwords was the same as that for the words. The set of words/nonwords is available at http://www.uv.es/amarhe5/VisSim.pdf

Procedure

It was the same as in Experiment 1.

Results and Discussion

Incorrect responses (3.58% for words and 6.03% for nonwords) and correct response times (RTs) shorter than 250 ms (less than 0.02%) were excluded from the latency analyses. The mean RTs for correct responses and accuracy are displayed in Table 2.

Table 2. Mean lexical decision times (in ms) and accuracy (in parentheses) for words and nonwords in Experiment 2

	Identity	Similar letter	Dissimilar letter
Words	606 (.971)	606 (.968)	625 (.954)
Nonwords	738 (.932)	737 (.944)	729 (.943)

The statistical analyses were parallel to those in Experiment 1. That is, we examined the effect of type of prime (identity [ID], similar letter [SIM], dissimilar letter [DIS]) using linear mixed-effects models. There were 6212 observations in the RT data. The model for the RT data included random intercepts for subjects and items as well as the by-subject random slopes for type of prime—the maximal random effects structure model did not converge.

The statistical analyses of the RT data showed a 19-ms advantage of the SIM priming condition over the DIS priming condition (606 vs. 625 ms, respectively), t = 5.05, $p < .001$, whereas there were no signs of a difference (< 1 ms) between the ID and SIM priming conditions (606 ms in both conditions), $|t| < 1$.

The statistical analyses of the accuracy showed parallel results as the latency data: the SIM priming condition was responded to more accurately than the DIS priming condition (0.968 vs. 0.954, respectively), z = -2.45, p = .015, whereas there were no signs of a difference between the ID and SIM priming conditions (0.971 vs. 0.968, respectively), $|z| < 1$.

Thus, as in Experiment 1, we found an advantage of the SIM condition over the DIS condition. Furthermore, the SIM condition behaved similarly to the ID condition—note that the visual similarity of the critical letter pair was higher than in Experiment 1.

General Discussion

The present masked priming experiments examined, using a large number of data points per condition (2160), whether visual similarity across letters plays a role during the early phases of written-word recognition. Results showed a sizable advantage of the visually similar letter (SIM) condition over the visually dissimilar letter (DIS) condition: 11 ms in Experiment 1 (nevtral-NEUTRAL faster than neztral-NEUTRAL) and 19 ms in Experiment 2 (dentjsta-DENTISTA faster than dentgsta-DENTISTA). This finding is consistent with previous facilitative effects of visual similarity for letter-like digits (e.g., 4 in M4TERI4L-MATERIAL) and letter-like symbols (e.g., Δ in MΔTERIΔL-MATERIAL) in masked priming experiments (Kinoshita & Lagoutaris, 2010; Lien et al., 2014; Perea et al., 2008). The divergences between the present data and Kinoshita et al.'s (2013) data with substituted-letter primes are more apparent than real. Kinoshita et al. (2013) found an 8-ms advantage of the visually similar letter condition over the visually dissimilar letter condition ($p = 0.0982$) with a lower number of data points per condition (740).[2]

The current findings have relevant implications for models of written-word recognition and reading. The presence of a masked priming effect of visual similarity with substituted-letter primes implies that there is some degree of ambiguity concerning letter identities in the early phases of word processing (see Norris et al., 2010) and hence, models of written-word recognition should account for this effect (i.e., it can be used as a benchmark for future simulation studies). Indeed, a number of experiments have shown that word identification times (and eye fixation times) are longer for the word BRUNCH, which has a higher frequency one-letter different neighbor (BRANCH), than for a control word (e.g., BUFFET, which does not have higher frequency neighbors) (Grainger, O'Regan, Jacobs, & Segui, 1989; Slattery, 2010; see also Segui & Grainger, 1990, for masked priming evidence). Clearly, if a word's letter

[2] There are some hints in the data that suggest that the degree of visual similarity across letters could modulate the effect. When the letter similarity of the critical pair was 4.93 of 7, we found an advantage of the SIM condition over the DIS condition (11 ms) that was accompanied by an advantage of the ID condition over the SIM condition (10 ms). When the visual similarity of the critical pair of letters was higher (5.17), we found a larger advantage of the SIM condition over the DIS condition (19 ms), whereas there were no signs of a difference between the ID and SIM conditions (< 1 ms). Further research should examine the precise role of visual similarity in this effect.

identities were perfectly attained in the early phases of word processing, one would not expect neighborhood frequency effects to occur during written-word recognition and reading.

In their implementation of the Bayesian reader model, Norris et al. (2011) acknowledged that the assumption of similar confusability for all letters was "unlikely to be an accurate characterisation of human perception" (p. 347). Similarly, in their model of eye movements in reading, Bicknell and Levy (2010) indicated that this assumption was "ignoring work on letter confusability which could be added to future model revisions" (p. 1172). The same argument applies to those computational models of written-word recognition that employ the orthographic coding scheme of Rumelhart and McClelland's (1982) interactive-activation model (e.g., spatial coding model, Davis, 2010)—these models assume an unrealistic letter feature level that only incorporates an uppercase font composed of straight lines.

As Davis (2010) indicated, future implementations of these models should incorporate a more sophisticated letter coding scheme to encode letter representations from their visual features. Three of the main challenges for modelers are how to specify: 1) the most diagnostic visual elements of letters (e.g., lines, curves, intersections, terminations) in the initial phases of word processing (see Blais et al., 2009; Rosa, Perea, & Enneson, 2016, for discussion); 2) how these visual features are dynamically weighted (see Wiley, Wilson, & Rapp, 2016)[3]; and 3) how visual information is mapped onto abstract representations (see Grainger et al., 2016). While a thorough description of these questions would be beyond the scope of this study, what is clear is that additional research is needed to help determine the time course of visual similarity effects across letters in during written-word recognition.

In sum, we found an advantage of visually similar substituted-letter primes over visually dissimilar substituted-letter primes in the initial stages of word processing. This

[3] In a masked priming lexical decision experiment in Arabic, Perea, Abu Mallouh, Mohammed, Khalifa, and Carreiras (2016) found similar RTs in a substituted-letter priming condition that only differed from the target in the number of diacritical marks (e.g., صخفية – صحفية) and in a substituted-letter priming condition that differed in letter shape (صكفية – صحفية). This finding reveals that diacritical marks are encoded very rapidly—note that most letters in Arabic only differ in the number/location of diacritical marks. As Wiley et al. (2016) showed, diacritical marks are the most relevant element to discriminating letters in Arabic.

finding strongly suggests that future implementations of models of written-word recognition and reading should employ more refined letter-feature and letter levels.

4.4 Tracking the time course of letter visual-similarity effects during word recognition: A masked priming ERP investigation

Abstract

Visual similarity effects during early stages of word processing have been consistently found for letter-like digits and symbols. However, despite its relevance for models of word recognition, evidence for letter visual-similarity effects is scarce and restricted to behavioral experiments. In two masked priming experiments, we measured ERP responses to words preceded by an identical (*dentist-DENTIST*), visually similar (*dentjst-DENTIST*), or visually dissimilar prime (*dentgst-DENTIST*) to track the time course of the effects of letter visual-similarity during word processing. In the 230-350 ms time window, the ERPs in the visual dissimilar condition showed larger negative-going amplitudes than in the visual similar condition, which in turn behaved like the identity condition. In a later time window (400-500 ms), the visually similar condition elicited larger negative-going amplitudes than the identity condition. This pattern of findings can be accommodated within those models of word recognition that assume uncertainty concerning letter identities early in word processing that is resolved over time.

Key words: Word recognition; ERPs; Lexical decision; Masked priming

The process of visual word recognition in skilled readers involves extremely efficient mechanisms that, in a few hundreds of milliseconds, convert the visual signal into the appropriate long-term lexical representation despite the similarity between letters (e.g., *prescribe*, but not the visually similar word *proscribe*) (see Grainger, 2018; Grainger, Dufau, & Ziegler, 2017, for recent reviews). However, visual similarity among stimuli seems to influence this process. Previous research has shown that sentences in which some of the letters are replaced by similar symbols or digits (e.g., MΔT3R1ΔL 7H1NGS C0M3 ΔND G0) can be read without much cost (Duñabeitia, Perea, & Carreiras, 2010). Indeed, a number of experiments using Forster and Davis' (1984) masked priming technique (i.e., a procedure that taps the initial stages of word processing; see Grainger, 2008) have consistently reported facilitative effects of visual similarity with letter-like digits and letter-like symbols during word recognition. In the initial demonstration of the effect, Perea, Duñabeitia, and Carreiras (2008) found faster lexical decision times to a target word like *MATERIAL* when preceded by a prime with similar letter-like digits (*M473RI4L*) or symbols (*MΔT€R!ΔL*) than when preceded by a dissimilar prime (*M568RI2L* or *M□T%R?□L*). Furthermore, Perea et al. (2008) found that visually similar primes were nearly as effective as the identity primes (see also Kinoshita, Robidoux, Mills, & Norris, 2013; Perea, Duñabeitia, Pollatsek, & Carreiras, 2009, for converging behavioral evidence).

Molinaro, Duñabeitia, Marín-Gutiérrez, and Carreiras (2009) used event-related potentials (ERPs) to examine the time course of visual similarity effects with words containing similar letter-like digits. In their masked priming experiment, targets that were preceded by an identity prime (e.g., *PRIMAVERA-PRIMAVERA* [spring]) or a similar prime containing letter-like digits (*PR1M4V3R4-PRIMAVERA)* elicited similar ERP waves in the 140-170 and 250-300 ms time windows. However, both ERPs differed from those elicited by a visually dissimilar control condition (e.g., *PR2M8V6R8-PRIMAVERA*). Likewise, in an unprimed semantic categorization experiment, Lien, Allen, and Martin (2014) found an N400 effect (i.e., a component that reflects lexical-semantic processing) that was similar in magnitude for the regular word *APPLE* and its counterpart *4PPL3*.

Taken together, the above-cited findings strongly suggest that the perceptual input produced by words composed of letter-like digits or symbols (*4PPL3*, *M473RI4L,* *MΔT€R!ΔL*) is comparable to that of regular words. Models of visual word recognition can easily accommodate this phenomenon by assuming that letter detectors tolerate "some shape distortion" (Dehaene & Cohen, 2008, p. 458). That is, in a reading context, the letter *A* is the best-matching letter for the non-letter form *4 in M4TERI4L* (see Kinoshita et al., 2013). Therefore, upon presentation of the embedded letter-like digit *4* in *M4TERI4L*, the letter *A* would be activated resulting in a processing advantage of *M4TERI4L-MATERIAL* over the control *M5TERI2L-MATERIAL*.

A research question with important implications to models of visual word recognition is whether these visual similarity effects are restricted to non-letter forms during word recognition or whether they also occur with visually similar letters (e.g., *H→A*: *MHTERIHL* is more visually similar to *MATERIAL* than *MDTERIDL*). Prior studies using isolated letters have consistently shown that visually similar letters (e.g., *A* and *H*) are more confusable than visually dissimilar letters (e.g., *A* and *D*) (e.g., see Mueller & Weidemann, 2012). For instance, using a two-alternative perceptual identification task with masked isolated letters, Kinoshita et al. (2013) found that participants made more errors on a target letter (e.g., *A*) when the distractor was visually similar (e.g., *H*) than when the distractor was visually different (e.g., *D*)—they found exactly the same pattern with letter-like digits (e.g., *4* [but not 6] was confusable with the letter *A*). Thus, one might expect a parallel letter visual-similarity effect with words. However, as argued by Kinoshita et al. (2013), the letter *H* itself is the best-matching letter for the letter form *H* in *MHTERIHL*, and hence the letter *A* would not be activated during the processing of the *MHTERIHL*—note that *A* would be the best-matching letter for *4* (i.e., a non-letter form) in *M4TERI4L*. Therefore, the visually similar prime *MHTERIHL* would not activate *MATERIAL* to a larger degree than the visually dissimilar prime *MDTERIDL*. Indeed, the interactive activation model (McClelland & Rumelhart, 1981) predicts a null effect of letter visual-similarity using the default parameters. For instance, the number of cycles to identify the word CODE is virtually the same when briefly preceded by the visually similar one-letter different prime *CQDE*—*O* and *Q* share all letter features except one in the orthographic scheme of the interaction activation model—and the visually different one-letter different prime *CXDE* (115 vs. 115

processing cycles using Davis, 2010, simulator). A similar null effect occurs when running simulations on other leading models of word recognition (e.g., Davis, 2010, spatial coding model).

Alternatively, one could argue that, in the initial stages of word processing, the identity of the letters that constitute the visual input comes with some degree of uncertainty, as also happens with letter order (e.g., *JUGDE* may be initially processed as *JUDGE*; see Perea & Lupker, 2004). In this scenario, the groups of neurons responsible to encode the visual features of the letter *H* may initially produce evidence compatible not only with the letter *H* but also with other visually similar letters (e.g., *A*). This perceptual uncertainty would be resolved with further processing at later processing stages (see Bicknell & Levy, 2010; Norris & Kinoshita, 2012). Consequently, the letter *H* in *MHTERIHL* could activate to some degree the letter representation of *A* at the early stages of word processing, thus producing a processing advantage of *MHTERIHL-MATERIAL* over a visually different control condition like *MDTERIDL-MATERIAL*.

The empirical evidence of letter visual-similarity effects at the initial moments of word processing is scarce and restricted to behavioral experiments. Kinoshita et al. (2013) conducted a masked priming lexical decision experiment that included priming conditions with letter-like digits ([visually similar] *484NDON-abandon* vs. [visually dissimilar] *676NDON-abandon*) and priming conditions with replaced letters ([visually similar] *HRHNDON-abandon* vs. [visually dissimilar] *DWDNDON-abandon*). For letter-like digits, Kinoshita et al. (2013) found faster word identification times for *484NDON-abandon* than for *676NDON-abandon*, hence replicating the findings reported by Perea et al. (2008). For letter-replacement primes, word identification times were faster for *HRHNDON–abandon* than for *DWDNDON-abandon*, but the difference only approached significance (p = .09). More recently, Marcet and Perea (2017c) conducted two masked priming lexical decision experiments with a larger number of data points per condition than in the Kinoshita et al. (2013) experiment (2,160 vs. 740, respectively). To create the replaced-letter primes from the target words, Marcet and Perea (2017c) substituted a single letter that was visually very similar (e.g., *i*→*j*, as in *dentjst-DENTIST*) or not (e.g., *i*→*g*, *dentgst–DENTIST*) using the Simpson, Mousikou, Montoya, and Defior (2012) ratings of visual letter similarity. To assess how effective the visually similar primes were, they also included an identity condition. Marcet and Perea (2017c) found faster word identification times in the visually similar substituted-letter condition than in the visually dissimilar substituted-letter condition (e.g., *dentjst–DENTIST* was responded to faster than *dentgst–DENTIST*). Furthermore, the visually similar substituted-letter condition produced word identification times that were only slightly slower than those in the identity condition. Likewise, Marcet and Perea (2018a) found faster lexical decision times on a target word when preceded by a visually similar prime containing a multi-letter homoglyph (*docurnent-DOCUMENT*, where *rn* is visually similar to *m*) than when preceded by an orthographically control prime (e.g., *docusnent-DOCUMENT*)—again, the visually similar condition yielded word identification times only slightly slower than those in the identity condition. Thus, the behavioral evidence suggests that letter visual-similarity affects the early moments of word recognition—note that Gomez, Perea, and Ratcliff (2013) provided empirical and modelling evidence that masked priming effects reflect early encoding processes. The limitation of the Marcet and Perea (2017c, 2018a) experiments is that the obtained letter visual-similarity effects cannot be unambiguously attributed to orthographic overlap between the stimuli (i.e., more orthographic overlap between *dentjst* and *DENTIST* than between *dentgst* and *DENTIST*) or to lexical-semantic activation (i.e., more lexical activation from *dentjst* to *DENTIST* than from *dentgst* to *DENTIST*), thus highlighting the need for additional evidence with a technique with better temporal resolution

The main aim of the current masked priming lexical decision experiments was to track the time course of the effects of letter visual-similarity as they unfold in time. Unlike response times—which only provide a response at the end of processing—the ERPs provide online, continuous measures during the course of word processing. We focused on two key components that have been respectively associated to orthographic overlap between prime-target pairs (the N250) and to lexical-semantic interactions (the N400) in masked priming experiments[1]. The N250, is a negative-going component that peaks around 250 ms post target onset, usually ranges from 150 to 350 ms, and has a widespread scalp distribution centered over midline and central-anterior electrode sites. The N250 component is thought to reflect the sub-lexical orthographic overlap between prime and target, as it shows a gradient modulated by orthographic similarity (being more negative to *porch–TABLE* [unrelated] < *teble–TABLE* [one-letter replaced] < *table–TABLE* [identity]; Holcomb & Grainger, 2006; see also Kiyonaga, Grainger, Midgley, & Holcomb, 2007). The N400 is a negative-going component that peaks around 400 ms, ranges approximately from 350 to 500 ms, and has a widespread central scalp distribution. In masked priming experiments, the N400 is larger (i.e. more negative) for word targets when preceded by an unrelated prime (*porch–TABLE*) than when preceded by an orthographically related prime (*teble–TABLE*). In turn, negative-going amplitudes in the N400 are larger in the orthographically related condition (*teble–TABLE*) than in the identity condition (*table–TABLE*) (e.g., see Holcomb & Grainger, 2006). The N250 is a domain-specific component thought to reflect the mapping of orthographic information onto whole-word representations, either directly or using phonological codes. In the context of visual word recognition, the N400 it is thought to reflect an interaction of lexical level (i.e., whole-word units) and the semantic level, matching the orthographic word representations to the concepts stored in memory (see Grainger & Holcomb, 2009, for discussion).

In the present experiments, we recorded both behavioral (word identification times, accuracy) and event-related potential (ERP) measures to target stimuli preceded by a masked prime. The priming conditions were the same as in the behavioral experiments conducted by Marcet and Perea (2017c): (a) a visually similar one-letter replacement prime [SIM] (e.g., *dentjst-DENTIST*); (b) a visually dissimilar one-letter replacement prime [DIS] (e.g., *dentgst-DENTIST*); and (c) an identity prime [ID] (e.g., *dentist-DENTIST*). As in the Marcet and Perea (2017c) experiments, the visually similar

[1] Although an earlier component, namely, the N/P150, has been associated to initial stages of the visual processing of words, we did not focus on the N/P150. The reason is that previous research using one-letter different lowercase primes and uppercase targets (e.g., Holcomb & Grainger, 2006) reported similar ERP responses at the N/P150 time window for one-different letter pairs and identity pairs (e.g., *teble-TABLE* and *table-TABLE)*—note that, unlike the present experiment, Molinaro et al. (2010) employed uppercase primes and uppercase targets (e.g., *PR1M4V3R4-PRIMAVERA*).

letters were i/j (Experiment 1) and u/v (Experiment 2)—these pairs of letters are visually very similar in letter confusability ratings (5.17 and 4.93 out of 7, respectively, in Simpsons et al.'s, 2012, ratings). Behaviorally, we expect faster word identification times in the visually similar (SIM) letter condition than in the visually dissimilar (DIS) letter condition (e.g., *dentjst–DENTIST* faster than *dentgst–DENTIST*) (i.e., the same pattern as in the Marcet & Perea, 2017c, experiments). More importantly, the examination of the ERPs allowed us to track the time course of these differences. If, early in orthographic processing, there were initial uncertainty about the letter identities that constitute the words that is resolved later in processing, the perceptual input initially produced by the SIM condition would be comparable to that of the ID condition (*dentjst-DENTIST* would be processed similarly to *dentist-DENTIST*), but not to the DIS condition (dentgst-DENTIST). In this scenario, we expect that the N250 (i.e., the sub-lexical orthographic component) would be more negative for the DIS than for the SIM condition—note that in the extreme case the SIM condition would elicit ERPs close to that of the ID condition, whereas at a later time window (N400; the lexical-semantic component), the SIM and DIS conditions would behave similarly—and with larger negative-going amplitude than the ID condition. Alternatively, if there were some degree of uncertainty concerning letter identity at both the orthographic and lexical-semantic stages, one would expect larger negative-going amplitudes in the DIS than in the SIM condition not only in the N250 component but also in the N400 component. Finally, if the abstract representations of the letters were accessed early in processing regardless of visual letter-similarity, one would expect similarly larger negative-going amplitudes in the SIM and DIS condition than the ID condition in both N250 and N400 components.

Experiment 1

Method

Participants

A group of 27 undergraduate students from the University of Valencia (Spain) were recruited for this study. The data of 4 participants were discarded because of incomplete data sets (1 participant) and noisy electroencephalogram (EEG; 3 participants: mostly due to blinks and alpha activity) recording. The remaining 23 participants' ages ranged from 18 to 32 years (15 female; mean age = 22 years, SD = 3.7). All participants were native speakers of Spanish with no history of neurological or psychiatric impairment and with normal or corrected-to-normal vision. All participants were right handed, as assessed with a Spanish abridged version of the Edinburgh handedness inventory (Oldfield, 1971). Written informed consent was obtained from all participants.

Materials

We employed a set of 228 word targets extracted from the stimuli used by Marcet and Perea (2017c). The average Zipf frequency in the EsPal database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013) was 3.65 (range: 1.72–5.91), the average number of letters was 7.6 (range: 5–11), and the average Levenshtein distance was 2.2 (range: 1.3–4.3). All words had the letters *i* or *j* in an internal position (e.g., *DENTISTA* [*dentist*]; *PASAJERO* [*passenger*]). For each target word, we created three primes: (1) an identity prime (*dentista–DENTISTA*; *pasajero–PASAJERO*); (2) a pseudoword prime created by replacing a single letter with a visually similar letter (e.g., *i→j, as in dentjsta–DENTISTA*; *j→i, as in pasaiero–PASAJERO*); (3) a pseudoword prime created by replacing a single letter with a visually dissimilar letter (e.g., *dentgsta–DENTISTA*; *pasauero–PASAJERO*)—note that the outline letter shape was the same in the visually similar and visually dissimilar primes. To act as foils in the lexical decision task, we selected 228 pseudoword targets from the Marcet and Perea (2017c) stimuli. All the pseudoword targets had the letters *i* or *j* in a middle position (e.g., *BESTINDA*; *MOMAJERA*) and were preceded by a prime with the same characteristics as in the word trials. To rotate the priming conditions across the word/pseudoword targets, we created three counterbalanced lists in a Latin square manner. The complete set of prime-target stimuli is presented in Appendix A.

Procedure

Participants sat comfortably in a dimly lit and sound attenuated room. All stimuli were presented on a high-resolution monitor that was positioned slightly below eye level, 85–90 cm in front of the participant. The size of the stimuli and distance from the screen allowed for a visual angle of less than 5 degrees horizontally. Stimuli were presented in white 24-pt Consolas font against a dark-gray background. Stimulus display was controlled by Presentation software (Neurobehavioral Systems). All the stimuli were displayed at the center of the screen.

The sequence of events in each trial was as follows: the participant was presented with a pattern mask (a series of "#" signs that matched the length of the target item) for 500 ms. A lowercase prime replaced the mask in the same spatial location for 50 ms, and was replaced by an uppercase target (either a word or a pseudoword) which remained on the screen until the participant responded or 2,000 ms had elapsed. After participants' response a blank screen of a random duration between 700 and 1,000 ms was shown. To minimize participant-generated artifacts in the EEG signal during the presentation of the experimental stimuli, participants were asked to refrain from blinking and moving from the onset of each trial to the set up period after response. Brief 10-second breaks occurred every 60 trials. Every 270 trials there was a brief pause for resting and impedance checking. Participants were asked to decide as fast and accurately as possible if the target stimulus was a real Spanish word or not. They pressed one of two response buttons (either the YES button or the NO button). The hand used for each response was balanced across participants. Lexical decision times were measured from target onset until the participant's response. Each participant was randomly assigned to one of the three counterbalanced lists. The order of the trials was randomized for each participant. Before the experiment began, participants were given a brief 16-trial practice session to acquaint them with the task.

The stimuli used in the practice session were different from those used in the actual experiment. The whole session, including set up, lasted approximately 1.5 hours.

EEG recording and analysis

The electroencephalogram (EEG) was recorded from 29 Ag/AgCl electrodes mounted in an elastic cap (EASYCAP GmbH, Herrsching, Germany) according to the 10/20 system (see Figure 1). Eye movements and blinks were monitored with four electrodes providing bipolar recordings of the horizontal and vertical (over the left eye) electrooculogram (EOG). Signals were sampled continuously throughout the experiment with a sampling rate of 250 Hz, and filtered offline with a bandpass filter of 0.01–20 Hz. Data from scalp and eye electrodes were referenced offline to the average of left and right mastoids. Initial analysis of the EEG data was performed using the ERPLAB plugin (Lopez-Calderon & Luck, 2010) for EEGLAB (Delorme & Makeig, 2004). Epochs of the EEG corresponding to 100 ms pre- to 550 ms post-target onset were analyzed. Baseline correction was performed using the average EEG activity in the 100ms preceding the onset of the target stimuli. Following baseline correction, trials with eye movements, blinks, muscle activity or other artifacts were rejected (25%).[2] All participants had a minimum of 40 acceptable correct trials per condition (ID: M = 53, SD = 10.9; SIM: M = 54, SD = 8.9; DIS: M = 56, SD = 9.1). There were no significant differences in the number of trials accepted per condition (ID vs. SIM: $t(22) = -0.71$, $p = .48$; SIM vs. DIS: $t(22) = -1.13$, $p = .27$; ID vs. DIS: $t(22) = -1.8$, $p = .09$). As in previous similar studies (see Kinoshita et al., 2013; Lupker, Perea, & Davis, 2008; Marcet & Perea, 2017c, 2018a) we focused on the word trials because masked priming effects for nonword trials are absent or minimal.

To characterize the time course and scalp distribution of letter visual-similarity effects (similar vs. dissimilar condition) we performed statistical analyses on the mean voltage values for 2 different time windows: 230-350 ms, and 400-500 ms. These epochs allowed for detailed assessment of the N250 and N400 components

[2] We acknowledge that this segment rejection rate is somewhat high. However, this does not compromise the pattern of observed findings because: i) the minimum number of trials remaining per condition was 40 (mean = 54), note that the initial number of trials per condition in most language experiments is around 40; ii) there were no significant differences between conditions in the number of trials rejected and, therefore, the effects are not likely to be due to more noise in one of the conditions; and iii) we conducted an additional experiment (Experiment 2) that, using a different set of stimuli, replicated these findings using exactly the same analysis parameters.

respectively. The selection of these epochs was based on the visual inspection of the waveforms and prior literature (see Laszlo & Federmeier, 2014, for a data-driven approach to investigate the time course of orthographic and semantic effects that validate the typically used a priori time windows). In a more data-driven manner, we also conducted repeated-measures t-tests at every 4-ms intervals between 1 and 550 ms at all scalp sites for the effects of visual letter similarity (SIM vs. DIS and SIM vs. ID; see Figure 2, panel a). We used a cluster-based approach to correct for multiple comparisons: if a sequence of 15 consecutive t-test samples exceeded the .05 significance level in at least two neighboring electrodes, then an onset latency for a given experimental contrast was considered reliable. If the *p* values from the t-tests were shorter than 15 consecutive time points (60 ms) or only in one isolated electrode, the difference was not considered reliable (see Guthrie & Buchwald, 1991; Gutiérrez-Sigut, Vergara-Martínez, & Perea, 2017, for a similar procedure). The differences shown by this approach are consistent with the selected time windows and electrode groups (see left panel in Figure 2).

Although it is not of theoretical interest here, the contrast between the DIS and ID conditions is included in Figure 2 for comparison purposes (i.e., it shows the typical N250 and N400 effects reported in previous masked form priming experiments, see Holcomb & Grainger, 2006). We analyzed the topographical distribution of the ERP results by including the averaged amplitude values across 3 electrodes of four representative scalp areas (see Figure 1) that resulted from the factorial combination of the factors hemisphere (left vs. right) and anterior-posterior (A-P) distribution (anterior vs. posterior): anterior left (F3, FC1, FC5), anterior right (F4, FC2, FC6), posterior left (CP1, CP5, P3) and posterior right (CP2, CP6, P4). Of note, we employed the same grouping of electrodes as in recent masked priming experiments examining the N250 and N400 conducted in our lab (see Gutierrez-Sigut, Vergara-Martínez & Perea, 2017; Vergara-Martínez, Gómez, Jimenez & Perea, 2015). For each time window, we performed two separate repeated measures analyses of variance (ANOVA) that included the factors hemisphere, A-P distribution, and type of prime (either SIM vs DIS, or SIM vs. ID). As in the Marcet and Perea (2017c) experiments, we focused on the two novel theoretically motivated a priori contrasts (i.e., SIM vs. DIS and ID vs. SIM) rather than on the ID vs. DIS contrast. Nonetheless, for the sake of completeness, Panel a in Figure 2 displays the ID vs. DIS differences in the ERP waves. Unsurprisingly, we obtained larger negative-going amplitudes in the one-letter visually dissimilar priming condition than in the identity condition in the N250 and N400 components, thus replicating prior research (e.g., Grainger & Holcomb, 2006). In all analyses, List (1–4) was included as a dummy between-subjects factor to remove the variance due to the lists (Pollatsek & Well, 1995). Effects of hemisphere or A-P distribution factors are only reported when they interact with the experimental manipulation. Interactions between factors were followed up with simple effects tests.

Results and Discussion

Behavioral results. Error responses (2.8 %) and lexical decision times shorter than 250 ms or longer than 2000 ms (1 observation) were omitted from the latency analyses. To examine the effect of type of prime, we performed ANOVAs that paralleled those conducted with the ERP data (Type of prime: SIM vs. DIS and SIM vs. ID; the dummy factor List was also included) separately for the latency and accuracy data. These analyses were conducted over subjects (*F*1) and over items (*F*2).

The statistical analyses of the word identification times showed a 18 ms advantage of the SIM condition over the DIS condition (687 and 705 ms, respectively), $F1(1,20) = 10.78$, $MSE = 448.2$, $p = .004$, $\eta^2 = .35$; $F2(1,225) = 15.98$, $MSE = 3663.5$, $p < .001$, $\eta^2 = .07$. In addition, we found a 20 ms advantage of the ID condition over the SIM condition (667 and 687 ms, respectively), $F1(1,20) = 6.94$, $MSE = 420.5$, $p = .016$, $\eta^2 = .26$; $F2(1,225) = 7.32$, $MSE = 4383.5$, $p = .007$, $\eta^2 = .03$.

The analyses of the error rates showed that, on average, participants committed fewer errors in the SIM than in the DIS condition (2.2 and 4.0 %, respectively), $F1(1,20) = 8.72$, $MSE = 4.396$, $p = .008$, $\eta^2 = .30$; $F2(1,225) = 8.88$, $MSE = 4.49$, $p = .003$, $\eta^2 = .04$.

There were no differences between the SIM and ID conditions (2.2 and 2.0 %, respectively), both *F*s < 1.[3]

ERP results. Figure 2 (panel b) shows the ERP waves of the Identity (ID), similar (SIM) and dissimilar (DIS) conditions in six representative electrodes from the four areas of interest. The ERPs showed a small negative going potential peaking around 50 ms, followed by a positive potential peaking around 190 ms (ranging from 100 to 240ms). These early components are followed by negative going waves from 240 ms that remained positive until the end of the epoch (550 ms). Within this negativity two negative peaks can be observed approximately at 320 and 390 ms respectively. The first ERP component to show differences in the amplitudes was the N250, a negative-going component that peaked around 320 ms after target onset. For this component, both the DIS condition showed a larger negativity than both the ID and SIM conditions. Further differences were found in the N400 time window, where both DIS and SIM showed larger negative-going amplitudes than the ID condition.

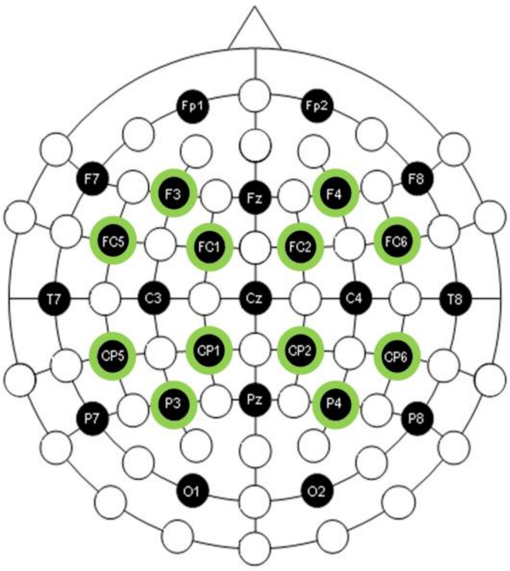


Figure 1. Schematic representation of the electrode montage. Electrodes are grouped in four different areas (anterior-left, anterior-right, posterior-left and posterior-right) for statistical analyses.

[3] We found the same pattern of significant results when using linear mixed effects models using the maximal random effect structure on the inverse-transformed RT data (i.e., -1000/RT) (SIM vs. DIS: t = 4.90, p < .001; ID vs. SIM, t = 4.06, p < .001). We also found the same pattern of significant effects using generalized mixed effects models on the accuracy data (SIM vs. DIS: z < 1, SIM vs. ID: z = 3.90, p = .002).

230-350 ms window

SIM vs. DIS: There was a main effect of type of prime $F(1,20) = 9.92$, $MSE = 8.55$, $p = .005$, $\eta^2 = .33$. The interactions between type of prime and AP distribution and between type of prime and hemisphere were not significant (both Fs < 1). More important, the three-way interaction between type of prime, AP distribution, and hemisphere was also significant $F(1,20) = 5.28$, $MSE = .895$, $p = .032$, $\eta^2 = .21$. Analysis of simple effects tests showed that amplitudes were more positive for the SIM than the DIS condition at anterior left, $F(1,20) = 8.35$, $MSE = 1.45$, $p = .009$, $\eta^2 = .295$, anterior right, $F(1,20) = 10.39$, $MSE = 3.38$, $p = .004$, $\eta^2 = .34$, and posterior left electrodes, $F(1,20) = 12.37$, $MSE = 2.41$, $p = .002$, $\eta^2 = .38$, whereas the effect approached significance in the posterior right electrodes, $F(1,20) = 3.55$, $MSE = 3.03$, $p = .054$, $\eta^2 = .17$.

SIM vs. ID: None of the effects approached significance (all Fs < 1).

400-500 ms window

SIM vs. DIS: The main effect of type of prime, $F(1,20) = 3.21$, $MSE = 19.37$, $p = .088$, $\eta^2 = .14$ and the interaction between type of prime and AP distribution, $F(1,20) = 3.5$, $MSE = 1.01$, $p = .075$, $\eta^2 = .15$, only approached significance. The other interactions were not significant (both ps > .1).

SIM vs. ID: There was a significant main effect of type of prime $F(1,20) = 4{,}41$, $MSE = 18.07$, $p = .049$, $\eta^2 = .18$, and this was accompanied by a significant interaction between type of prime and hemisphere, $F(1,20) = 7.13$, $MSE = .34$, $p = .015$, $\eta^2 = .26$. Analysis of the simple effects tests showed that N400 amplitudes were more positive for the ID than the SIM condition at right electrodes, $F(1,20) = 5.00$, $p = .037$, $\eta^2 = .20$, whereas the effect approached significance at left electrodes, $F(1,20) = 3.67$, $p = .070$, $\eta^2 = .16$. The other interactions did not approach significance (all Fs < 1).

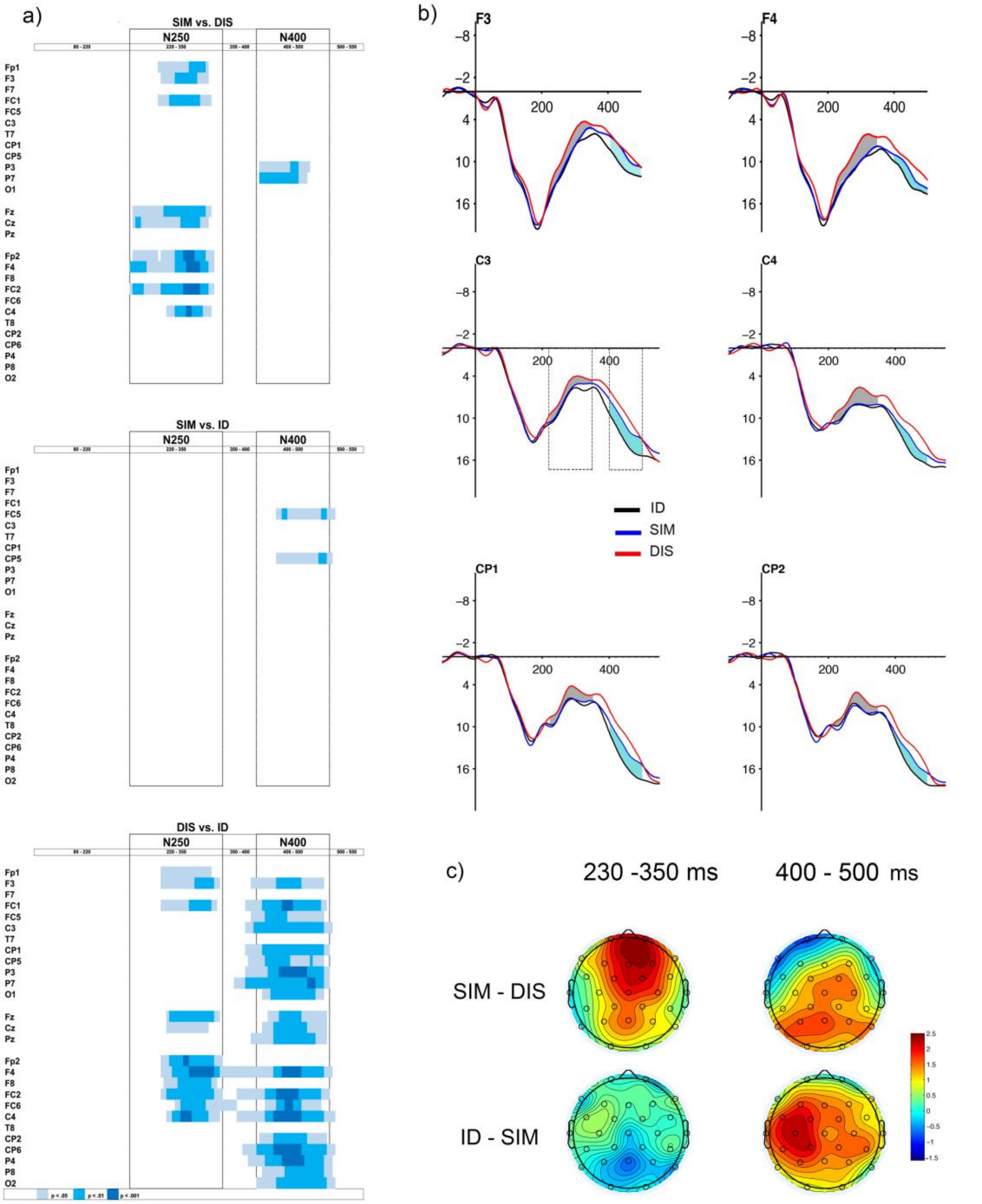


Figure 2. Panel (a) shows the results of the univariate statistical analysis of the time course of the effects of letter visual-similarity for each of the 3 comparisons (SIM vs. DIS; SIM vs. ID; DIS vs. ID). The plots convey the results of the comparisons between 80 and 550 ms at all 27 electrodes (listed in an anterior-posterior progression within the left hemisphere at the top, midline and right hemisphere at the bottom). *P* values are coded from lighter (lighter blue: < .05) to darker (dark blue: < .001). Panel (b) shows the grand average ERPs to targets preceded ID (black line), SIM (blue line) and DIS (red line) priming conditions. The differences between the SIM and DIS conditions in the first time window (230-350 ms) are highlighted in grey. The differences between the SIM and ID conditions in the second time window (400-500 ms) are highlighted in blue. Panel (c) shows the topographic distribution of the effects of visual letter similarity (calculated as the difference in voltage amplitude between the ERP responses to the SIM vs. DIS and ID vs. SIM priming conditions) in the two time windows of the analysis.

In sum, the behavioral data showed that the visually similar condition (SIM condition; e.g., *dentjst-DENTIST*) produced faster word identification times and fewer errors than the visually dissimilar condition (DIS condition e.g., *dentgst-DENTIST*), thus replicating the behavioral findings reported by Marcet and Perea (2017c). More important, the ERP data revealed differences between the SIM and DIS conditions at the 230-350 ms time window, with larger negative-going amplitudes for the DIS than for the SIM condition. Furthermore, the SIM condition produced ERP waves comparable to those of the identity (ID) condition (e.g., *dentist-DENTIST*) (see Figure 2). When inspecting the N400 component, we found more negative-going amplitudes in the SIM than in the ID condition, whereas the difference between the SIM and DIS conditions only approached significance. Taken together, these findings suggest that, at an early orthographic stage, there is some degree confusability when encoding letter identities (N250: ID = SIM < DIS), which tends to vanish at later processing stages.

Experiment 2 was designed to replicate Experiment 1 using another set of items in which the visually similar pairs were u/v instead of i/j (see Marcet & Perea, 2017c, for a similar strategy). This new experiment will allow us to conduct a combined, more powerful analysis of the time course of visual letter-similarity effects.

Experiment 2

Method

Participants

A group of 24 students from the University of Valencia (Spain) were recruited for this study. The data of 4 participants were discarded because of noisy electroencephalogram (EEG; mostly due to alpha activity and blinks) recording. The remaining 20 participants' ages ranged from 18 to 30 years (12 female; mean age = 22.6 years, SD = 4.5). All participants were right handed, native speakers of Spanish with no history of neurological or psychiatric impairment and with normal or corrected-to-normal vision. Written informed consent was obtained from all participants.

Materials

We employed a set of 228 word targets extracted from the stimuli used by Marcet and Perea (2017c)—we chose the same number of items as in Experiment 1. The average Zipf frequency in the EsPal database (Duchon et al., 2013) was 4.08 (range: 3.33–5.50), the average number of letters was 7.5 (range: 5–11), and the average Levenshtein distance was 2.1 (range: 1.2–4.3). All words had the letters *u* or *v* in a middle position (e.g., *NEUTRAL*; *CAVERNA* [*cavern*]). The prime-target conditions were parallel to those in Experiment 1 (i.e., identity condition [*neutral–NEUTRAL*; *caverna–CAVERNA*]; visually similar condition [*nevtral–NEUTRAL*; *cauerna–CAVERNA*]; visually dissimilar condition [*neztral–NEUTRAL*; *caoerna–CAVERNA]*). We also selected 228 pseudoword targets from the Marcet and Perea (2017c) stimuli—these stimuli had the letters *u* or *v* in a middle position (e.g., *CARCURA; OLCLIVO*) and were preceded by a prime with the same characteristics as in the word trials. We created three counterbalanced lists to rotate the priming conditions across the word/pseudoword targets. The complete set of prime-target stimuli is presented in Appendix B.

Procedure

The procedure was the same as in Experiment 1.

EEG recording and analysis

The EEG recording and analysis were the same as in Experiment 1. Trials with artifacts (i.e. eye movements, blinks, muscle activity, etc.) were rejected (36 %). All participants had a minimum of 33 acceptable correct trials per condition (ID: M = 45, SD = 10.0; SIM: M = 46, SD = 8.7; DIS: M = 45, SD = 8.8). There were no significant differences in the number of trials accepted per condition [ID vs. SIM: $t(19) = -1.17$, $p = .26$; SIM vs. DIS: $t(19) = 1.36$, $p = .19$; ID vs. DIS: $t(19) = -0.29$, $p = .77$). Importantly, as this experiment was parallel to Experiment 1—except for the set of items and the visually similar letters (u/v instead of i/j)—we performed statistical analyses on the mean voltage values for the same two different time windows: 230-350 ms, and 400-500 ms and electrode groups. Visual inspection of the morphology of the ERP waves (see below and figure 3) confirmed that the selected time windows and electrode groups allow for the examination of the N250 and N400 components respectively. As in Experiment 1, we did not focus on the comparison between the ID and DIS conditions—again, the ERP data replicates a well-known finding of larger negative-going amplitudes for the one-letter visually dissimilar priming condition than in the identity condition in the N250 and N400 components (see Grainger & Holcomb, 2006).

Results and Discussion

The inferential analyses, both behavioural and ERPs, were parallel to those conducted in Experiment 1.

Behavioral results. Error responses (3.2 %) and lexical decision times shorter than 250 ms or longer than 2000 ms (0 observations) were omitted from the latency analyses. The statistical analyses of the word identification times showed a 22 ms advantage of the SIM condition over the DIS priming condition (671 and 693 ms, respectively), $F1(1,17) = 11.90$, $MSE = 364.22$, $p = .003$, $\eta^2 = .41$; $F2(1,225) = 11.69$, $MSE = 4252.2$, $p < .001$, $\eta^2 = .05$. In addition, the ID priming condition also showed a 16 ms advantage over the SIM condition (655 and 671 ms, respectively), $F1(1,17) = 4.94$, $MSE = 375.6$, $p = .040$, $\eta^2 = .23$; $F2(1,225) = 3.75$, $MSE = 5066.1$, $p = .054$, $\eta^2 = .02$.

The analyses of the error rates showed that, on average, participants committed a similar percentage of errors in the SIM and in the DIS condition (3.5 and 3.9 %, respectively), both *F*s < 1. In addition, participants committed more errors in the SIM than in the ID condition (3.5 and 2.2 %, respectively), $F1(1,17) = 5.76$, $MSE = 3.08$, $p = .028$, $\eta^2 = .25$; $F2(1,225) = 5.43$, $MSE = 41.4$, $p = .021$, $\eta^2 = .02$.[4]

ERP results. Figure 3 (panel a) shows the ERP waves of the Identity (ID), similar (SIM) and dissimilar (DIS) conditions in six representative electrodes from the four areas of

[4] As in Experiment 1, the analyses using linear mixed effects models showed the same pattern as the ANOVAs (latency data: SIM vs. DIS: $t = 3.73$, $p < .001$; ID vs. SIM, $t = 4.02$, $p < .001$; accuracy data: SIM vs. DIS: $z = 2.19$, $p = .028$, SIM vs. ID: $z < 1$).

interest. The ERPs showed the same morphology as Experiment 1. There was a small negative-going potential peaking around 50 ms, followed by a positive potential peaking around 200 ms (ranging from 100 to 240ms). These early components are followed by negative-going waves from 240 ms that remain positive until the end of the epoch (550 ms). Within this negativity, two negative peaks can be observed approximately at 310 and 380 ms respectively. The first ERP component to show differences in the amplitudes was the N250, a negative-going component that peaked around 320 ms after target onset. For this component, the DIS condition showed a larger negative-going amplitude than both the ID and SIM conditions. Further differences were found in the N400 time window, where both DIS and SIM showed larger negative-going amplitudes than the ID condition, especially at posterior electrodes.

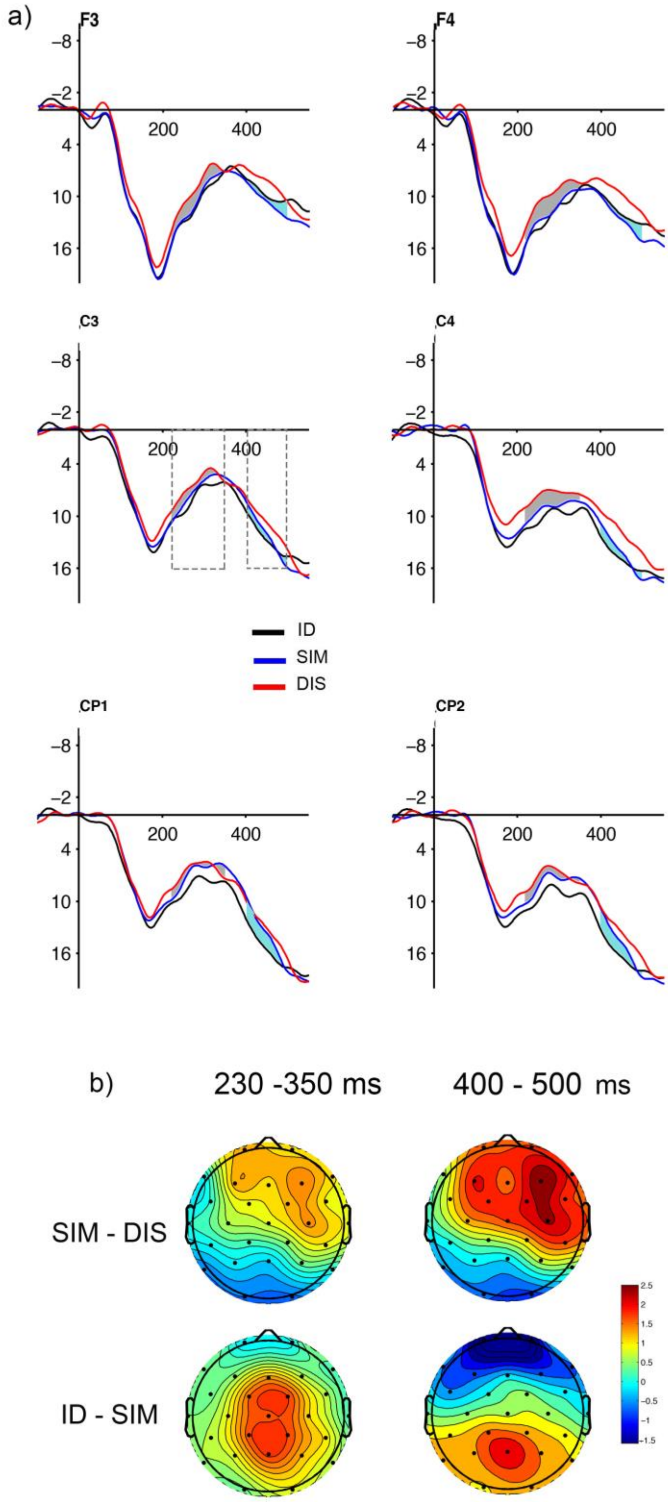


Figure 3. Panel (a) shows the grand average ERPs to targets preceded ID (black line), SIM (blue line) and DIS (red line) priming conditions. The differences between the SIM and DIS conditions in the first time window (230-350 ms) are highlighted in grey. The differences between the SIM and ID conditions in the second time window (400-500 ms) are highlighted in blue. Panel (b) shows the topographic distribution of the effects of visual letter similarity (calculated as the difference in voltage amplitude between the ERP responses to the SIM vs. DIS and ID vs. SIM priming conditions) in the two time windows of the analysis.

230-350 ms window

SIM vs. DIS: There was a main effect of type of prime $F(1,17) = 6.06$, $MSE = 9.24$, $p = .025$, $\eta^2 = .26$. The interaction between type of prime and hemisphere was significant $F(1,17) = 8.11$, $MSE = .55$, $p = .011$, $\eta^2 = .32$: amplitudes were more positive for the SIM than the DIS condition at right electrodes, $F(1,17) = 7.28$, $p = .015$, whereas the effect approached significance in the left electrodes, $F(1,17) = 4.16$, $p = .057$. The other interactions did not approach significance, all *ps* > .28.

SIM vs. ID: None of the effects approached significance (main effect of type of prime: $F(1,17) = 2.32$, $MSE = 15.97$, $p = .146$, $\eta^2 = .12$, remaining *F*s < 1).

400-500 ms window

SIM vs. DIS: The main effect of type of prime approached significance, $F(1,17) = 4.38$, $MSE = 22.59$, $p = .052$, $\eta^2 = .21$. The interaction between type of prime and AP distribution was not significant, $F(1,17) = 1.75$, $MSE = 3.49$, $p = .203$, $\eta^2 = .09$.

The interaction between type of prime and hemisphere was significant $F(1,17) = 4.995$, $MSE = 1.5$, $p = .039$, $\eta^2 = .23$: amplitudes were more positive for the SIM than the DIS condition at right electrodes, $F(1,17) = 7.69$, $p = .013$, but not at left electrodes, $F(1,17) = 1.9$, $p = .186$. The three-way interaction was not significant $F(1,17) = 1.10$, $MSE = .26$, $p = .31$, $\eta^2 = .06$.

SIM vs. ID: The main effect of type of prime was not significant, $F(1,17) = 3.15$, $MSE = 15.26$, $p = .094$, $\eta^2 = .16$.

The interaction between type of prime and AP distribution approached significance, $F(1,17) = 4.38$, $MSE = 3.21$, $p = .052$, $\eta^2 = .21$—note that N400 amplitudes were more positive for the ID than the SIM condition at posterior electrodes, $F(1,17) = 6.78$, $p = .019$, but not at anterior electrodes, $F < 1$. The other interactions did not approach significance (both *F*s < 1).

To sum up, the analyses of the latency data mimicked those in Experiment 1. With respect the ERP data, we found a very similar pattern as in Experiment 1 in the

N250 component (i.e., ID = SIM < DIS). However, results for the N400 time window showed that the SIM condition was different from the DIS condition, whereas the differences between the SIM and ID condition only approached significance. The discrepancy between Experiments 1 and 2 in the N400 component is more apparent than real: the non-significant differences were very close to the .05 criterion. To overcome this issue, and to offer a more powerful test of the effects of letter visual-similarity during word processing, we carried out combined analyses of Experiments 1 and 2 with Experiment as a between-subjects factor.

Combined analyses of Experiments 1 and 2

Behavioral analyses

The ANOVAs on the latency data showed faster response times on the target words when preceded by a visually similar prime than when preceded by a visually dissimilar prime, $F1(1,37) = 22.24$, $MSE = 409.2$, $p < .001$, $\eta^2 = .38$; $F2(1,450) = 27.20$, $MSE = 4087.2$, $p < .001$, $\eta^2 = .06$, and, in turn, response times on the target words were faster when preceded by an identity prime than when preceded by a visually similar prime, $F1(1,37) = 11.61$, $MSE = 399.9$, $p < .001$, $\eta^2 = .24$; $F2(1,450) = 10.63$, $MSE = 4724.8$, $p < .001$, $\eta^2 = .02$. None of these effects interacted with experiment (all *F*s < 1).

The ANOVAs on the error data showed that participants committed more errors to target words when preceded by a visually dissimilar prime than when preceded by a visually similar prime, $F1(1,37) = 4.84$, $MSE = 4.2$, $p = .034$, $\eta^2 = .12$; $F2(1,450) = 4.73$, $MSE = 49.5$, $p = .030$, $\eta^2 = .01$, and, in turn, participants committed more errors to target words when preceded by a visually similar prime than when preceded by an identity prime, $F1(1,37) = 6.19$, $MSE = 2.0$, $p = .017$, $\eta^2 = .14$; $F2(1,450) = 3.92$, $MSE = 35.2$, $p = .048$, $\eta^2 = .01$. None of these effects interacted with experiment (all *F*s < 4.0, all *p*s > .053).

ERP analyses

230-350 ms window

SIM vs. DIS: There was a main effect of type of prime $F(1,37) = 15.54$, $MSE = 8.87$, $p < .001$, $\eta^2 = .3$. The interaction between type of prime and hemisphere was significant

F(1,37) = 8.23, *MSE* = .37, p = .007, η^2 = .18. The interaction between type of prime hemisphere and experiment was significant *F*(1,37) = 5.13, *MSE* = .37, p = .030, η^2 = .12. The three-way interaction between type of prime, AP distribution, and hemisphere approached significance *F*(1,37) = 3.42, *MSE* = .56, p = .072, η^2 = .09.

The four-way interaction between type of prime, AP distribution, hemisphere and experiment was significant, *F*(1,37) = 4.37, *MSE* = .56, p = .044, η^2 = .11. Analysis of simple effects tests showed that in Experiment 1 the difference between the SIM and the DIS conditions were at anterior (left: *F*(1,37) = 5.60, p = .023, right: *F*(1,37) = 9.3, p = .004), and posterior left electrodes, *F*(1,37) = 14.00, p = .001, but they only approached significance in the posterior right electrodes, *F*(1,37) = 3.73, p = .061. In Experiment 2 the differences were at anterior (left: *F*(1,37) = 6.33, p = .016, right: *F*(1,37) = 8.56, p = .006) and posterior right electrodes, *F*(1,37) = 4.5, p = .041, but not at posterior left electrodes, $F < 1$. The remaining interactions were not significant (all *p*s > .244).

SIM vs. ID: None of the effects approached significance (type of prime: *F*(1,37) = 1.23, *MSE* = 15.27, p = .266, η^2 = .03; for the other effects, all *p*s > .25).

400-500 ms window

SIM vs. DIS: The main effect of type of prime was significant, *F*(1,37) = 7.68, *MSE* = 20.85, p = .009, η^2 = .17. There was a significant interaction between type of prime, AP distribution and experiment, *F*(1,37) = 4.47, *MSE* = 2.15, p = .041, η^2 = .11: the differences between SIM and DIS were more posterior in Experiment 1, whereas there were more anterior in Experiment 2 (see Figures 2 and 3). The interaction between type of prime and hemisphere was significant *F(*1,37) = 7.83, *MSE* = .87, p = .008, η^2 = .18: the differences between the SIM and the DIS conditions were stronger at right, *F*(1,37) = 10.4, p = .003, than left electrodes, *F(*1,37) = 4.79, p = .035. The remaining interactions were not significant (all *p*s > .13).

SIM vs. ID: The main effect of type of prime was significant, $F(1,37) = 7.4$, $MSE = 16.78$, $p = .010$, $\eta^2 = .17$. The interaction between type of prime and AP distribution was significant, $F(1,37) = 4.76$, $MSE = 1.98$, $p = .036$, $\eta^2 = .11$: amplitudes were more positive for the ID than for the SIM condition at posterior electrodes, $F(1,37) = 10.29$, $p = .003$, but the effect only approached significance at anterior electrodes, $F(1,37) = 3.65$, $p = .064$. The interaction between type of prime, AP distribution and experiment was not significant, $F(1,37) = 3.05$, $MSE = 1.98$, $p = .089$, $\eta^2 = .08$.

The interaction between type of prime, hemisphere and experiment was significant, $F(1,37) = 4.58$, $MSE = .61$, $p = .039$, $\eta^2 = .11$: in Experiment 1, the effects were stronger at right electrodes, whereas in Experiment 2 the effects were stronger at left sites. The remaining interactions were not significant, *p*s > .28.

Unsurprisingly, this combined analysis corroborated the behavioural and N250 findings from the Experiments 1 and 2 (i.e., ID = SIM < DIS). More importantly, these analyses—using a larger sample size (N = 43)—provided a more complete picture of the effects of letter visual-similarity at a later stage of processing (i.e., N400: ID < SIM < DIS) than the data from the individual experiments.

General Discussion

The main aim of the present ERP masked priming experiments was to track the time course of letter visual-similarity effects during word processing. The behavioral data in both experiments replicated previous findings (Marcet & Perea, 2017c) of faster word identification times for target words when preceded by a visually similar nonword (SIM condition; e.g., *dentjist-DENTIST*)) than when preceded by a visually dissimilar nonword (DIS condition; e.g., *dentgist-DENTIST*). The ERP data showed that, in both experiments, the DIS condition elicited larger negative-going amplitudes in the N250 time window for the SIM condition (i.e., DIS > SIM). Importantly, at this time window the SIM condition did not differ from the ID condition (i.e., SIM = ID). Assuming that the N250 reflects a gradient of orthographic overlap between prime and target (see Grainger & Holcomb, 2009), the present data strongly suggest the visually similar one-letter different prime *dentjst*, but not the visually dissimilar one-letter different prime *dentgst*, initially produced a similar perceptual input as the identity prime *dentist.* This outcome favors the view that, early during orthographic processing, there is some uncertainty when attaining the abstract letter identities for visually similar letters (e.g., Bayesian Reader model, see Norris & Kinoshita, 2012).

Later on, when inspecting lexical-semantic activation via the N400 component, the combined analyses showed not only larger negative-going amplitudes for the DIS than for the SIM conditions—as in the N250 component, but also that the SIM condition elicited larger negative-going amplitudes than the ID condition. This latter difference suggests that, at this time window, the identity condition activated the lexical-semantic representations of the target words to a larger degree than the SIM condition. This can be taken as an indication of resolution of the visual ambiguity. At this same time window, the DIS condition elicited larger N400 amplitudes than the SIM condition, suggesting that visual letter similarity might play a role at late processing stages (see Carreiras, Perea, Gil-López, Abu Mallouh, & Salillas, 2013; Madec, Rey, Dufau, Klein, & Grainger, 2012, for late ERP effects of visual similarity in single letter identification experiments). Further research is needed to examine the exact contribution of letter visual-similarity to the N400 component (see Carreiras, Armstrong, Perea & Frost, 2013, for a discussion of recent advances that can aid the study of the contributions of feed-forward and top-down activations to the amplitude of the N400 component).

Therefore, the present experiments confirmed that visual similarity effects during word recognition are not limited to non-letter forms (numbers and symbols; e.g., *M4TERI4L* or *M4TERI4L*) but they also occur with visually similar letters (see also Marcet & Perea, 2017c, 2018a, for behavioral evidence). Critically, the ERP results in the 230-350 ms time window showed that the identity condition and the visually similar condition (e.g., *dentist–DENTIST* and *dentjst–DENTIST*) behaved similarly, whereas the visually different primes produced larger negative-going amplitudes. This pattern of data qualifies those hierarchical accounts of orthographic processing that propose an access to the abstract orthographic representations by this time window, regardless of the physical similarities among letters. For instance, Grainger and

Holcomb (2009) postulated a bi-modal interactive activation model in which the orthographic information would be attained in the N250 component. Indeed, Holcomb and Grainger (2006) found more negative-going amplitudes in one-letter different priming condition than in the identity condition in this component, which does suggests that readers had access to the abstract letter representations of the stimuli. However, the one-letter replaced condition in the Holcomb and Grainger (2006) was not visually similar to the identity condition (e.g., *teble-TABLE* vs. *table-LETTER*). Indeed, in the two experiments, we found more negative-going amplitudes in the visually dissimilar condition than in the identity condition in the N250 (see Figures 2 and 3), hence replicating the Holcomb and Grainger (2006) experiment. Thus, the more parsimonious account of the current masked priming data is that in the 230-350 ms time window there is still some degree of uncertainty concerning letter identity during word recognition when the perceptual input involves visually similar letters (e.g., *dentjst-DENTIST*).

The present results can be accommodated by those models that assume that there is uncertainty concerning letter identities at the early stages of word recognition (e.g., Bayesian Reader model; Norris & Kinoshita, 2012; see also Bicknell & Levy, 2010, for a Bayesian model of eye movement control in reading). As Norris and Kinoshita (2012) indicated "letter-identity and letter-order information accumulate gradually over time by a stimulus-sampling process" (p. 540) and this uncertainty is eventually resolved, as shown by the larger negative-going amplitudes for the SIM condition than for the ID condition in the N400 component. Therefore, the Bayesian Reader model can readily capture that at an earlier stage in processing (230-350 ms time window), the ERPs of the visually similar condition—but not the visually dissimilar condition—behave similar to those of the identity conditions, whereas later in processing, the ERPs of the identity condition behave differently from the visually similar condition. (We acknowledge that the Bayesian Reader model does not make any claims on the specific time windows of these effects, as this is a formal model that focuses on word identification times and accuracy rates.) The present data also go in line with the idea of uncertainty with respect to the order of the letters during word processing (see Davis, 2010; Gomez, Ratcliff, & Perea, 2008; see Vergara-Martínez, Perea, Gomez, & Swaab, 2013, for ERP evidence of the time course of transposed-letter effects). An avenue for future research would be to determine whether letter visual-similarity effects in a reading context occur in a purely bottom-up manner or whether they are modulated by higher level elements such as the transitional probabilities of letters or top-down feedback from the lexical level (see Dehaene & Cohen, 2007). That is, the letter *j* in *dentjst* may be interpretable as a letter *i* during word processing not only because of its visual similarity but also by orthotactic/phonotactic or lexical constraints. Furthermore, as the critical features that determine letter perception are not entirely understood yet (see Rosa, Enneson, & Perea, 2016, for discussion), additional ERP experimentation should also investigate whether low-level spatial information interacts with the effects of letter visual-similarity during word recognition (e.g., manipulating the outline letter shape; e.g., *dentgst-DENTIST* vs. *dentcst-DENTIST*).

In sum, the present experiments sought to shed some light on the mechanisms to access abstract orthographic codes from the visual input. To that end, we recorded the participants' ERPs in two masked priming experiments in which each word could be preceded by a visually similar or visually dissimilar one-letter replaced prime (*dentjst-DENTIST* vs. *dentgst-DENTIST*). In the 230-350 ms time window, the identity and visually similar condition behaved similarly, whereas there were larger negative-going amplitudes in the visual dissimilar condition. Thus, there is some degree of uncertainty at attaining letter identities during the first moments of word processing that is modulated by letter visual-similarity. Additional work is necessary to comprehend the intricacies underlying the processes that mediate between the printed stimulus and the long-term orthographic abstract representations.

Appendix A. Prime-target pairs used in Experiment 1

The stimuli are presented in quadruplets: identity prime, visually similar prime, visually dissimilar prime, and target.

Word targets: regaliz, regaljz, regalgz, REGALIZ; burbuja, burbuia, burbuea, BURBUJA; economista, economjsta, economgsta, ECONOMISTA; minuto, mjnuto, mgnuto, MINUTO; espejo, espeio, espeao, ESPEJO; concejal, conceial, conceoal, CONCEJAL; reciclado, recjclado, recgclado, RECICLADO; gruñir, gruñjr, gruñgr, GRUÑIR; desfile, desfjle, desfgle, DESFILE; editorial, editorjal, editorgal, EDITORIAL; rojizo, roiizo, roeizo, ROJIZO; debajo, debaio, debaeo, DEBAJO; tarjeta, tarieta, taraeta, TARJETA; hojalata, hoialata, hoealata, HOJALATA; ventaja, ventaia, ventaea, VENTAJA; equipaje, equipaie, equipaoe, EQUIPAJE; enemiga, enemjga, enempga, ENEMIGA; fugitiva, fugitjva, fugitgva, FUGITIVA; majestad, maiestad, maoestad, MAJESTAD; dibujar, dibuiar, dibuoar, DIBUJAR; revivir, revivjr, revivgr, REVIVIR; estrategia, estrategja, estrategpa, ESTRATEGIA; carril, carrjl, carrgl, CARRIL; lentejas, lenteias, lenteoas, LENTEJAS; azulejo, azuleio, azuleuo, AZULEJO; suspiro, suspjro, suspgro, SUSPIRO; conjunto, coniunto, coneunto, CONJUNTO; bandeja, bandeia, bandeoa, BANDEJA; confesión, confesjón, confesgón, CONFESIÓN; cotilleo, cotjlleo, cotglleo, COTILLEO; ermita, ermjta, ermgta, ERMITA; bricolaje, bricolaie, bricolaue, BRICOLAJE; pelirrojo, pelirroio, pelirroao, PELIRROJO; tejado, teiado, teuado, TEJADO; camuflaje, camuflaie, camuflaoe, CAMUFLAJE; ajusticiar, aiusticiar, aeusticiar, AJUSTICIAR; espíritu, espírjtu, espírgtu, ESPÍRITU; socializar, socialjzar, socialgzar, SOCIALIZAR; orujo, oruio, orueo, ORUJO; montaje, montaie, montaue, MONTAJE; ejemplo, eiemplo, eaemplo, EJEMPLO; meñique, meñjque, meñgque, MEÑIQUE; moraleja, moraleia, moraleua, MORALEJA; cartulina, cartuljna, cartulgna, CARTULINA; relojero, reloiero, reloaero, RELOJERO; viento, vjento, vgento, VIENTO; sonajero, sonaiero, sonaoero, SONAJERO; reportaje, reportaie, reportaoe, REPORTAJE; dopaje, dopaie, dopaoe, DOPAJE; milagro, mjlagro, mglagro, MILAGRO; natillas, natjllas, natgllas, NATILLAS; ácido, ácjdo, ácgdo, ÁCIDO; cerrajero, cerraiero, cerraoero, CERRAJERO; infrarrojos, infrarroios, infrarrouos, INFRARROJOS; ciclista, cicljsta, ciclgsta, CICLISTA; balneario, balnearjo, balneargo, BALNEARIO; servicio, servicjo, servicgo, SERVICIO; rodaje, rodaie, rodaoe, RODAJE; mejillón, meiillón, meoillón, MEJILLÓN; pegajoso, pegaioso, pegaeoso, PEGAJOSO; abrigo, abrjgo, abrpgo, ABRIGO; relajante, relaiante, relaeante, RELAJANTE; salir, saljr, salgr, SALIR; embajador, embaiador, embauador, EMBAJADOR; mujer, muier, muaer, MUJER; fósil, fósjl, fósgl, FÓSIL; rival, rjval, rgval, RIVAL; cocodrilo, cocodrjlo, cocodrglo, COCODRILO; lenguaje, lenguaie, lenguaoe, LENGUAJE; arbitraje, arbitraie, arbitraue, ARBITRAJE; casino, casjno, casgno, CASINO; memorizar, memorjzar, memorgzar, MEMORIZAR; tatuaje, tatuaie, tatuaoe, TATUAJE; suprimir, suprimjr, suprimgr, SUPRIMIR; naranja, narania, naranea, NARANJA; árbitro, árbjtro, árbgtro, ÁRBITRO; pediatra, pedjatra, pedgatra, PEDIATRA; reflejo, refleio, refleao, REFLEJO; acantilado, acantjlado, acantglado, ACANTILADO; similar, simjlar, simglar, SIMILAR; granjero, graniero, granaero, GRANJERO; serie, serje, serge, SERIE; subjetivo, subietivo, subaetivo, SUBJETIVO; emocionar, emocjonar, emocgonar, EMOCIONAR; prójimo, próiimo, próeimo, PRÓJIMO; nochevieja, nochevieia, nochevieoa, NOCHEVIEJA; auditorio, audjtorio, audgtorio, AUDITORIO; oasis, oasjs, oasgs, OASIS; avaricia, avarjcia, avargcia, AVARICIA; escritor, escrjtor, escrgtor, ESCRITOR; subjuntivo, subiuntivo, subauntivo, SUBJUNTIVO; viejo, vieio, vieao, VIEJO; renacuajo, renacuaio, renacuaeo, RENACUAJO; adjunto, adiunto, adeunto, ADJUNTO; refugiado, refugjado, refugpado, REFUGIADO; ajedrez, aiedrez, auedrez, AJEDREZ; picadura, pjcadura, pgcadura, PICADURA; gráfica, gráfjca, gráfgca, GRÁFICA; pajarita, paiarita, paearita, PAJARITA; oveja, oveia, oveua, OVEJA; esguince, esgujnce, esgugnce, ESGUINCE; pesimismo, pesimjsmo, pesimgsmo, PESIMISMO; pájaro, páiaro, páearo, PÁJARO; novelista, noveljsta, novelgsta, NOVELISTA; patinaje, patinaie, patinaue, PATINAJE; elegido, elegjdo, elegpdo, ELEGIDO; portátil, portátjl, portátgl, PORTÁTIL; extranjero, extraniero, extranaero, EXTRANJERO; despiste, despjste, despgste, DESPISTE; crujido, cruiido, crueido, CRUJIDO; sujeto, suieto, suaeto, SUJETO; donativo, donatjvo, donatgvo, DONATIVO; paisaje, paisaie, paisaue, PAISAJE; ambiental, ambjental, ambgental, AMBIENTAL; fichaje, fichaie, fichaue, FICHAJE; conserje, conserie, conserae, CONSERJE; nativo, natjvo, natgvo, NATIVO; ejercer, eiercer, eaercer, EJERCER; fotocopia, fotocopja, fotocopga, FOTOCOPIA; cinéfilo, cinéfjlo, cinéfglo, CINÉFILO; fichar, fjchar, fgchar, FICHAR; físico, físjco, físgco, FÍSICO; chantaje, chantaie, chantaoe, CHANTAJE; reducir, reducjr, reducgr, REDUCIR; espionaje, espionaie, espionaue, ESPIONAJE; viajero, viaiero, viauero, VIAJERO; respirar, respjrar, respgrar, RESPIRAR; practicar, practjcar, practgcar, PRACTICAR; diamante, djamante, dgamante, DIAMANTE; aconsejar, aconseiar, aconseoar, ACONSEJAR; ventanilla, ventanjlla, ventanglla, VENTANILLA; cuestión, cuestjón, cuestgón, CUESTIÓN; vendaje, vendaie, vendaoe, VENDAJE; bingo, bjngo, bgngo, BINGO; sabotaje, sabotaie, sabotaoe, SABOTAJE;

trilogía, trjlogía, trglogía, TRILOGÍA; vejiga, veiiga, veoiga, VEJIGA; conejo, coneio, coneuo, CONEJO; aceite, acejte, acegte, ACEITE; aterrizaje, aterrizaie, aterrizaoe, ATERRIZAJE; flojo, floio, floeo, FLOJO; oreja, oreia, oreua, OREJA; ejercicio, eiercicio, euercicio, EJERCICIO; visual, vjsual, vgsual, VISUAL; remedio, remedjo, remedgo, REMEDIO; ejecutivo, eiecutivo, euecutivo, EJECUTIVO; empujón, empuión, empueón, EMPUJÓN; brujería, bruiería, bruaería, BRUJERÍA; estropajo, estropaio, estropaeo, ESTROPAJO; consejo, conseio, conseao, CONSEJO; maquillaje, maquillaie, maquillaue, MAQUILLAJE; berenjena, bereniena, berenaena, BERENJENA; refinar, refjnar, refgnar, REFINAR; pareja, pareia, pareoa, PAREJA; carcajada, carcaiada, carcaoada, CARCAJADA; repetir, repetjr, repetgr, REPETIR; esponja, esponia, esponea, ESPONJA; testigo, testjgo, testpgo, TESTIGO; cangrejo, cangreio, cangreao, CANGREJO; lombriz, lombrjz, lombrgz, LOMBRIZ; ejército, eiército, euército, EJÉRCITO; desafinar, desafjnar, desafgnar, DESAFINAR; trabajador, trabaiador, trabauador, TRABAJADOR; reciclaje, reciclaie, reciclaue, RECICLAJE; masaje, masaie, masaoe, MASAJE; porcentaje, porcentaie, porcentaue, PORCENTAJE; complejo, compleio, compleao, COMPLEJO; hinchado, hjnchado, hgnchado, HINCHADO; pacifista, pacifjsta, pacifgsta, PACIFISTA; prisionero, prisjonero, prisgonero, PRISIONERO; gratis, gratjs, gratgs, GRATIS; garaje, garaie, garaoe, GARAJE; ejecución, eiecución, euecución, EJECUCIÓN; envejecer, enveiecer, enveaecer, ENVEJECER; injusticia, iniusticia, ineusticia, INJUSTICIA; confianza, confjanza, confganza, CONFIANZA; aspirina, aspirjna, aspirgna, ASPIRINA; exigir, exigjr, exigpr, EXIGIR; compartir, compartjr, compartgr, COMPARTIR; pastilla, pastjlla, pastglla, PASTILLA; consumición, consumjción, consumgción, CONSUMICIÓN; tequila, tequjla, tequgla, TEQUILA; milenio, milenjo, milengo, MILENIO; cojín, coiín, coeín, COJÍN; lejía, leiía, leaía, LEJÍA; localizar, localjzar, localgzar, LOCALIZAR; calcio, calcjo, calcgo, CALCIO; deprisa, deprjsa, deprgsa, DEPRISA; hojaldre, hoialdre, houaldre, HOJALDRE; personaje, personaie, personaoe, PERSONAJE; homenaje, homenaie, homenaue, HOMENAJE; adivinanza, adivjnanza, adivgnanza, ADIVINANZA; ático, átjco, átgco, ÁTICO; felicitar, felicjtar, felicgtar, FELICITAR; mojado, moiado, mouado, MOJADO; frito, frjto, frgto, FRITO; mismo, mjsmo, mgsmo, MISMO; lejano, leiano, leuano, LEJANO; pasajero, pasaiero, pasauero, PASAJERO; prejuicio, preiuicio, preouicio, PREJUICIO; timidez, timjdez, timgdez, TIMIDEZ; digital, digjtal, digptal, DIGITAL; violeta, vjoleta, vgoleta, VIOLETA; musical, musjcal, musgcal, MUSICAL; callejero, calleiero, calleaero, CALLEJERO; cocina, cocjna, cocgna, COCINA; potaje, potaie, potaue, POTAJE; clorofila, clorofjla, clorofgla, CLOROFILA; recibidor, recibjdor, recibgdor, RECIBIDOR; alquiler, alqujler, alqugler, ALQUILER; casualidad, casualjdad, casualgdad, CASUALIDAD; mejorar, meiorar, meaorar, MEJORAR; adjetivo, adietivo, adaetivo, ADJETIVO; carruaje, carruaie, carruaue, CARRUAJE; cajón, caión, caeón, CAJÓN; mendigar, mendjgar, mendpgar, MENDIGAR; desventaja, desventaia, desventaoa, DESVENTAJA; horrible, horrjble, horrgble, HORRIBLE; precavido, precavjdo, precavgdo, PRECAVIDO; dentista, dentjsta, dentgsta, DENTISTA; sujetador, suietador, suoetador, SUJETADOR; mensaje, mensaie, mensaoe, MENSAJE; abajo, abaio, abauo, ABAJO; injurias, iniurias, inaurias, INJURIAS; digestivo, digestjvo, digestgvo, DIGESTIVO; riqueza, rjqueza, rgqueza, RIQUEZA; vitalidad, vitaljdad, vitalgdad, VITALIDAD; bolsillo, bolsjllo, bolsgllo, BOLSILLO

Nonword targets: vantuja, vantuia, vantuea, VANTUJA; sunvajemo, sunvaiemo, sunvauemo, SUNVAJEMO; etjonto, etionto, eteonto, ETJONTO; cimujaca, cimuiaca, cimueaca, CIMUJACA; ecotiucar, ecotjucar, ecotgucar, ECOTIUCAR; ajeculisa, aieculisa, aueculisa, AJECULISA; agifinarma, agifjnarma, agifgnarma, AGIFINARMA; fritocaje, fritocaie, fritocaue, FRITOCAJE; becerjeca, becerieca, beceraeca, BECERJECA; relsantaja, relsantaia, relsantaoa, RELSANTAJA; gilloje, gilloie, gilloue, GILLOJE; redectaje, redectaie, redectaoe, REDECTAJE; cosmajeda, cosmaieda, cosmaoeda, COSMAJEDA; lacenja, lacenia, lacenea, LACENJA; siesunte, sjesunte, sgesunte, SIESUNTE; ajartiniar, aiartiniar, aeartiniar, AJARTINIAR; telbucicián, telbucjcián, telbucgcián, TELBUCICIÁN; mújoro, múioro, múeoro, MÚJORO; comborcir, comborcjr, comborcgr, COMBORCIR; dieje, dieie, dieae, DIEJE; calbia, calbja, calbga, CALBIA; parnidio, parnidjo, parnidgo, PARNIDIO; pacuositad, pacuosjtad, pacuosgtad, PACUOSITAD; bombiche, bombjche, bombgche, BOMBICHE; corjonto, corionto, coreonto, CORJONTO; machurraje, machurraie, machurraue, MACHURRAJE; crájizo, cráiizo, cráeizo, CRÁJIZO; pramajadar, pramaiadar, pramauadar, PRAMAJADAR; gínico, gínjco, gíngco, GÍNICO; istrellejos, istrelleios, istrelleuos, ISTRELLEJOS; ejálciso, eiálciso, euálciso, EJÁLCISO; suanpión, suanpjón, suanpgón, SUANPIÓN; tenceja, tenceia, tenceoa, TENCEJA; zachojera, zachoiera, zachoaera, ZACHOJERA; natujo, natuio, natueo, NATUJO; incitidea, incitjdea, incitgdea, INCITIDEA; sejallón, seiallón, seoallón, SEJALLÓN; fechisa, fechjsa, fechgsa, FECHISA; soljentido, solientido, solaentido, SOLJENTIDO; aopiloria, aopjloria, aopgloria, AOPILORIA; penloje, penloie, penloue, PENLOJE; abjotilo, abiotilo, abaotilo, ABJOTILO; desnisar, desnjsar, desngsar, DESNISAR;

bejodo, beiodo, beuodo, BEJODO; mujanabor, muianabor, muoanabor, MUJANABOR; ejuldro, eiuldro, eauldro, EJULDRO; ranvaje, ranvaie, ranvaoe, RANVAJE; amejo, ameio, ameuo, AMEJO; majacisa, maiacisa, maeacisa, MAJACISA; injartinia, iniartinia, ineartinia, INJARTINIA; emblatajo, emblataio, emblataeo, EMBLATAJO; cuntacirra, cuntacjrra, cuntacgrra, CUNTACIRRA; ajofutión, aiofutión, auofutión, AJOFUTIÓN; plojo, ploio, ploeo, PLOJO; sonaneja, sonaneia, sonaneua, SONANEJA; darrejaro, darreiaro, darreoaro, DARREJARO; sufrabir, sufrabjr, sufrabgr, SUFRABIR; descidar, descjdar, descgdar, DESCIDAR; pelciedio, pelciedjo, pelciedgo, PELCIEDIO; tisidaz, tisjdaz, tisgdaz, TISIDAZ; bojadasa, boiadasa, boeadasa, BOJADASA; peimoje, peimoie, peimoue, PEIMOJE; temoludia, temoludja, temoludga, TEMOLUDIA; resifraje, resifraie, resifraue, RESIFRAJE; maceja, maceia, maceoa, MACEJA; bibal, bjbal, bgbal, BIBAL; bestizo, bestjzo, bestgzo, BESTIZO; pogenivar, pogenjvar, pogengvar, POGENIVAR; enmojener, enmoiener, enmoaener, ENMOJENER; frética, frétjca, frétgca, FRÉTICA; pojedo, poiedo, pouedo, POJEDO; ropuje, ropuie, ropuoe, ROPUJE; mimasuro, mjmasuro, mgmasuro, MIMASURO; safudraje, safudraie, safudraoe, SAFUDRAJE; pemifrada, pemjfrada, pemgfrada, PEMIFRADA; devucir, devucjr, devucgr, DEVUCIR; fantejes, fanteies, fanteoes, FANTEJES; deblica, debljca, deblgca, DEBLICA; mocaje, mocaie, mocaue, MOCAJE; frujenía, fruienía, fruaenía, FRUJENÍA; senaleajo, senaleaio, senaleaeo, SENALEAJO; revunir, revunjr, revungr, REVUNIR; embriter, embrjter, embrgter, EMBRITER; liajaro, liaiaro, liauaro, LIAJARO; ablapo, abljpo, ablgpo, ABLAPO; mafonaje, mafonaie, mafonaoe, MAFONAJE; mofiche, mofjche, mofgche, MOFICHE; primobío, prjmobío, prgmobío, PRIMOBÍO; plabis, plabjs, plabgs, PLABIS; eficoriez, eficorjez, eficorgez, EFICORIEZ; matecaje, matecaie, matecaue, MATECAJE; dunciul, duncjul, duncgul, DUNCIUL; erprerjero, erpreriero, erpreraero, ERPRERJERO; amacinio, amacjnio, amacgnio, AMACINIO; avaire, avajre, avagre, AVAIRE; remabicar, remabjcar, remabgcar, REMABICAR; escurja, escuria, escurea, ESCURJA; ejarsinio, eiarsinio, euarsinio, EJARSINIO; etobida, etobjda, etobgda, ETOBIDA; colcrejo, colcreio, colcreao, COLCREJO; cociro, cocjro, cocgro, COCIRO; ajaclad, aiaclad, auaclad, AJACLAD; punical, punjcal, pungcal, PUNICAL; clenjero, cleniero, clenaero, CLENJERO; polfiosma, polfjosma, polfgosma, POLFIOSMA; grújusa, grúiusa, grúeusa, GRÚJUSA; carroeja, carroeia, carroeua, CARROEJA; espínisa, espínjsa, espíngsa, ESPÍNISA; sividal, sivjdal, sivgdal, SIVIDAL; évida, évjda, évgda, ÉVIDA; monlicha, monljcha, monlgcha, MONLICHA; ecudipa, ecudjpa, ecudgpa, ECUDIPA; tujemo, tuiemo, tuaemo, TUJEMO; acallipaje, acallipaie, acallipaoe, ACALLIPAJE; ponjeta, ponieta, ponaeta, PONJETA; grujilo, gruiilo, grueilo, GRUJILO; rescisbe, rescjsbe, rescgsbe, RESCISBE; plito, pljto, plgto, PLITO; fronopiva, fronopjva, fronopgva, FRONOPIVA; pajusdad, paiusdad, paousdad, PAJUSDAD; goduniste, godunjste, godungste, GODUNISTE; bomarivar, bomarjvar, bomargvar, BOMARIVAR; angiflaje, angiflaie, angiflaue, ANGIFLAJE; ocejo, oceio, oceuo, OCEJO; viesto, vjesto, vgesto, VIESTO; calmejal, calmeial, calmeoal, CALMEJAL; tarir, tarjr, targr, TARIR; palmoraje, palmoraie, palmoraoe, PALMORAJE; divontilo, divontjlo, divontglo, DIVONTILO; asediciero, asedicjero, asedicgero, ASEDICIERO; detrejo, detreio, detreao, DETREJO; nañido, nañjdo, nañgdo, NAÑIDO; moljetino, molietino, molaetino, MOLJETINO; detuja, detuia, detuea, DETUJA; dinquedo, djnquedo, dgnquedo, DINQUEDO; repalid, repaljd, repalgd, REPALID; norritre, norrjtre, norrgtre, NORRITRE; aschinde, aschjnde, aschgnde, ASCHINDE; desvise, desvjse, desvgse, DESVISE; echiluje, echiluie, echiluoe, ECHILUJE; calfrejo, calfreio, calfreao, CALFREJO; damibista, damibjsta, damibgsta, DAMIBISTA; canmurica, canmurjca, canmurgca, CANMURICA; nompentaje, nompentaie, nompentaue, NOMPENTAJE; espijás, espiiás, espieás, ESPIJÁS; taloeja, taloeia, taloeoa, TALOEJA; áldigro, áldjgro, áldpgro, ÁLDIGRO; memidisto, memidjsto, memidgsto, MEMIDISTO; sichega, sjchega, sgchega, SICHEGA; pepiodra, pepjodra, pepgodra, PEPIODRA; manuje, manuie, manuoe, MANUJE; gochibiuja, gochibiuia, gochibiuoa, GOCHIBIUJA; sivujer, sivuier, sivuoer, SIVUJER; amarsejar, amarseiar, amarseoar, AMARSEJAR; rancifar, rancjfar, rancgfar, RANCIFAR; viduar, vjduar, vgduar, VIDUAR; aceje, aceie, aceue, ACEJE; piletro, pjletro, pgletro, PILETRO; momajera, momaiera, momaoera, MOMAJERA; alchiser, alchjser, alchgser, ALCHISER; decedia, decedja, decedga, DECEDIA; expita, expjta, expgta, EXPITA; piletia, piletja, piletga, PILETIA; vansuaje, vansuaie, vansuaoe, VANSUAJE; elocenisma, elocenjsma, elocengsma, ELOCENISMA; emidir, emidjr, emidgr, EMIDIR; dilmo, djlmo, dglmo, DILMO; momatipa, momatjpa, momatgpa, MOMATIPA; afudeja, afudeia, afudeua, AFUDEJA; dirgo, djrgo, dgrgo, DIRGO; lomionidar, lomionjdar, lomiongdar, LOMIONIDAR; anquivo, anqujvo, anqugvo, ANQUIVO; caciro, cacjro, cacgro, CACIRO; doduje, doduie, doduoe, DODUJE; andejador, andeiador, andeuador, ANDEJADOR; lirrar, ljrrar, lgrrar, LIRRAR; sicuro, sjcuro, sgcuro, SICURO; hojectre, hoiectre, houectre, HOJECTRE; bosuraje, bosuraie, bosuraue, BOSURAJE; lojín, loiín, loeín, LOJÍN; iljenies, ilienies, ilaenies, ILJENIES; ciplinde, cipljnde, ciplgnde, CIPLINDE; sejonar, seionar, seaonar, SEJONAR; bestinda, bestjnda, bestgnda, BESTINDA; mujón, muión, mueón, MUJÓN; boncósil, boncósjl, boncósgl, BONCÓSIL; empiuctar, empjuctar, empguctar, EMPIUCTAR; sarfaje, sarfaie, sarfaoe, SARFAJE; llentaje, llentaie, llentaoe, LLENTAJE; écita, écjta, écgta, ÉCITA; fejano, feiano, feuano, FEJANO; fremalina, fremaljna, fremalgna, FREMALINA; comofriza, comofrjza, comofrgza, COMOFRIZA; cimápivo, cimápjvo, cimápgvo, CIMÁPIVO; esciuraje, esciuraie, esciuraue, ESCIURAJE; rujiga, ruiiga, ruoiga, RUJIGA; bructicar, bructjcar, bructgcar, BRUCTICAR; bubetila, bubetjla, bubetgla, BUBETILA; bemirisar, bemirjsar, bemirgsar, BEMIRISAR; mefajoto, mefaioto, mefaeoto, MEFAJOTO; faruje, faruie, faruoe, FARUJE; mavajera, mavaiera, mavauera, MAVAJERA; fómil, fómjl, fómgl, FÓMIL; roujico, rouiico, roueico, ROUJICO; brimiacera, brimjacera, brimgacera, BRIMIACERA; disilar, disjlar, disglar, DISILAR; calichos, caljchos, calgchos, CALICHOS; landaje, landaie, landaoe, LANDAJE; pemajonte, pemaionte, pemaeonte, PEMAJONTE; pefubiada, pefubjada, pefubgada, PEFUBIADA; corcejo, corceio, corceao, CORCEJO; melillojo, melilloio, melilloao, MELILLOJO; tiureta, tjureta, tgureta, TIURETA; nelia, nelja, nelga, NELIA; oesin, oesjn, oesgn, OESIN; revipin, revipjn, revipgn, REVIPIN; ancejo, anceio, anceao, ANCEJO; dontasién, dontasjén, dontasgén, DONTASIÉN; cimadital, cimadjtal, cimadgtal, CIMADITAL; asernirado, asernjrado, aserngrado, ASERNIRADO; asminica, asminjca, asmingca, ASMINICA; pemojera, pemoiera, pemoaera, PEMOJERA; bruzir, bruzjr, bruzgr, BRUZIR; ocuja, ocuia, ocuea, OCUJA; nujor, nuior, nuaor, NUJOR; gojía, goiía, goaía, GOJÍA; matipe, matjpe, matgpe, MATIPE; sundiro, sundjro, sundgro, SUNDIRO

Appendix B.Prime-target pairs used in Experiment 2

The stimuli are presented in quadruplets: identity prime, visually similar prime, visually dissimilar prime, and target.

Word targets: travieso, trauieso, traoieso, TRAVIESO; sirvienta, siruienta, siroienta, SIRVIENTA; jubilación, jvbilación, jzbilación, JUBILACIÓN; estufa, estvfa, estzfa, ESTUFA; avería, auería, aoería, AVERÍA; novio, nouio, noeio, NOVIO; mandíbula, mandíbvla, mandíbzla, MANDÍBULA; alivio, aliuio, alioio, ALIVIO; mutación, mvtación, mztación, MUTACIÓN; convención, conuención, conoención, CONVENCIÓN; universo, uniuerso, unioerso, UNIVERSO; matrícula, matrícvla, matríczla, MATRÍCULA; nocturno, noctvrno, noctzrno, NOCTURNO; evaluación, eualuación, eoaluación, EVALUACIÓN; civil, ciuil, cioil, CIVIL; revés, reués, reoés, REVÉS; cinturón, cintvrón, cintzrón, CINTURÓN; argumento, argvmento, argzmento, ARGUMENTO; avión, auión, aoión, AVIÓN; nervioso, neruioso, neroioso, NERVIOSO; fórmula, fórmvla, fórmzla, FÓRMULA; rutina, rvtina, rztina, RUTINA; muchacho, mvchacho, mzchacho, MUCHACHO; entusiasmo, entvsiasmo, entzsiasmo, ENTUSIASMO; relevo, releuo, releao, RELEVO; tortuga, tortvga, tortzga, TORTUGA; carnaval, carnaual, carnaoal, CARNAVAL; muralla, mvralla, mzralla, MURALLA; polvo, poluo, polao, POLVO; caravana, carauana, caraoana, CARAVANA; crucero, crvcero, crzcero, CRUCERO; portavoz, portauoz, portaeoz, PORTAVOZ; archivo, archiuo, archiao, ARCHIVO; primavera, primauera, primaoera, PRIMAVERA; motivación, motiuación, motioación, MOTIVACIÓN; huevo, hueuo, hueao, HUEVO; muebles, mvebles, mzebles, MUEBLES; navegación, nauegación, naoegación, NAVEGACIÓN; facultad, facvltad, faczltad, FACULTAD; nochebuena, nochebvena, nochebzena, NOCHEBUENA; aduana, advana, adzana, ADUANA; diputado, dipvtado, dipztado, DIPUTADO; cobertura, cobertvra, cobertzra, COBERTURA; novedad, nouedad, noaedad, NOVEDAD; clavo, clauo, claeo, CLAVO; aluminio, alvminio, alzminio, ALUMINIO; paraguas, paragvas, paragzas, PARAGUAS; salvaje, saluaje, saloaje, SALVAJE; lavabo, lauabo, laoabo, LAVABO; cumbre, cvmbre, czmbre, CUMBRE; reverencia, reuerencia, reoerencia, REVERENCIA; apuesta, apvesta, apzesta, APUESTA; malvado, maluado, maloado, MALVADO; prueba, prveba, przeba, PRUEBA; muñeca, mvñeca, mzñeca, MUÑECA; industria, indvstria, indzstria, INDUSTRIA; capítulo, capítvlo, capítzlo, CAPÍTULO; locura, locvra, loczra, LOCURA; sabiduría, sabidvría, sabidzría, SABIDURÍA; fractura, fractvra, fractzra, FRACTURA; lechuga, lechvga, lechzga, LECHUGA; tranvía, tranuía, tranoía, TRANVÍA; titular, titvlar, titzlar, TITULAR; respuesta, respvesta, respzesta, RESPUESTA; invisible, inuisible, inoisible, INVISIBLE; movida, mouida, moaida, MOVIDA; futuro, futvro, futzro, FUTURO; evidente, euidente, eoidente, EVIDENTE; esclavo, esclauo, esclaeo, ESCLAVO; almuerzo, almverzo, almzerzo, ALMUERZO; navidad, nauidad, naoidad, NAVIDAD; tribunal, tribvnal, tribznal, TRIBUNAL; alumno, alvmno, alzmno, ALUMNO; álbum, álbvm, álbzm, ÁLBUM; confusión, confvsión, confzsión, CONFUSIÓN; insulto, insvlto, inszlto, INSULTO; aviso, auiso, aoiso, AVISO; novela, nouela, noaela, NOVELA; divorcio, diuorcio, diaorcio, DIVORCIO; anuncio, anvncio, anzncio, ANUNCIO; calavera, calauera, calaoera, CALAVERA; reserva, reserua, reseroa, RESERVA; subasta, svbasta, szbasta, SUBASTA; tubería, tvbería, tzbería, TUBERÍA; desayuno, desayvno, desayzno, DESAYUNO; caviar, cauiar, caoiar, CAVIAR; revancha, reuancha, reoancha, REVANCHA; conducta, condvcta, condzcta, CONDUCTA; seguridad, segvridad, segzridad, SEGURIDAD; desnudo, desnvdo, desnzdo, DESNUDO; salud, salvd, salzd, SALUD; adversario, aduersario, adoersario, ADVERSARIO; favorito, fauorito, faeorito, FAVORITO; rumbo, rvmbo, rzmbo, RUMBO; cadáver, cadáuer, cadáoer, CADÁVER; suciedad, svciedad, szciedad, SUCIEDAD; acusado, acvsado, aczsado, ACUSADO; saliva, saliua, salioa, SALIVA; angustia, angvstia, angzstia, ANGUSTIA; agujero, agvjero, agzjero, AGUJERO; musical, mvsical, mzsical, MUSICAL; aplauso, aplavso, aplazso, APLAUSO; móvil, móuil, móail, MÓVIL; pueblo, pveblo, pzeblo, PUEBLO; joven, jouen, joaen, JOVEN; invierno, inuierno, inoierno, INVIERNO; puntería, pvntería, pzntería, PUNTERÍA; evangelio, euangelio, eoangelio, EVANGELIO; división, diuisión, dioisión, DIVISIÓN; movimiento, mouimiento, moaimiento, MOVIMIENTO; altura, altvra, altzra, ALTURA; selva, selua, seloa, SELVA; inversión, inuersión, inoersión, INVERSIÓN; comunismo, comvnismo, comznismo, COMUNISMO; desvío, desuío, desoío, DESVÍO; censura, censvra, censzra, CENSURA; evento, euento, eoento, EVENTO; sustancia, svstancia, szstancia, SUSTANCIA; salvación, saluación, saloación, SALVACIÓN; neutral, nevtral, neztral, NEUTRAL; basura, basvra, baszra, BASURA; provincia, prouincia, proaincia, PROVINCIA; directiva, directiua, directioa, DIRECTIVA; pólvora, póluora, pólaora, PÓLVORA; descuido, descvido, desczido, DESCUIDO; cueva, cueua, cueoa, CUEVA; producto, prodvcto, prodzcto, PRODUCTO; documental, docvmental, doczmental, DOCUMENTAL; lavadora, lauadora, laoadora, LAVADORA; ambulancia, ambvlancia, ambzlancia, AMBULANCIA; revisión, reuisión, reoisión, REVISIÓN; nevera, neuera, neoera, NEVERA; chaval, chaual, chaoal, CHAVAL; ciudadano, civdadano, cizdadano, CIUDADANO; circuito, circvito, circzito, CIRCUITO; discurso, discvrso, disczrso, DISCURSO; pubertad, pvbertad, pzbertad, PUBERTAD; actitud, actitvd, actitzd, ACTITUD; observador, obseruador, obseroador, OBSERVADOR; célula, célvla, célzla, CÉLULA; revolución, reuolución, reaolución, REVOLUCIÓN; automóvil, automóuil, automóail, AUTOMÓVIL; novato, nouato, noeato, NOVATO; altavoz, altauoz, altaeoz, ALTAVOZ; fabulosa, fabvlosa, fabzlosa, FABULOSA; divino, diuino, dioino, DIVINO; bruja, brvja, brzja, BRUJA; obstáculo, obstácvlo, obstáczlo, OBSTÁCULO; escuela, escvela, esczela, ESCUELA; tortura, tortvra, tortzra, TORTURA; círculo, círcvlo, círczlo, CÍRCULO; artículo, artícvlo, artíczlo, ARTÍCULO; privilegio, priuilegio, prioilegio, PRIVILEGIO; película, pelícvla, película, PELÍCULA; buscador, bvscador, bzscador, BUSCADOR; invasión, inuasión, inoasión, INVASIÓN; cuervo, cueruo, cuereo, CUERVO; invencible, inuencible, inoencible, INVENCIBLE; abuelo, abvelo, abzelo, ABUELO; dibujo, dibvjo, dibzjo, DIBUJO; corrupto, corrvpto, corrzpto, CORRUPTO; maravilla, marauilla, maraoilla, MARAVILLA; evolución, euolución, eaolución, EVOLUCIÓN; salvavidas, saluavidas, salvaoidas, SALVAVIDAS; envidia, enuidia, enoidia, ENVIDIA; masculino, mascvlino, masczlino, MASCULINO; gravedad, grauedad, graoedad, GRAVEDAD; nieve, nieue, nieoe, NIEVE; aventura, auentura, aoentura, AVENTURA; estudiante, estvdiante, estzdiante, ESTUDIANTE; caverna, cauerna, caoerna, CAVERNA; curva, curua, curoa, CURVA; provocación, prouocación, proaocación, PROVOCACIÓN; tumba, tvmba, tzmba, TUMBA; cálculo, cálcvlo, cálczlo, CÁLCULO; orgulloso, orgvlloso, orgzlloso, ORGULLOSO; costumbre, costvmbre, costzmbre, COSTUMBRE; cirujano, cirvjano, cirzjano, CIRUJANO; atractivo, atractiuo, atractiao, ATRACTIVO; cerveza, cerueza, ceroeza, CERVEZA; mudanza, mvdanza, mzdanza, MUDANZA; brújula, brújvla, brújzla, BRÚJULA; desván, desuán, desoán, DESVÁN; televisión, teleuisión, teleoisión, TELEVISIÓN; entrevista, entreuista, entreoista, ENTREVISTA; impuesto, impvesto, impzesto, IMPUESTO; navaja, nauaja, naoaja, NAVAJA; travesía, trauesía, traoesía, TRAVESÍA; individuo, indiuiduo, indioiduo, INDIVIDUO; octavo, octauo, octaeo, OCTAVO; invento, inuento, inoento, INVENTO; apertura, apertvra, apertzra, APERTURA; objetivo, objetiuo, objetieo, OBJETIVO; diversión, diuersión, dioersión, DIVERSIÓN; bufanda, bvfanda, bzfanda, BUFANDA; natural, natvral, natzral, NATURAL; pañuelo, pañvelo, pañzelo, PAÑUELO; nueva, nueua, nueoa, NUEVA; excursión, excvrsión, exczrsión, EXCURSIÓN; noveno, noueno, noaeno, NOVENO; masivo, masiuo, masiao, MASIVO; ridículo, ridícvlo, ridíczlo, RIDÍCULO; ciervo, cieruo, cierao, CIERVO; cultura, cultvra, cultzra, CULTURA; habitual, habitval, habitzal, HABITUAL; invitada, inuitada, inoitada, INVITADA; sucursal, sucvrsal, suczrsal, SUCURSAL; vivienda, viuienda, vioienda, VIVIENDA; inevitable, ineuitable, ineoitable, INEVITABLE; avenida, auenida, aoenida, AVENIDA; festival, festiual, festioal, FESTIVAL; submarino, svbmarino, szbmarino, SUBMARINO; absurdo, absvrdo, abszrdo, ABSURDO; servilleta, seruilleta, seroilleta, SERVILLETA; factura, factvra, factzra, FACTURA; llave, llaue, llaoe, LLAVE; calvo, caluo, caleo, CALVO; turista, tvrista, tzrista, TURISTA; embustero, embvstero, embzstero, EMBUSTERO; privacidad, priuacidad, prioacidad, PRIVACIDAD; convento, conuento, conoento, CONVENTO; tiburón, tibvrón, tibzrón, TIBURÓN; nivel, niuel, nioel, NIVEL; chuletas, chvletas, chzletas, CHULETAS; adivino, adiuino, adioino, ADIVINO; relevante, releuante, releoante, RELEVANTE; culpable, cvlpable, czlpable, CULPABLE; revista, reuista, reoista, REVISTA

<u>Nonword targets</u>: ovepo, ouepo, oaepo, OVEPO; celvival, celviual, celvioal, CELVIVAL; serud, servd, serzd, SERUD; corcuro, corcvro, corczro, CORCURO; advangario, aduangario, adoangario, ADVANGARIO; iomomóvel, iomomóuel, iomomóael, IOMOMÓVEL; casvo, casuo, caseo, CASVO; apevico, apeuico, apeoico, APEVICO; mugrarino, mvgrarino, mzgrarino, MUGRARINO; lesvén, lesuén, lesoén, LESVÉN; soscurno, soscvrno, sosczrno, SOSCURNO; cavema, cauema, caoema, CAVEMA; lugitoción, lvgitoción, lzgitoción, LUGITOCIÓN; avabente, auabente, aoabente, AVABENTE; epuana, epvana, epzana, EPUANA; cécugo, cécvgo, céczgo, CÉCUGO; gavel, gauel, gaoel, GAVEL; dinestiva, dinestiua, dinestioa, DINESTIVA; mimudada, mimvdada, mimzdada, MIMUDADA; incupto, incvpto, inczpto, INCUPTO; tascura, tascvra, tasczra, TASCURA; érdud, érdvd, érdzd, ÉRDUD; pullarro, pvllarro, pzllarro, PULLARRO; nolmuja, nolmvja, nolmzja, NOLMUJA; ravadad, rauadad, raoadad, RAVADAD; zueva, zueua, zueoa, ZUEVA; prenvía, prenuía, prenoía, PRENVÍA; admusenta, admvsenta, admzsenta, ADMUSENTA; nucura, nvcvra, nzczra, NUCURA; letuago, letvago, letzago, LETUAGO; lloval, lloual, lloeal, LLOVAL; avacimio, auacimio, aoacimio, AVACIMIO; admuliscia, admvliscia, admzliscia, ADMULISCIA; ceufatano, cevfatano, cezfatano, CEUFATANO; suñesa, svñesa, szñesa, SUÑESA; bamudova, bamvdova, bamzdova, BAMUDOVA; natutol, natvtol, natztol, NATUTOL; revenfla, reuenfla, reoenfla, REVENFLA; ceiva, ceiua, ceioa, CEIVA; culva, culua, culoa, CULVA; tuñenda, tvñenda, tzñenda, TUÑENDA; navima, nauima, naoima, NAVIMA;

invemifle, inuemifle, inoemifle, INVEMIFLE; govia, gouia, goaia, GOVIA; alupco, alvpco, alzpco, ALUPCO; avisgura, auisgura, aoisgura, AVISGURA; neveto, neueto, neoeto, NEVETO; respuodo, respvodo, respzodo, RESPUODO; situmo, sitvmo, sitzmo, SITUMO; espuoba, espvoba, espzoba, ESPUOBA; gollipuena, gollipvena, gollipzena, GOLLIPUENA; sucefa, svcefa, szcefa, SUCEFA; ovisguda, ovisgvda, ovisgzda, OVISGUDA; sunfa, svnfa, sznfa, SUNFA; hovito, houito, hoaito, HOVITO; fuacres, fvacres, fzacres, FUACRES; crovenidad, crouenidad, croaenidad, CROVENIDAD; azgurdo, azgvrdo, azgzrdo, AZGURDO; portaved, portaued, portaoed, PORTAVED; ancuro, ancvro, anczro, ANCURO; cunsible, cvnsible, cznsible, CUNSIBLE; ralova, raloua, raloea, RALOVA; evosto, euosto, eaosto, EVOSTO; anvamión, anuamión, aneamión, ANVAMIÓN; sival, siual, sioal, SIVAL; bavoniso, bauoniso, baeoniso, BAVONISO; tevijación, teuijación, teoijación, TEVIJACIÓN; larultad, larvltad, larzltad, LARULTAD; cimunaca, cimvnaca, cimznaca, CIMUNACA; olsavo, olsauo, olsaeo, OLSAVO; guive, guiue, guioe, GUIVE; rustencia, rvstencia, rzstencia, RUSTENCIA; avicución, auicución, aoicución, AVICUCIÓN; crueja, crveja, crzeja, CRUEJA; actinun, actinvn, actinzn, ACTINUN; descuesbo, descvesbo, desczesbo, DESCUESBO; calívor, calíuor, calíaor, CALÍVOR; apuenda, apvenda, apzenda, APUENDA; leltura, leltvra, leltzra, LELTURA; nicurón, nicvrón, niczrón, NICURÓN; ompurroto, ompvrroto, ompzrroto, OMPURROTO; avicigo, auicigo, aoicigo, AVICIGO; mabrétula, mabrétvla, mabrétzla, MABRÉTULA; curfre, cvrfre, czrfre, CURFRE; evecío, euecío, eoecío, EVECÍO; umevarso, umeuarso, umeoarso, UMEVARSO; pífvora, pífuora, pífaora, PÍFVORA; borvanto, boruanto, boroanto, BORVANTO; mipítuto, mipítvto, mipítzto, MIPÍTUTO; tonuro, tonvro, tonzro, TONURO; ivazo, iuazo, ioazo, IVAZO; amubono, amvbono, amzbono, AMUBONO; sovedod, souedod, soaedod, SOVEDOD; rucolla, rvcolla, rzcolla, RUCOLLA; sível, síuel, síoel, SÍVEL; balnudo, balnvdo, balnzdo, BALNUDO; fivoenda, fiuoenda, fiaoenda, FIVOENDA; bavasoro, bauasoro, baoasoro, BAVASORO; antovid, antouid, antoaid, ANTOVID; damavora, damauora, damaeora, DAMAVORA; morvación, moruación, moroación, MORVACIÓN; envadio, enuadio, enoadio, ENVADIO; pubanga, pvbanga, pzbanga, PUBANGA; gruba, grvba, grzba, GRUBA; proburto, probvrto, probzrto, PROBURTO; zatavo, zatauo, zataeo, ZATAVO; jaramuos, jaramvos, jaramzos, JARAMUOS; everbenio, euerbenio, eoerbenio, EVERBENIO; enmusiente, enmvsiente, enmzsiente, ENMUSIENTE; zanavicha, zanauicha, zanaoicha, ZANAVICHA; cuciodod, cvciodod, czciodod, CUCIODOD; devinda, deuinda, deoinda, DEVINDA; cesvema, cesuema, cesoema, CESVEMA; cadécuto, cadécvto, cadéczto, CADÉCUTO; pacirual, pacirval, pacirzal, PACIRUAL; subonda, svbonda, szbonda, SUBONDA; entumierso, entvmierso, entzmierso, ENTUMIERSO; simavación, simauación, simaoación, SIMAVACIÓN; arnuerzo, arnverzo, arnzerzo, ARNUERZO; mustiría, mvstiría, mzstiría, MUSTIRÍA; cósnulo, cósnvlo, cósnzlo, CÓSNULO; emufada, emvfada, emzfada, EMUFADA; pirvo, piruo, pireo, PIRVO; agofución, agofvción, agofzción, AGOFUCIÓN; janavo, janauo, janaeo, JANAVO; sonva, sonua, sonoa, SONVA; privenefio, priuenefio, prioenefio, PRIVENEFIO; pevicencia, peuicencia, peoicencia, PEVICENCIA; plivo, pliuo, plieo, PLIVO; carcura, carcvra, carczra, CARCURA; renvantaca, renuantaca, renoantaca, RENVANTACA; frelcura, frelcvra, frelczra, FRELCURA; pritunas, pritvnas, pritznas, PRITUNAS; inviscifle, inuiscifle, inoiscifle, INVISCIFLE; esfrivo, esfriuo, esfrieo, ESFRIVO; sivano, siuano, sioano, SIVANO; tercuma, tercvma, terczma, TERCUMA; erpursión, erpvrsión, erpzrsión, ERPURSIÓN; gautrol, gavtrol, gaztrol, GAUTROL; pavarución, pauarución, paoarución, PAVARUCIÓN; llumiros, llvmiros, llzmiros, LLUMIROS; cempurón, cempvrón, cempzrón, CEMPURÓN; fricavero, fricauero, fricaoero, FRICAVERO; noveme, noueme, noaeme, NOVEME; pravisío, prauisío, praoisío, PRAVISÍO; clovedol, clouedol, cloaedol, CLOVEDOL; incividoz, inciuidoz, incioidoz, INCIVIDOZ; psivaración, psiuaración, psioaración, PSIVARACIÓN; pravioco, prauioco, praoioco, PRAVIOCO; fellufa, fellvfa, fellzfa, FELLUFA; turtador, tvrtador, tzrtador, TURTADOR; sasvocio, sasuocio, saseocio, SASVOCIO; cánsulo, cánsvlo, cánszlo, CÁNSULO; pemivante, pemiuante, pemioante, PEMIVANTE; aflirtavo, aflirtauo, aflirtaeo, AFLIRTAVO; dolvienta, doluienta, doloienta, DOLVIENTA; cisvarsión, cisuarsión, cisoarsión, CISVARSIÓN; asundio, asvndio, aszndio, ASUNDIO; govin, gouin, goain, GOVIN; olpitivo, olpitiuo, olpitiao, OLPITIVO; ibstáluto, ibstálvto, ibstálzto, IBSTÁLUTO; nonsulta, nonsvlta, nonszlta, NONSULTA; rusvío, rusuío, rusoío, RUSVÍO; divanrión, diuanrión, dioanrión, DIVANRIÓN; sovediento, souediento, soaediento, SOVEDIENTO; ectundero, ectvndero, ectzndero, ECTUNDERO; sarvije, saruije, saroije, SARVIJE; provoscio, prouoscio, proaoscio, PROVOSCIO; bupinía, bvpinía, bzpinía, BUPINÍA; avoán, auoán, aeoán, AVOÁN; ulavia, ulauia, ulaoia, ULAVIA; nasvioso, nasuioso, nasoioso, NASVIOSO; memucidad, memvcidad, memzcidad, MEMUCIDAD; runfo, rvnfo, rznfo, RUNFO; divescio, diuescio, dioescio, DIVESCIO; marvido, maruido, maroido, MARVIDO; derevo, dereuo, dereao, DEREVO; sacuelo, sacvelo, saczelo, SACUELO; nalcurno, nalcvrno, nalczrno, NALCURNO; bicusar, bicvsar, biczsar, BICUSAR; mudartad, mvdartad, mzdartad, MUDARTAD; mampunico, mampvnico, mampznico, MAMPUNICO; cilmuoto, cilmvoto, cilmzoto, CILMUOTO; lenavigión, lenauigión, lenaoigión, LENAVIGIÓN; amusicia, amvsicia, amzsicia, AMUSICIA; collucto, collvcto, collzcto, COLLUCTO; mivisián, miuisián, mioisián, MIVISIÁN; ircuesbo, ircvesbo, irczesbo, IRCUESBO; demabumo, demabvmo, demabzmo, DEMABUMO; acuozo, acvozo, aczozo, ACUOZO; cenruro, cenrvro, cenrzro, CENRURO; covancura, covancvra, covanczra, COVANCURA; olclivo, olclivo, olcliao, OLCLIVO; nuelvo, nueluo, nuelao, NUELVO; nocuto, nocvto, noczto, NOCUTO; envonta, enuonta, enaonta, ENVONTA; cevós, ceuós, ceaós, CEVÓS; envanrión, enuanrión, enoanrión, ENVANRIÓN; socuncal, socvncal, socznca l, SOCUNCAL; cumavaco, cumauaco, cumaoaco, CUMAVACO; encupa, encvpa, enczpa, ENCUPA; indumbria, indvmbria, indzmbria, INDUMBRIA; enflivisca, enfliuisca, enflioisca, ENFLIVISCA; costustre, costvstre, costzstre, COSTUSTRE; gavibo, gauibo, gaoibo, GAVIBO; ilevemache, ileuemache, ileoemache, ILEVEMACHE; tucinda, tvcinda, tzcinda, TUCINDA; plave, plaue, plaoe, PLAVE; caviod, cauiod, caoiod, CAVIOD; osmanvador, osmanuador, osmanoador, OSMANVADOR; juetro, jvetro, jzetro, JUETRO; invedudo, inuedudo, inoedudo, INVEDUDO; morvirreta, moruirreta, moroirreta, MORVIRRETA; ansustio, ansvstio, anszstio, ANSUSTIO; padabulía, padabvlía, padabzlía, PADABULÍA; manséjula, manséjvla, manséjzla, MANSÉJULA; comuranco, comvranco, comzranco, COMURANCO; meléluto, melélvto, melélzto, MELÉLUTO; povafa, pouafa, poeafa, POVAFA; inviesco, inuiesco, inoiesco, INVIESCO; vérmula, vérmvla, vérmzla, VÉRMULA; everesción, eueresción, eoeresción, EVERESCIÓN; domudentel, domvdentel, domzdentel, DOMUDENTEL; mumarión, mvmarión, mzmarión, MUMARIÓN; corpunlo, corpvnlo, corpznlo, CORPUNLO; resisva, resisua, resisoa, RESISVA; grucena, grvcena, grzcena, GRUCENA; cavonra, cauonra, caeonra, CAVONRA

4.5 Visual letter similarity effects during sentence reading: Evidence from the boundary technique

Abstract

The study of how the cognitive system encodes letter identities from the visual input has received much attention in models of visual word recognition but it has typically been overlooked in models of eye movement control in reading. Here we examined how visual letter similarity affects early word processing during reading using Rayner's (1975) boundary change technique in which the parafoveal preview of the target word was either identical (e.g., *frito-frito* [*fried*]) or a one-letter-different nonword (e.g., *frjto-frito* vs. *frgto-frito*). Critically, the substituted letter in the nonword was visually similar (based on letter confusability norms) or visually dissimilar. Results showed shorter viewing times on the target word when the parafoveal preview was visually similar than when it was visually dissimilar. Thus, visual letter similarity modulates the integration of parafoveal and foveal information during sentence reading. Future implementations of models of eye movement control in reading should incorporate a more developed orthographic-lexical module to capture these effects.

Keywords: reading; word recognition; parafoveal processing; visual letter similarity

When reading, adults show a remarkable ability to access the appropriate lexical entry among thousands of potential competitors—some of them perceptually similar (e.g., compare *moose* vs. *mouse* or *calm* vs. *clam*)—in 150-300 milliseconds (see Rayner, Pollatsek, Ashby, & Clifton, 2012, for review). This process requires a set of highly efficient operations that extract the identity and the order of the letters that compose each word (Grainger, 2018). In hierarchical models of letter/word recognition (e.g., see Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger, Rey, & Dufau, 2008, for neural models), the visual features of the letters are combined by shape-specific letter detectors (e.g., "a" and "*a*", but not "A", activate the shape-specific letter detector of the letter "a"). These letter detectors are in turn, combined by complex, case-insensitive letter detectors (e.g., "a", "*a*", and "A" would activate the complex letter detector of "a", which, in turn, drive the process of lexical access. Although a detailed account of the orthographic processes that underlie lexical access is necessary for a full comprehensive model of eye movement control during reading (Reichle, 2015), the most influential models of eye movement control in reading (e.g., E-Z Reader model, Reichle, Pollatsek, Fisher, & Rayner, 1998; SWIFT model, Engbert, Nuthmann, Richter, & Kliegl, 2005) have not yet implemented detailed modules of orthographic and lexical processing.

Prior research using word recognition tasks (e.g., lexical decision, naming, semantic categorization) has consistently shown that orthographic processing (i.e., letter identity and letter order) is subject to perceptual uncertainty in the early moments of lexical access (e.g., the pseudoword *nevtral* would generate a similar perceptual input as the word *neutral*), which is eventually resolved (see Marcet & Perea, 2018a, for review). Using Forster and Davis' (1984) masked priming technique, words with visually similar embedded letter-like digits (e.g., *M473R14L*) are more effective at activating their base words (*MATERIAL*) than visually dissimilar controls (e.g., M629R32L) (Perea, Duñabeitia, & Carreiras, 2008). That is, the digit *4* in M473R14L activates the letter detector corresponding to the visually similar letter *A*. Furthermore, Marcet and Perea (2017c) found that word response times to a target word (e.g., *NEUTRAL*) were faster when the one-letter different prime was visually similar (*nevtral*) than when it was visually dissimilar (*neztral*)—word identification times to *nevtral-NEUTRAL* were only slightly longer than those to *neutral-NEUTRAL* (see also Marcet & Perea, 2018a, for evidence with multi-letter homoglyphs [e.g., *docurnent-DOCUMENT* faster than *docusnent-DOCUMENT*]). Taken together, these findings favor the view that in the initial moments of word processing, there is some uncertainty concerning letter identity for highly visually similar letters (e.g., *frjed* produces a similar perceptual input as *fried*). In order to shed more light on the time course of the effects of visual letter similarity during word recognition, Gutiérrez-Sigut, Marcet, and Perea (2018a) conducted two masked priming experiments while measuring event-related potentials—they used the same materials as Marcet and Perea (2017c). Gutiérrez-Sigut et al. found that, at an early time-window associated with orthographic processing (N250; see Grainger & Holcomb, 2009, for review), the ERP waves for the identity condition (e.g., *neutral-NEUTRAL*) and the visually similar condition (*nevtral-NEUTRAL*) behaved similarly, while the visually dissimilar condition (*neztral-NEUTRAL*) produced a larger negativity. This is consistent with the idea of an early perceptual uncertainty concerning letter identity for visually similar letters. In addition, at a later time-window associated to lexico-semantic component (N400), the visually similar condition (*nevtral-NEUTRAL*) produced a larger negativity than the identity condition. This latter finding suggests that the uncertainty concerning letter identity is resolved over time.

The issue under scrutiny in the current experiment is whether these visual letter similarity effects that have been found in word identification tasks with the masked priming technique can be generalized to normal reading. When we read text, we extract information not only from the fixated word, but also from the following word/s in the parafovea (see Rayner et al., 2012, for review). Importantly, information in the parafovea has shown to impact the processing of the word once it is fixated in the fovea, hence this allows for an ecological scenario to examine visual letter similarity effects during the early stages of word processing. An excellent technique to tap these early word identification processes during text reading is Rayner's (1975) gaze-contingent boundary change paradigm. Rayner's boundary change technique allows for the manipulation of parafoveal information that is available to the reader before the foveal processing of a target word (see Figure 1 for a depiction of the technique). Importantly, although the text may be altered, readers are typically unaware of these changes. Similarly to the masked priming technique, the boundary technique examines the relationship between a prime stimulus and a target stimulus (e.g., the parafoveal previews *nevtral* or *neztral* and the target word *neutral*). Results from this paradigm have revealed that the nature of the codes integrated across fixations is orthographic (or phonological) rather than visual. As found by McConkie and Zola (1979) and Rayner, McConkie, and Zola (1980), changing the case of words from fixation to fixation (e.g., *cHaIr→ChAiR*) does not interfere with reading. Likewise, in a change detection paradigm, Slattery, Angele, and Rayner (2011) found that the probability of detecting a display change from the parafoveal preview to the target was higher when there was a change in letter identities (*jNxVa→gReEn*) than when there was a change in letter case (*gReEn→GrEeN*) (see also Angele, Slattery, & Rayner, 2016, for discussion). Finally, recent research has shown that readers may also extract semantic and higher-order contextual information from the parafoveal previews (e.g., see Hohenstein & Kliegl, 2014, to cite one recent example).

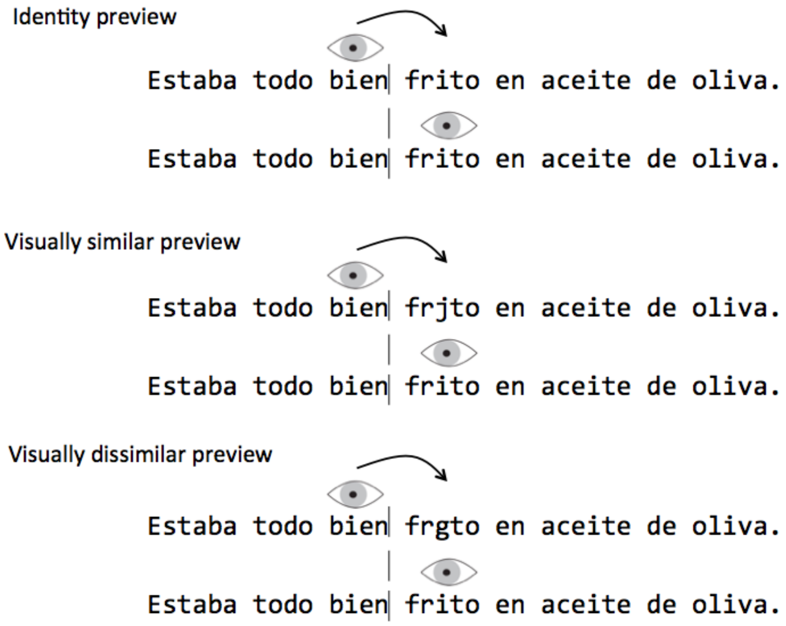


Figure 1. Description of an eye movement contingent display-change trial with the three experimental conditions (identity preview, visually similar preview, visually dissimilar preview). The eye symbol represents where the reader is fixating, and the arrow represents the saccade crossing the invisible boundary (the dashed vertical line) preceding the target word. Before crossing the boundary, the sentence is presented with the identity, visually similar or dissimilar previews. When the eyes cross the boundary, the parafoveal preview is replaced by the target word.

To explain how orthographic information from the parafoveal previews is integrated across saccades in the word recognition stream, Rayner et al. (1978; see also Rayner et al., 2012) proposed the "preliminary letter identification" hypothesis. The rationale of this account is that while the eye is fixating on word *n*, factors such as visual acuity and lateral masking would hinder the identification and relative order of the letters in word *n+1*. Hence, orthographic processing in the parafovea would be subject to letter confusability, particularly for those letters that share many visual features (e.g., *b* and *h*). Support for the preliminary letter identification hypothesis comes from the boundary experiments reported by Rayner and colleagues (Rayner; 1975; Rayner, McConkie, & Ehrlich, 1978; Rayner, Well, Pollatsek, & Bertera, 1982). In a sentence reading experiment, Rayner (1975) included an identity preview (e.g., *tested*), a visually similar nonword preview (e.g., *tcrted*) and a visually dissimilar nonword preview (e.g., *tflmed*). Rayner (1975) found shorter viewing times for the target words when the preview was a visually similar nonword than when the preview was a visually dissimilar preview—this was accompanied by briefer viewing times in the identity condition than in the visually similar preview condition. In the Rayner et al. (1978) experiments, readers looked at a dot in the center of the screen while a word or nonword appeared in the parafovea. When the participants moved their eyes toward the letter string, the word/nonword was replaced by a target word that the participant had to read aloud. The parafoveal preview conditions comprised: 1) a visually similar word (*police-palace*); 2) a visually similar replaced-letter nonword (*pcluce-palace*); and 3) a visually dissimilar replaced-letter nonword (*pyltce-palace*). Rayner et al. (1978) found longer naming times for those words that were preceded by a visually dissimilar preview than by a visually similar preview, which in turn produced longer naming times than the identity preview condition (see also Rayner et al., 1982, for converging evidence). Similarly, other boundary change experiments only found slightly faster viewing times on a target word in the identity condition than in a visually similar preview condition (e.g., *song-song* vs. *sorp-song*) (e.g., Altarriba, Kambe, Pollatsek, & Rayner, 2001; Balota, Pollatsek, & Rayner, 1985; Rayner, Balota, & Pollatsek, 1986; see also Cutter, Drieghe, & Liversedge, 2015, and Hÿonä, Bertram, & Pollatsek, 2004, for reviews).[1]

Taken together, the above-cited experiments suggest that visual letter similarity plays a role in the initial moments of processing during normal reading. However, a limitation of these experiments is that visual letter similarity was merely operationalized in terms of letter shape. For instance, when creating the stimuli in the visually similar condition, Rayner et al. (1982) indicated that "every ascender was replaced by an ascender, every descender was replaced by a descender, and letters that did not extend above or below the line of print were replaced by other similar nonascending or nondescending letters" whereas in the visually dissimilar letter condition, "every letter was replaced by a dissimilar letter, with ascenders replaced by descenders or letters that did not extend above or below the line" (p. 542). That is, visual letter similarity was simplified to three categories of letter shape: (a) ascending letters (e.g., *b, t, h*); (b) descending letters (e.g., *g, j, p*), and (c) neutral (short) letters (e.g., *a, v, m*). Whereas it is quite frequent that letters that share the basic shape are also visually similar (e.g., *b* and *h*; *c* and *e*), two letters may share the outline letter shape while being visually dissimilar (e.g., *d* and *k; r* and *s*) and, conversely, two letters may differ in outline letter shape while being visually similar (e.g., i and *j*).

Importantly, letter shape per se does not seem to be the critical factor underlying visual similarity effects in word recognition. An excellent demonstration is the proofreading experiment conducted by Paap, Newsome, and Noel (1984). They found that the percentage of misses did not depend on whether the misspelled word shared the letter shape with the target word, but on the visual confusability of the replaced letter: for the target word *than*, the misspelled items *tdan* [same letter shape] and *tman* [different letter shape] were detected more easily than *tban* or *tnan* [note that both *b* and *n* are visually confusable to *h*, but only *b* shared the letter shape with *h*]. Further evidence that letter shape per se does not play a main role in word recognition comes from the lexical decision experiment conducted by Perea and

[1] Pollatsek, Lesch, Morris, and Rayner (1992) found a sizeable advantage of the identity condition over a visually similar condition (around 25 ms in the first fixation on the target word), but this difference occurred primarily when the visually similar preview did not share the initial letter with the target word (e.g., *aerial-cereal*).

Panadero (2014). They found similar response times for visually similar and visually dissimilar pseudowords created by replacing a letter from a base word with the same/different letter shape (e.g., *fiesda* vs. *fiesna*; the base word was *fiesta*). More recently, in a series of masked priming lexical decision experiments, Marcet and Perea (2017c) found faster word identification times for visually similar pairs over visually dissimilar pairs regardless of letter shape (*frjto-FRITO* [fried] faster than *frgto-FRITO*; *nevtral-NEUTRAL* faster than *neztral-NEUTRAL*). Taken together, these findings suggest that letter shape per se does not play a major role during foveal word processing.

The lack of an effect from outline letter shape during word identification has also been obtained during sentence reading. Johnson, Perea, and Rayner (2007) included parafoveal previews created by transposing two letters (e.g., *jugde* from the target word *judge*) or by replacing two letters that kept the letter shape (*jupte*—note that *p* was replaced with another descending letter and *t* was replaced with another ascending letter) together with an identity condition (the parafoveal preview *judge*). Johnson et al. (2007) found shorter viewing times on the target word in the transposed-letter condition than in the replacement-letter condition (*jugde–judge* < *jupte–judge*) and, furthermore, viewing times on the target word were only slightly shorter in the identity condition than in the transposed-letter condition (see also Winskel & Perea, 2013, for similar evidence in Thai). Moreover, this pattern of data occurred regardless of whether the parafoveal previews did or did not maintain the same outline letter shape as the target word (e.g., similar advantage for *corwn-crown* vs. *ceswn-crown* as for *celrk-clrek* vs. *cbork-clerck*). The Johnson et al. (2007) findings have two important implications: 1) there is some uncertainty concerning letter order when processing parafoveal stimuli, thus extending the Perea and Lupker (2003) masked priming findings to a normal reading scenario; and 2) readers were able to obtain more information on the identities of the letters from the parafoveal previews over and above letter shape.

The main goal of the current boundary change experiment was to examine the role of visual letter similarity on parafoveal processing during sentence reading while controlling for outline letter shape. The criterion to select the pairs was based on visual letter similarity ratings (see Simpson, Mousikou, Montoya, & Defior, 2012). The preview/target stimuli were extracted from the masked priming experiments conducted by Marcet and Perea (2017c) in Spanish. This allows us to directly compare the visual letter similarly effects when using masked priming during visual word recognition and when using parafoveal previews during sentence reading (see Johnson et al., 2007, for a similar strategy of using stimuli from prior masked priming experiments). For the visually similar condition, the target words contained a middle letter with a high degree of similarity with another letter: *i/j* (5.17 out of 7 in the Simpson et al., 2012, ratings) and *u/v* (4.93 out of 7)—note that *i/j* and *u/v* were originally allographs that acquired a different orthography and phonology in the Middle Ages. In Spanish, the consonant letter *j* corresponds to the voiceless velar fricative /x/ (this may sound like the Scottish grapheme *ch* in *loch*), whereas the consonant letter *v* corresponds to the voiced bilabial stop /b/. This manipulation allowed us to generate parafoveal previews created by replacing a single letter that could be visually similar (e.g., *frjto*; the target word was *frito* [*fried*]) or visually dissimilar (*frgto*)—note that we kept the ascending/descending pattern in the visually dissimilar condition.

The present experiment has two advantages over previous studies on visual letter similarity during sentence reading. First, as letter shape in terms of ascenders and descenders is not a strict marker of visual letter similarity (e.g., the letters *k* and *d* are not visually very similar despite sharing the letter shape, whereas *i* and *j* are visually similar despite not sharing the letter shape), we used a criterion of visual letter similarity based on a letter confusability matrix (i.e., the matrix collected by Simpson et al., 2012). Second, we controlled the consonant/vowel status of the replaced letters across visually similar and visually dissimilar previews (e.g., *frjto* vs. *frgto*), as this factor may modulate lexical access such as (see New, Araujo, & Nazzi, 2009; Perea, Marcet, & Acha, 2018, for evidence during word recognition). Consonant/vowel status was not controlled in previous research (e.g., the visually similar preview *pcluce* was compared with the visually dissimilar *pyltce* for the target word *palace*; see Rayner, 1975; Rayner et al., 1978)—in fairness to Rayner and colleagues, the effects of consonant/vowel status of letters during word recognition only started to be studied in the past two decades.

In sum, we used Rayner's (1975) boundary change technique to examine the role of visual letter similarity during sentence reading while controlling for outline letter shape. We employed three parafoveal preview conditions: (a) a parafoveal preview that was identical to the target word (identity preview; e.g., *frito-frito* [*fried*]); (b) a parafoveal preview in which an internal letter from the target word was replaced by a letter that was visually similar (visually similar preview; e.g., *frjto-frito*); and (c) a parafoveal preview in which an internal letter from the target word—the same as in the visually similar condition—was replaced by a visually different letter (visually dissimilar preview: e.g., *frgto-frito*). The predictions are clear-cut. According to the preliminary letter identification hypothesis (Rayner et al., 1980, 2012), while fixating on word n, readers would obtain information from the letters of word n+1 in the parafovea. As Rayner et al. (2012) claimed, "information based partly on visual features and partly on orthographic rules would begin accumulating for the beginning letters of the parafoveal word, but identification would not take place until after the eye movement" (p. 123). Therefore, the preliminary letter identification hypothesis would predict that a visually similar nonword preview (*frjto*) would produce a processing advantage on the subsequent word (i.e., shorter viewing times) over a visually dissimilar nonword preview (*frgto*). This outcome would generalize the idea that there is some degree of uncertainty on the identity of the letters during word recognition not only in foveal processing (see Marcet & Perea, 2017c, 2018a, for evidence with masked priming) but also in parafoveal processing. Alternatively, if—unlike foveal processing—the processing of orthographic information in the parafovea occurs mostly in terms of low-spatial frequency information that is insensitive to fine-grained processing, one would expect similar viewing times on the targets words when preceded by a visually similar (*frjto-frito*) or visually dissimilar parafoveal preview (*frgto-frito*). This latter outcome would reveal a dissociation between orthographic processing in the fovea and parafovea.

Method

Participants

The participants were twenty-seven undergraduate students from the Universitat de València. All of them were native speakers of Spanish with normal vision—none of them used glasses or contact lenses. This study was approved by Experimental Research Ethics Committee of the Universitat de València and written informed consent was obtained from all participants before starting the experimental session. Sample size (*N* = 27) was the same as in previous experiments on visual letter similarly with the masked priming technique (see Marcet & Perea, 2017c).

Apparatus

To register the participant's eye movements during sentence reading, we employed an Eyelink 1000 video-based eye tracker with a 1000-Hz sample rate, < .5 degrees average gaze position error, and a 3 ms delay—this device only recorded the eye movements from the right eye. The sentences were presented in a 24-inch LCD Asus VG248 monitor with a refresh rate of 144 Hz.

Materials

We created 240 sentences in Spanish. Each sentence contained a target word with *i/j* or *u/v* as internal letters (e.g., the target word *frito* [*fried*] in the sentence "*Estaba todo bien frito en aceite de oliva*." [*It was all well fried in olive oil*.]). These target words were extracted from the materials used by Marcet and Perea (2017c) in their masked priming experiments. The mean Zipf frequency was 4.02 (range: 1.94–5.87), the mean number of letters was 6.7 (range: 5–8), and the mean OLD20 was 2.0 (range: 1.3–3.3) in the Spanish lexical database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras, 2013). For each target word, we created three parafoveal previews: 1) the same as the target word (identity condition; e.g., preview: *frito*; target: *frito*); 2) a nonword that was the same to the target word except for the replacement of a letter with a visually similar letter (*i→j, j→i, u→v, v→u*) (visually similar condition: e.g., preview: *frjto*; target: *frito*); 3) a nonword was the same as the target word except for the replacement of a letter—the same as in the previous condition—with a visually dissimilar letter with the same letter shape as in the visually similar condition (visually dissimilar condition: e.g., preview: *frgto*; target: *frito*). The parafoveal previews were counterbalanced across three lists following a Latin square design. Each participant received 80 trials in each of the three conditions. The complete set of sentences, including the parafoveal previews, is presented in the Appendix. To prevent the target words from being anticipated from the previous context, the sentences included target words that were not easily predictable. This was verified via a cloze task in which the initial part of each sentence—until the word preceding the target word—was presented to 10 naïve individuals that were asked to predict the following word—none of these individuals took part in the experiment. The percentage of words that was predicted from the previous context was very low (less than 1%). We also verified that the sentences were easy to understand: the ten individuals that performed the cloze task were also asked to rate how comprehensible each sentence was (1 = not understandable at all; 10 = very easily understandable). The average score was very high (*M* = 9.9).

Procedure

The experimental session took place in a dimly lit room. The sentences were presented in 20-pt Consoles font (i.e., a fixed-width font) using the software from the University of Massachusetts Eyetracking laboratory (Eyetrack; https://blogs.umass.edu/eyelab/software/) in a Windows XP computer. The participants were sitting approximately 60 cm from the computer monitor. At that distance, the 20-pt Consolas font yielded approximately 2.53 letters per degree of visual angle. The participants were first informed about the experimental procedure. Their task was to read sentences for comprehension in a computer screen while their eye movements were registered. They were told that there would be comprehension questions on the sentence they had just read in around 20% of the time. They were also told that before starting the experiment, the system had to be calibrated—this process could be repeated along the experiment. In order for the participants to be comfortable and to reduce head movements, we used a chinrest and a height adjustable chair.

The experiment procedure began with a three-point calibration phase in which the participants had to look at individual dots on the screen. This was followed by eight practice sentences to familiarize the participants with the procedure. Each trial had the following arrangement. First, a fixation point was presented in the center of the screen to verify the quality of the calibration—the eye-movement device was recalibrated when necessary. Second, a black square was presented on the left side of the screen—this coincided with the location of the initial letter of each sentence. Third, the sentence was presented once the participant looked at the black square. The display change occurred when the participant's eyes crossed an invisible boundary located just before the target word (see Figure 1). The sentence remained on the screen until the participant finished reading it—participants were asked to press a key on a gamepad. Fourth, on 20% of the trials there was a yes/no comprehension question on the previous sentence—this was done to verify that participants were reading for comprehension. Participants did not notice any displays changes—or in a minuscule number of sentences (no more than five)—when asked after the experiment. Each participant received the sentences in a different random order.

Data analysis

The essential idea underlying Rayner's (1975) boundary technique is that the parafoveal preview allows some preprocessing of the target word. Specifically, if the reader extracts more useful information from the visually similar parafoveal preview than for the visually dissimilar parafoveal preview, the processing time on the target word will be reduced when directly fixated, thus resulting in shorter fixation durations (see Rayner et al., 2012). We examined three eye fixation measures on the target word (i.e., the critical region): 1) the duration of the initial fixation on the target word (first fixation duration); 2) the sum of fixation durations before leaving it (gaze duration); and 3) the duration of the fixation when there was only one fixation (single fixation). Although the key comparison was between the eye fixation durations on the target word in the visually similar vs. the visually dissimilar conditions, we also examined how effective the visually similar condition was relative to the identity condition.

Results

Participants were quite accurate to responding the comprehension questions (mean accuracy: 94.4%, range: 85-98%). To analyze the eye movement data we employed the suite of programs available at the University of Massachusetts Eyetracking lab (Eyedoctor and Eyedry; https://blogs.umass.edu/eyelab/software/). The data were initially screened (e.g., track losses, blinks, early/late display changes) with the EyeDoctor software—this resulted in less than 7% of the data lost in the target region—and successive fixations within the range of one character were merged as a single fixation. Then the data were processed with Eyedry software. Fixations shorter than 100 ms or longer than 800 ms were removed. Eyedry was also used to obtain the fixation durations on the target word (i.e., the critical region) for the three dependent variables (first fixation duration, single fixation, gaze duration). Before conducting the statistical analyses, and to minimize the influence of outliers, those eye fixation durations that exceeded three standard deviations of the average per subject and condition were removed (less than 1% of the data). The average eye fixation measures per condition across participants are presented in Table 1.

We analyzed the eye fixation data with linear mixed effects models that included preview-target relationship as a fixed factor and subjects and items as random factors—both intercepts and slopes—using the *lmer* package in R (Bates, Maechler, Bolker, & Walker, 2015). Fixation durations were inverse-transformed (i.e., -1000/fix_duration) to maintain the normality assumption of these models—this was the same transformation as in the parallel masked priming experiments conducted by Marcet and Perea (2017c). The critical contrast involved the comparison between the visually similar condition and the visually dissimilar condition, but we also compared the identity condition vs. visually similar condition (see Marcet & Perea, 2017c, 2018a). The *p* values for each contrast were obtained from the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017). We employed the maximal random structure model with the first fixation durations: LME_FIXDUR = lmer(-1000/FixDur) ~ previewtype + (previewtype +1|item) + (previewtype +1|subject), data = VIS_SIM). For single fixation duration and gaze duration, we kept that most complex random structure model that successfully converged: LME_GD = lmer(-1000/GD) ~ previewtype + (1|item) + (previewtype +1|subject).

First Fixation Duration. The first fixation duration on the target word was longer in the visually dissimilar condition than in the visually similar condition, *b* = 0.091, *SE* = 0.043, *t* = 2.09, *p* = .039, and in turn, the first fixation duration on the target word was longer in the visual similar condition than in the identity condition, *b* = 0.110, *SE* = 0.044, *t* = 2.46, *p* = .021.

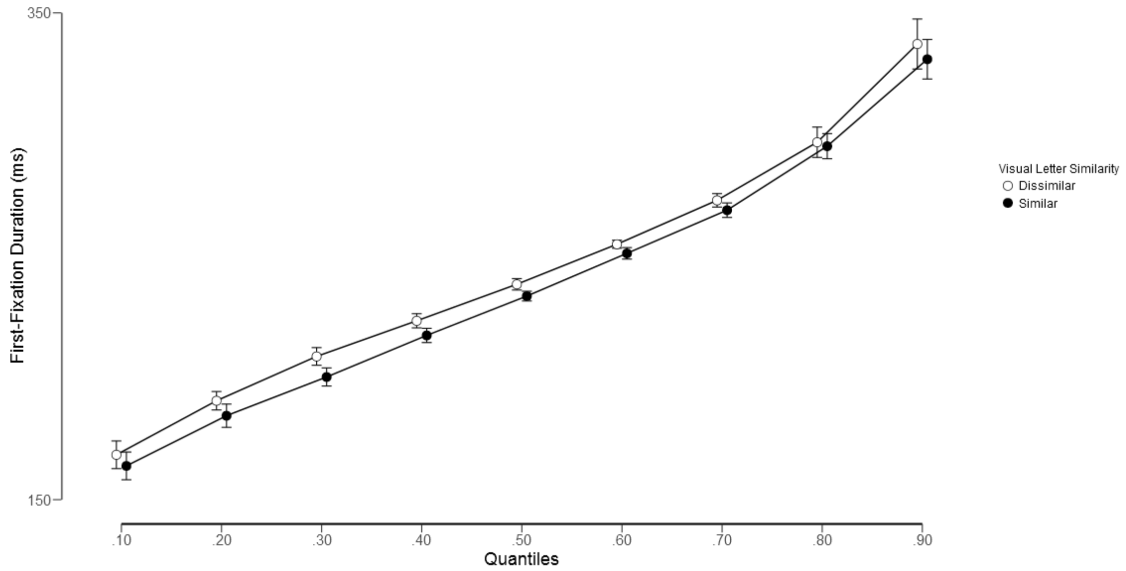
Single Fixation Duration. Ten advantage of the visually similar condition over the visually dissimilar condition approached significance, *b* = 0.076, *SE* = 0.041, *t* = 1.82, *p* = .077, whereas the advantage of the identity condition over the visually similar condition was quite robust, *b* = 0.18, *SE* = 0.048, *t* = 3.71, *p* = .001.

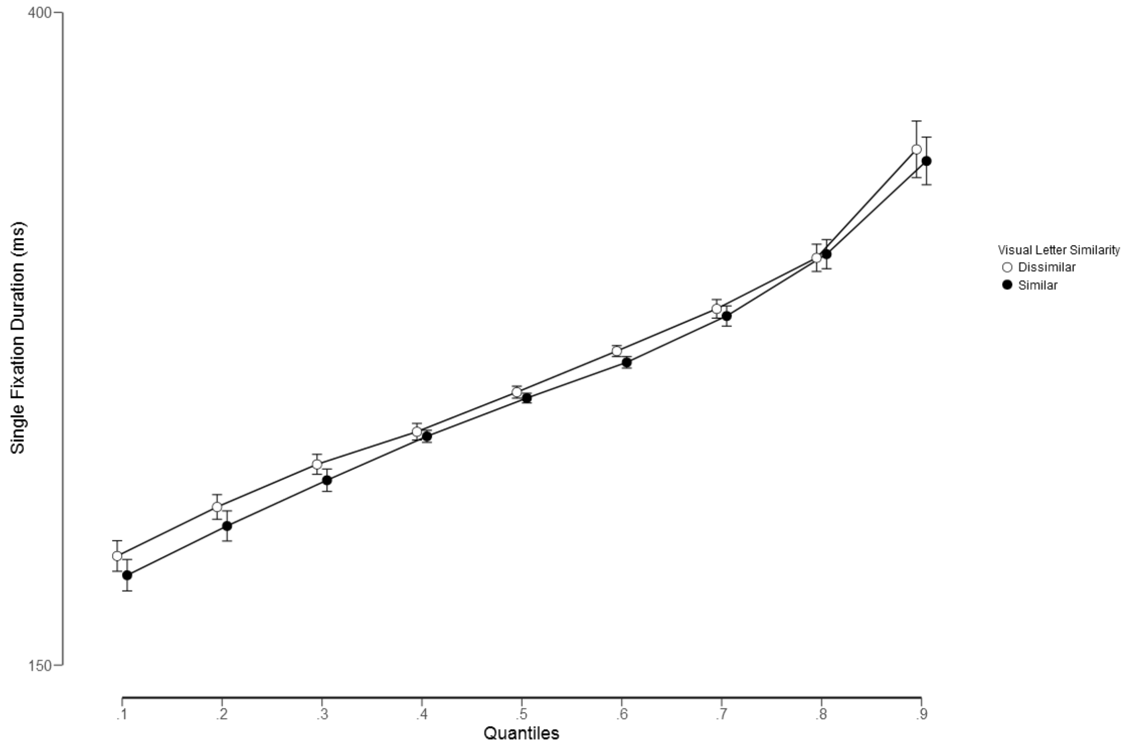
Gaze Duration. Gaze durations on the target word were longer in the visually dissimilar condition than in the visually similar condition, *b* = 0.103, *SE* = 0.042, *t* = 2.54, *p* = .013, and gaze durations on the target words in the visually similar condition were longer than in the identity condition, *b* = 0.113, *SE* = 0.050, *t* = 2.79, *p* = .032.[2]

Table 1. Averages of the eye movement measures (first fixation duration, single fixation duration, and gaze duration) in milliseconds for three preview conditions. Standard Errors are presented between brackets.

	First-Fixation Duration	Single Fixation	Gaze Duration
Type of parafoveal preview			
Identity	236 (7)	241 (8)	277 (14)
Visually Similar	243 (8)	252 (11)	284 (13)
Visually Dissimilar	248 (9)	255 (11)	291 (14)

[2] For the interested readers, the pattern of significant effects was the same if we had applied a logarithm transformation. For the critical comparison (visually similar vs. visually dissimilar), we found *t* = 2.07, *p* = .04 for first-fixation duration and *t* = 2.54, *p* = .013 for gaze duration. Similarly, the by-participant and by-item t-tests on the untransformed data also showed the same pattern (first-fixation duration: *t*1(26) = 2.20, *p* = .037, *t*2(239) = 1.99, *p* = .048; gaze duration: *t*1(26) = 2.38, *p* = .02, *t*2(239) = 2.53, *p* = .012).


350
150
First-Fixation Duration (ms)
.10
.20
.30
.40
.50
.60
.70
.80
.90
Quantiles
Visual Letter Similarity
Dissimilar
Similar


400
150
Single Fixation Duration (ms)
.1
.2
.3
.4
.5
.6
.7
.8
.9
Quantiles
Visual Letter Similarity
Dissimilar
Similar

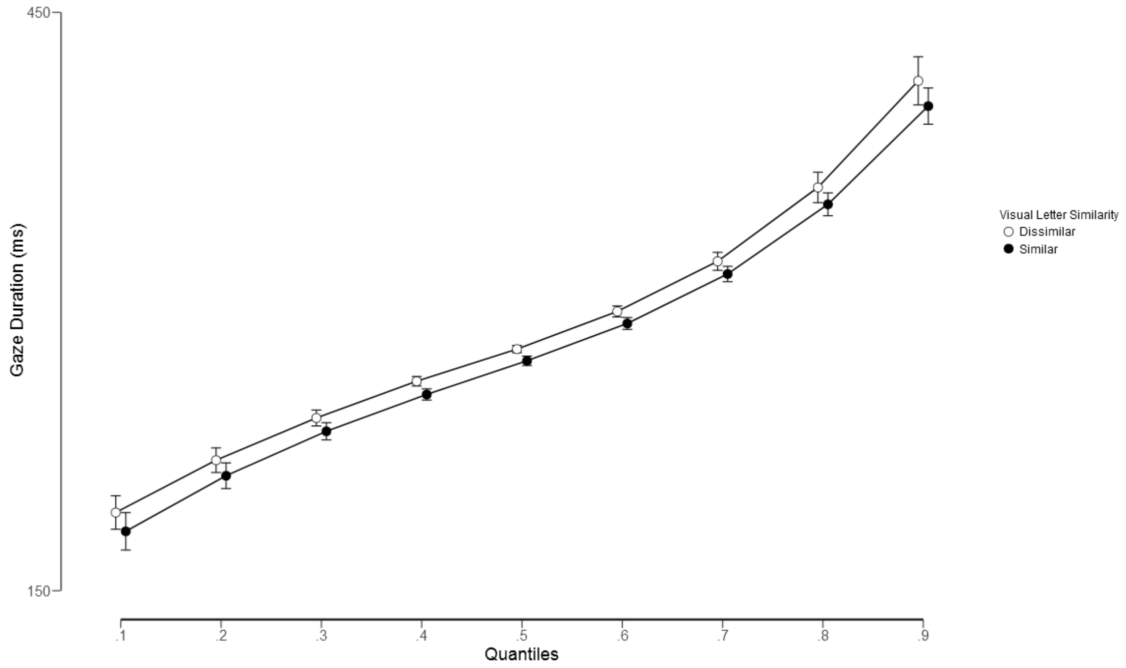


Figure 2. Averaged viewing duration distributions across quantiles for first fixation durations (top), single fixation durations (middle), and gaze durations (bottom) in the visually similar and visually dissimilar parafoveal conditions. The Bars represent the Standard Errors.

To corroborate the previous analyses and to shed more light on the nature of the effect of visual letter similarity during parafoveal processing, we conducted distributional analyses—via averaging the .1, .2, .3, .4, .5, .6, .7, .8, and .9 quantiles per participant and condition—on the first fixation durations, single fixations, and gaze durations. The rationale of these distributional analyses is that they allow us to examine whether the effect is approximately the same magnitude across quantiles (i.e., a shift in the distributions) or whether it grows in the higher quantiles (i.e., a change in shape)—note that this may be used to deduce whether the effect occurs at an encoding or decision stage (e.g., see Gomez & Perea, 2014). The distributional analyses on these three dependent variables are displayed in Figure 2. As can be seen in the Figure, the preview benefit of the visually similar condition over the visually dissimilar condition was stable across quantiles for first fixation duration and gaze duration (first fixation duration: $F(1,26) = 5.15$, $MSE = 607$, $p = .032$; gaze duration: $F(1,26) = 5.62$, $MSE = 1952$, $p = .025$; in both cases, the interaction yielded Fs < 1). For single-fixation duration, the effect of visual similarity did not reach significance, $F(1,26)$

= 2.11, *MSE* = 1281, *p* = .158—note that, although admittedly ad hoc, we found an advantage of the visually similar condition over the visually dissimilar condition in the leading edge of the distribution (Cohen's d values: 0.67, .65, and .49 at the .1, .2, and .3 quantiles; the *p* values were .002, .004, and .017, respectively).

Finally, under the assumption that completion of at least an initial word identification stage (e.g., L1 in the E-Z Reader model) in the parafovea may induce readers to skip the word n+1, we examined whether the probability of fixating the target word was higher when the preview was visually dissimilar than when the preview was visually similar. We found a higher probability of fixations on the target word when the preview was visually dissimilar than when the preview was visually similar (0.966 vs. 0.953, b = 0.35, SE = 0.15, t = 2.31, p = .021). In addition, the probability of fixations for the identity preview condition (0.947) did not differ from that of visually similar previews (b = -0.14, SE = 0.139, t = -1.03, p > .30).

Discussion

We designed a sentence reading experiment using Rayner's (1975) boundary change technique to examine the role of visual letter similarity—on the basis of visual similarity ratings—during the early moments of word identification while controlling for outline letter shape. To that end, the parafoveal preview on word n+1 could be a visually similar nonword preview (e.g., *frjto* for the target word *frito* [*fried*]; *i* and *j* are visually very similar [5.17 out of 7] in the Simpson et al., 2012, letter similarity norms) or a visually dissimilar nonword preview (e.g., *frgto*; *i* and *g* are visually different [1.53 out of 7]). For comparison purposes, an identity preview condition was also included. The eye fixation durations showed a reasonably consistent pattern: viewing times on target words were shorter when the parafoveal nonword preview was visually similar than when it was visually dissimilar, and this was accompanied by an advantage of the identity condition over the visually similar condition. These findings generalize the visual letter similarity effects reported by Marcet and Perea (2017c) using masked priming to a reading scenario with parafoveal previews. Critically, the effects of visual letter similarity during parafoveal processing were not due to an uncontrolled influence of letter shape, as letter shape was the same for the visually similar and visually dissimilar conditions. In sum, visual letter similarity effects do occur in normal reading, hence generalizing the findings reported by Rayner et al. (1978, 1982) when manipulating outline letter shape. We must keep in mind that whilst outline letter shape per se may not influence word processing in normal skilled readers (see Paap et al., 1984; Perea & Panadero, 2014), letters that share the outline shape (e.g., *c/a* in *pcluce-palace*) tend to be more visually similar than those that do not share the outline shape (e.g., *y/a* in *pyltce-palace*).

One might argue that the effects of visual letter similarity in the initial stages of word processing (e.g., the processing advantage of the visually similar preview [prime] *dentjst* over the control *dentgst* for the target *dentist*; this Experiment; see also Marcet & Perea, 2017c, 2018a, for evidence with the masked priming technique) are at odds with the null effect of case alternation in the earliest stages of word processing (e.g., both *dentist* and *dEnTiSt* are equally effective at activating the target word *DENTIST*; Forster, 1998; Perea, Vergara-Martínez, & Gomez, 2015; see also Rayner et al. 1980, for eye movement evidence). However, these two phenomena reflect different processing levels. On the one hand, the effect of visual letter similarity originates when the featural visual information is mapped onto case-specific letter detectors. Because of perceptual noise in the visual system, the shape-specific letter detectors for the letter "*i*" may be activated when the stimulus contains a highly visually similar letter, such as the letter "*j*" in *dentjst*, which in turn would activate the complex case-insensitive letter detector of "*i*". As a result, this explanation would correctly predict a processing advantage of *dentjst*-*dentist* over *dentgst*-*dentist*. On the other hand, the effect of case alternation does not originate early (i.e., the alternating-case prime *dEnTiSt* is as effective as the same-case prime *dentist*, Forster, 1998; see also Reingold, Yang, & Rayner, 2010, for evidence during sentence reading), but late in processing when the visual percept is compared with the stored representations in memory (see Perea et al., 2015, for discussion).

Further insights on the nature of the effects of visual letter similarity during reading can be obtained from distributional analyses on eye fixation durations. The rationale is the following: in evidence accumulation models (e.g., Ratcliff's, 1978, diffusion model), a given effect may provide a head-start to word processing (i.e., faster encoding) or it may modulate the quality of information (i.e., decision processes). While in the first scenario, there would be just a shift in the response time or eye fixation duration distributions, the second scenario would also produce changes in shape—the slower condition would produce larger effects at the higher quantiles. As shown by Gomez, Perea, and Ratcliff (2013), masked repetition priming effects (identity vs. unrelated priming conditions) reflect shifts in the response time distributions. In contrast, lexical effects such as the word frequency effect (i.e., low vs. high frequency words) produce changes in both the location and shape of the response time distributions (greater word-frequency effects at the higher quantiles; see Gomez & Perea, 2014) or eye fixation durations (see Staub, White, Drieghe, Hollway, & Rayner, 2008). The present distributional analyses on eye fixation durations showed that the advantage of the visually similar condition over the visually dissimilar condition was approximately the same across quantiles, especially in first-fixation duration and gaze duration (i.e., a shift in the distributions; see Figure 2). This pattern is consistent with the idea that the effects of visual letter similarity are due to an early "head-start" to word identification. That is, there is an initial encoding advantage of *frjto-frito* over the control *frgto*-frito, which is maintained during lexical processing (see Gomez et al., 2013, for modeling evidence of a shift in response time distributions in masked priming).

Taken together, the present findings show that, as predicted by Rayner et al. (1978), visual letter similarity modulates the integration of parafoveal and foveal information. Specifically, readers may benefit from the similarity between information extracted from the parafovea and the information extracted from the target once it is fixated in the fovea (i.e., a visually similar preview yields a benefit due to pre-activation of target letters). That is, when readers fixate on the target word *frito* (i.e., once the eye crossed the invisible boundary), there would be briefer viewing times when the parafoveal preview was a visually similar nonword (*frjto*) than when it was a visually dissimilar nonword (*frgto*). Additionally, visually similar previews may be more likely to be misidentified as the target word (e.g., see Gregg & Inhoff, 2016, for the role of misperceptions during reading). For instance, when readers are fixating the word "*bien*" in the sentence "*Estaba todo bien frito en aceite de oliva*" ["*It was all well frjed in olive oil*"], the letter *j* in *frjed* might be misperceived as the visually similar letter *i*, thus explaining the higher skipping rate on that target word when the parafoveal preview was visually similar than when the parafoveal preview was visually dissimilar. A limitation of Rayner et al.'s (1978) preliminary letter identification hypothesis, however, is that it has not yet been implemented in a full model of eye movement control in reading.

How can contemporary models of eye movement control accommodate the present findings? The E-Z Reader model (Reichle et al., 1998; Reichle, Pollatsek, & Rayner, 2003) and the SWIFT model (Engbert et al., 2005) do not include a module for orthographic or lexical processing. Clearly, the specification of the initial mapping from visual objects to letter features and letter identity/position is a challenge for all models of visual word recognition and reading (see Rosa, Perea, & Enneson, 2016, for discussion). As Reichle (2015) pointed out, it is desirable that the models of eye movement control during reading are elaborated to provide a more complete account of the orthographic processes during word recognition and how they contribute to normal reading. This would require specifying how letter identity and letter position are initially attained and integrated from the parafoveal information. In this line, Bicknell and Levy (2010) proposed a rational model of eye movement control in reading that includes a detailed account on how readers acquire word information in a sentence. A key idea of the Bicknell and Levy (2010) proposal, which fits well with the preliminary letter hypothesis (Rayner et al., 1978), is that readers extract information from a noisy visual input in the spirit of the Bayesian reader model of visual word recognition (Norris, 2006; see also Norris & Kinoshita, 2012). The noisy input in the Bayesian reader model would produce some degree of uncertainty at the initial moments of processing with respect to both letter identities and letter identity, thus capturing not only the effects of visual letter similarity (e.g., *dentjst* would produce a similar perceptual inputs *as dentist*) but also the effects of transposed-letter similarity (e.g., *jugde* would produce a similar perceptual input as *judge*; see Johnson et al., 1997). We acknowledge, however, that the size of these effects with the boundary change technique is small. For gaze duration, the difference between the visually similar condition and the visually different condition was 7 ms (284 vs. 291 ms, respectively); similarly, the magnitude of the transposed-letter similarity effect for internal letters reported by Johnson et al. (1997; Experiment 1) was 8 ms (300 ms for the transposed-letter condition; 308 ms for the replacement-letter condition). This suggests that readers can extract, on most occasions, accurate abstract orthographic representations from the parafoveal previews.[3] Indeed, the small size of visual letter similarity and transposed-letter effects with parafoveal previews is consistent with recent empirical evidence that shows that readers can extract semantic and high-level information from the parafoveal previews (see Hohenstein & Kliegl, 2014).

In sum, we examined the participants' eye fixation durations in a sentence reading experiment with the boundary change technique using visually similar vs. visually dissimilar parafoveal previews on the basis of objective letter confusability, with letter shape controlled (e.g., *frjto* vs. frgto for the target word *frito*). Results showed shorter viewing times on the target word when the nonword preview was visually similar to the target word than when it was visually dissimilar. Further empirical and theoretical work is necessary to offer a comprehensive account of how visual letter similarity modulates the initial stages of word identification during sentence reading.

[3] For comparison purposes with the Marcet and Perea (2017) masked priming experiments, we focused on a relatively constrained set of highly visually similar letters. We acknowledge that further empirical research is necessary to examine the impact of visual letter similarity in the early stages of word processing during sentence reading for a larger set of visually similar letters (e.g., c/e, c/o) or multi-letter homoglyphs (e.g., rn/m; cl/d).

Appendix

Experimental Sentences and Preview Conditions

El profesor comentó que José había sido un buen (sujeto, suieto, suaeto) **sujeto** en el experimento.

Ese hotel es el quinto (casino, casjno, casgno) **casino** por importancia en Las Vegas.

Esa estudiante afirma que hace (brujería, bruiería, bruaería) **brujería** y magia negra.

Alicia compró una nueva (estufa, estvfa, estzfa) **estufa** para la casa del pueblo.

Por fin acabamos la larga (mudanza, mvdanza, mzdanza) **mudanza** a la capital.

Pablo vive en un pueblo (lejano, leiano, leuano) **lejano** en los Picos de Europa.

A Juan le parece (horrible, horrjble, horrgble) **horrible** la moda de este año.

Mi abuela pone mucho (conejo, coneio, coneuo) **conejo** a la paella pero poco arroz.

El jurado parece (objetivo, obietivo, obaetivo) **objetivo** a la hora de nombrar al campeón.

Inés pintó un elegante (desnudo, desnvdo, desnzdo) **desnudo** para su clase de pintura.

Ese profesor había sido (granjero, graniero, granaero) **granjero** antes de empezar a estudiar.

Este es el primer (almuerzo, almverzo, almzerzo) **almuerzo** que me preparo yo solo.

Beatriz se asegura que no falte (aceite, acejte, acegte) **aceite** en la cocina.

Dijeron que ayer no hacía (viento, vjento, vgento) **viento** y los árboles estaban quietos.

Javier es un fabuloso (escritor, escrjtor, escrgtor) **escritor** de relatos cortos.

Laura había comprado un enorme (ático, átjco, átgco) **ático** en el centro de la ciudad.

Sufrió una fuerte (censura, censvra, censzra) **censura** cuando quiso contar su historia.

Este es ya el segundo (abrigo, abrjgo, abrpgo) **abrigo** que mancho con tinta.

Silvia tiene bastante (salud, salvd, salzd) **salud** pero poco dinero.

Cuando ves a María parece fácil (dibujar, dibuiar, dibuoar) **dibujar** en un lienzo de dos metros.

No entiendo el carácter (divino, diuino, dioino) **divino** de la risa.

Han hecho una nueva (travesía, trauesía, traoesía) **travesía** para ir hasta el pueblo.

Mi abuela hizo un exquisito (potaje, potaie, potaue) **potaje** ayer para comer.

Daniel tiene mucha (basura, basvra, baszra) **basura** en su habitación.

El gato empleaba su cascabel como (sonajero, sonaiero, sonaoero) **sonajero** para despertarme.

Es el cuatro (archivo, archiuo, archiao) **archivo** que elimino por virus.

No entiendo la tremenda (avaricia, auaricia, aoaricia) **avaricia** que tiene Miguel.

Laura escribió un maravilloso (discurso, discvrso, disczrso) **discurso** para el primer aniversario.

Leí en una revista una estupenda (novedad, nouedad, noaedad) **novedad** educativa.

Quiero pintar mi habitación totalmente (naranja, narania, naranea) **naranja** porque me da mucha vitalidad.

Aquel frasco oscuro tiene (ácido, ácjdo, ácgdo) **ácido** en su interior.

El payaso hizo una enorme (burbuja, burbuia, burbuea) **burbuja** que tardó mucho tiempo en romperse.

Tenemos que esperar al segundo (tranvía, tranuía, tranoía) **tranvía** porque en éste no cabemos.

Me interesa mucho la desconocida (cultura, cultvra, cultzra) **cultura** de esta tribu.

Es importante tener (espíritu, espírjtu, espírgtu) **espíritu** ganador para superarse a sí mismo.

Susana tiene su viejo (móvil, móuil, móail) **móvil** guardado en un cajón.

Visité una estupenda (escuela, escvela, esczela) **escuela** con métodos innovadores.

Carmen y yo hicimos un divertido (invento, inuento, inoento) **invento** para pasar la tarde.

Le dijeron que su pequeña (vejiga, veiiga, veoiga) **vejiga** le haría ir mucho al baño.

Cristina dibujó un horrible (círculo, círcvlo, círczlo) **círculo** dentro del cuadrado.

Pasamos el domingo viendo un largo (desfile, desfjle, desfgle) **desfile** en la calle principal.

Mi hermano consigue comer (gratis, gratjs, gratgs) **gratis** todos los días.

Nos cobraron mal el primer (alquiler, alqujler, alqugler) **alquiler** y ahora les reclamamos.

Tengo una nueva (navaja, navaia, navaea) **navaja** en mi colección de antigüedades.

He comprado una vieja (caravana, carauana, caraoana) **caravana** para irme por toda Europa.

Vimos que toda la prensa (mundial, mundjal, mundgal) **mundial** se ha hecho eco de la noticia.

Carolina ha generado suficiente (riqueza, rjqueza, rgqueza) **riqueza** para vivir sin trabajar.

Pablo es claramente (natural, natvral, natzral) **natural** cuando habla de esos temas.

Me encontré un bonito (pañuelo, pañvelo, pañzelo) **pañuelo** tirado en la calle.

Mi prima nos regaló un bonito (espejo, espeio, espeao) **espejo** a juego con el peine.

Fernando era un joven (físico, físjco, físgco) **físico** de gran prestigio.

Antonio García es el nuevo (fichaje, fichaie, fichaue) **fichaje** de la oficina.

Finalmente encontramos la nevera (portátil, portátjl, portátgl) **portátil** para nuestro viaje.

Raquel participó en una emocionante (subasta, svbasta, szbasta) **subasta** de Madrid.

Mario es el nuevo (titular, titvlar, titzlar) **titular** del puesto de recursos humanos.

Mi madre pudo abrir el pequeño (mejillón, meiillón, meoillón) **mejillón** que encontramos en la playa.

Olga dice que quiere (salir, saljr, salgr) **salir** a comprar esta tarde.

Estuvimos en un tranquilo (crucero, crvcero, crzcero) **crucero** durante una semana.

Resulta muy fácil (mejorar, meiorar, meaorar) **mejorar** cuando tienes a alguien que te guía.

Nos maravillaba encontrar algún (cangrejo, cangreio, cangreao) **cangrejo** rojo en la orilla del mar.

El policía nacional tenía (mujer, muier, muaer) **mujer** y dos hijos pequeños.

Lucía no ha visto este (mensaje, mensaie, mensaoe) **mensaje** tan gracioso.

El niño explicó una complicada (fórmula, fórmvla, fórmzla) **fórmula** a sus compañeros.

Su noviazgo es un claro (montaje, montaie, montaue) **montaje** de cara a su familia.

Ayer vino el nuevo (acusado, acvsado, aczsado) **acusado** al juzgado.

En Brasil tuvimos un excelente (servicio, servicjo, servicgo) **servicio** de habitaciones.

No me gusta comer (regaliz, regaljz, regalgz) **regaliz** después de lavarme los dientes.

Paula se mantiene (neutral, nevtral, neztral) **neutral** en la discusion entre hermanos.

Tenemos como principal (objetivo, objetiuo, objetieo) **objetivo** solucionar el problema.

Éste es nuestro (noveno, noueno, noaeno) **noveno** partido juntos.

El niño de mi vecina se vuelve (salvaje, salvaie, salvaoe) **salvaje** cuando juega al futbol.

Ignacio es el mejor (portavoz, portauoz, portaeoz) **portavoz** que hemos tenido en el grupo.

Hicieron un reportaje del enorme (ajedrez, aiedrez, auedrez) **ajedrez** con piezas de marfil.

Nos encontramos una pringosa (esponja, esponia, esponea) **esponja** detrás del inodoro.

He sufrido una horrible (avería, auería, aoería) **avería** en el sistema de aire acondicionado.

Era la primera vez que probaba (oreja, oreia, oreua) **oreja** y morro de cerdo.

Ese líquido parece (cerveza, cerueza, ceroeza) **cerveza** negra internacional.

Pepa me dijo que hubo una fuga (masivo, masjvo, masgvo) **masivo** de cerebros a Alemania.

En la calle vi a un antiguo (rival, rjval, rgval) **rival** de los campeonatos de karate.

Tuve que coger el complicado (desvío, desuío, desoío) **desvío** para llegar a mi casa.

Vimos un enorme (canguro, cangvro, cangzro) **canguro** en el zoo.

El estudiante no podía (exigir, exigjr, exigpr) **exigir** que le repitieran el examen.

Este libro no tiene mucho (polvo, poluo, polao) **polvo** por encima.

No me cabe el teléfono en este (bolsillo, bolsjllo, bolsgllo) **bolsillo** del pantalón.

No te fíes de ese conductor (novato, nouato, noeato) **novato** y ve despacio.

Estábamos en un profundo (agujero, agvjero, agzjero) **agujero** sin darnos cuenta.

Supimos ayer que la última (factura, factvra, factzra) **factura** contenía un error.

Estuvimos esperando el momento (cumbre, cvmbre, czmbre) **cumbre** pero nunca llegó.

Sonia examina cada (desván, desuán, desoán) **desván** de las casas que visitamos.

Jorge es demasiado (travieso, trauieso, traoieso) **travieso** para su edad.

En Navarra tienen un coordinado (servicio, seruicio, seroicio) **servicio** de ambulancias.

Irina trabaja en esta (vivienda, viuienda, vioienda) **vivienda** tutelada de Valencia.

Paquito consiguió un auténtico (milagro, mjlagro, mglagro) **milagro** al mantenerme despierto anoche.

Tienen una mirada casi (similar, simjlar, simglar) **similar** a la de un gato.

Estoy ilusionada por el gran (evento, euento, eoento) **evento** del próximo mes.

Ese cuadro estaba pintado sobre (hojalata, hoialata, hoealata) **hojalata** con óleo de calidad.

Teresa resolvió un complicado (cálculo, cálcvlo, cálczlo) **cálculo** en clase de matemáticas.

Sergio tiene un amigo (ciclista, cicljsta, ciclgsta) **ciclista** que compite profesionalmente.

Compramos algunos (muebles, mvebles, mzebles) **muebles** para el salón.

Encontramos un enorme (tiburón, tibvrón, tibzrón) **tiburón** en la playa.

Es una suerte contar con un profesor (nativo, natiuo, natiao) **nativo** dentro de la escuela.

No creo que tenga cierta (ventaja, ventaia, ventaea) **ventaja** por ser el hijo del director.

En casa encontré un extraño (bingo, bjngo, bgngo) **bingo** de colores chillones.

El niño egocéntrico decía que la única (majestad, maiestad, maoestad) **majestad** era él mismo.

Ya se ha caído el primer (azulejo, azuleio, azuleuo) **azulejo** de la pared de la cocina.

Lucas parece el típico (malvado, maluado, maloado) **malvado** de telenovela.

Vi una graciosa (lombriz, lombrjz, lombrgz) **lombriz** en el barro.

Descubrí el maravilloso (universo, uniuerso, unioerso) **universo** de la magia.

Juan hizo un comentario bastante (absurdo, absvrdo, abszrdo) **absurdo** sobre el machismo.

Lucía tiene pura (envidia, enuidia, enoidia) **envidia** de su hermana mayor.

Andrés compró una colorida (bufanda, bvfanda, bzfanda) **bufanda** para su hermana.

Estoy esperando que llegue mi nuevo (altavoz, altauoz, altaeoz) **altavoz** para el comedor.

Marcos ha enviado un correo (masivo, masiuo, masiao) **masivo** para todos sus empleados.

No entiendo tanta (locura, locvra, loczra) **locura** por ese programa televisivo.

Esta es la enfermedad más común del último (milenio, milenjo, milengo) **milenio** en nuestro país.

Vi un hermoso (pueblo, pveblo, pzeblo) **pueblo** en mis vacaciones.

Se compró un libro (digital, digjtal, digptal) **digital** de última generación.

Queda una única (brújula, brúiula, brúeula) **brújula** en la tienda de mi primo.

No hace falta que lleves tanto (equipaje, equipaie, equipaoe) **equipaje** para dos días.

Carmen quiere estudiar (lenguaje, lenguaie, lenguaoe) **lenguaje** musical en el conservatorio.

Silvia sintió un tremendo (alivio, aliuio, alioio) **alivio** al ver el resultado de las pruebas.

A Costa Rica no le hace falta (ejército, eiército, euército) **ejército** para defenderse.

Beatriz es experta en hacer (hojaldre, hoialdre, houaldre) **hojaldre** casero con productos ecológicos.

Este coche tiene demasiado (rodaje, rodaie, rodaoe) **rodaje** como para querer comprarlo.

Corred, que si no perderéis vuestro (avión, auión, aoión) **avión** de vuelta a casa.

Asistí al mejor (festival, festiual, festioal) **festival** que existe en España.

Mi abuela me regaló un inmenso (diamante, djamante, dgamante) **diamante** que era de su madre.

Marcos protagonizó un precioso (musical, mvsical, mzsical) **musical** en Barcelona.

Recogimos una original (lechuga, lechvga, lechzga) **lechuga** de hojas rosas.

Laura rompió su propio (álbum, álbvm, álbzm) **álbum** de la Comunión.

Eva y Pedro forman una gran (pareja, pareia, pareoa) **pareja** de cómicos en el escenario.

Mi madre dice que siempre existe (remedio, remedjo, remedgo) **remedio** para los problemas.

Fuimos al maravilloso (carnaval, carnaual, carnaoal) **carnaval** de Cádiz.

Vimos un hermoso (ciervo, cieruo, cierao) **ciervo** por la sierra de mi pueblo.

Tenía todo el cuerpo (pegajoso, pegaioso, pegaeoso) **pegajoso** por el calor húmedo.

Susana tiene una moderna (lavadora, lauadora, laoadora) **lavadora** en su piso nuevo.

Si tienes mucha (avaricia, avarjcia, avargcia) **avaricia** no conseguirás amigos.

Siempre suelo poner poca (lejía, leiía, leaía) **lejía** cuando tengo que lavar ropa blanca.

Laura dejó un libro (debajo, debaio, debaeo) **debajo** de la carpeta rosa.

Es el último (aviso, auiso, aoiso) **aviso** para embarcar rumbo a Málaga.

Laura sólo tiene dinero para un único (masaje, masaie, masaoe) **masaje** cada tres meses.

Fran me regaló un bonito (dibujo, dibvjo, dibzjo) **dibujo** para mi cumpleaños.

Lucía tiene un vecino (cinéfilo, cinéfjlo, cinéfglo) **cinéfilo** al que presta sus películas.

El primer premio (mundial, mvndial, mzndial) **mundial** fue para Rocío.

Realizamos una campaña para (reducir, reducjr, reducgr) **reducir** el consumo de alcohol.

Creamos un interminable (aplauso, aplavso, aplazso) **aplauso** en la sala de juntas.

No conocía a este (chaval, chaual, chaoal) **chaval** y me cae muy bien.

Es el segundo (cuervo, cueruo, cuereo) **cuervo** que veo sobrevolando la casa.

No existe ningún (culpable, cvlpable, czlpable) **culpable** en esta situación.

Analizaremos cada (célula, célvla, célzla) **célula** hasta dar con la anomalía.

Natalia compró una vieja (muñeca, mvñeca, mzñeca) **muñeca** en el rastro.

En mis vacaciones vi un único (oasis, oasjs, oasgs) **oasis** en medio del desierto.

Fernando me recomendó esta (novela, nouela, noaela) **novela** tan aburrida.

Marta tiene demasiado (nivel, niuel, nioel) **nivel** para estar en esa clase.

Sebastián es nuestro (favorito, fauorito, faeorito) **favorito** para la presidencia de la empresa.

Carlos necesita poca (saliva, saliua, salioa) **saliva** para estar hablando durante horas.

Estaba todo bien (frito, frjto, frgto) **frito** en aceite de oliva.

Nos han dicho que nuestra (cocina, cocjna, cocgna) **cocina** es de corte moderno.

Gabriel no tiene mucha (puntería, pvntería, pzntería) **puntería** cuando juega a los dardos.

Mi primo encontró el primer (fósil, fósjl, fósgl) **fósil** del yacimiento el año pasado.

Mireia recuerda con emoción aquel (minuto, mjnuto, mgnuto) **minuto** que cambió su vida.

Mi tío Carlos es un experto (relojero, reloiero, reloaero) **relojero** formado en Suiza.

Javier es un respetado (adivino, adiuino, adioino) **adivino** en el mundo esotérico.

La maqueta está en el tercer (cajón, caión, caeón) **cajón** de la mesita de noche.

Ese señor insistía que nuestro (prójimo, próiimo, próeimo) **prójimo** debe ser tratado justamente.

Escribí un cuento sobre (timidez, timjdez, timgdez) **timidez** que encantó a todos los docentes.

El periquito de Marta parece (viejo, vieio, vieao) **viejo** pero solo tiene un año.

Alejandro Ibáñez es un excelente (cirujano, ciruiano, cirueano) **cirujano** a nivel internacional.

En mi calle hay una larguísima (muralla, mvralla, mzralla) **muralla** de la época medieval.

Mi madre siempre pasa (revista, reuista, reoista) **revista** a los armarios.

Sergio ha quedado (octavo, octauo, octaeo) **octavo** en la carrera popular.

El comité local quería (suprimir, suprimjr, suprimgr) **suprimir** la regla número ocho.

Carla bebió tanto (tequila, tequjla, tequgla) **tequila** que acabó vomitando.

No soporto vuestra (rutina, rvtina, rztina) **rutina** tan aburrida.

Necesito urgentemente otra (nevera, neuera, neoera) **nevera** en el apartamento.

Elena compró una antigua (brújula, brújvla, brújzla) **brújula** en la tienda de la esquina.

Tuvimos una discusión sobre si existe (dopaje, dopaie, dopaoe) **dopaje** en el fútbol actual.

Alba tiene poca (altura, altvra, altzra) **altura** para ser policía.

Fue un fin de semana para (repetir, repetjr, repetgr) **repetir** una y mil veces.

Javier es un excelente (alumno, alvmno, alzmno) **alumno** de fisioterapia.

Paco es un buen (árbitro, árbjtro, árbgtro) **árbitro** que trabaja en la federación.

Vicente parece (turista, tvrista, tzrista) **turista** porque no para de hacerle fotos a todo.

Sara estuvo en un grandísimo (convento, conuento, conoento) **convento** de Zamora.

Vivimos un gran (aventura, auentura, aoentura) **aventura** en Tailandia.

Vi a Paco un poco (nervioso, neruioso, neroioso) **nervioso** después de la discusión.

Pedro creó una maravillosa (prueba, prveba, przeba) **prueba** para los novios.

Carmen me dio otra (aspirina, aspirjna, aspirgna) **aspirina** porque no se me pasaba el dolor de cabeza.

Tu tío está (abajo, abaio, abauo) **abajo** desayunando un tazón de leche.

Nunca había visto aquel (lavabo, lauabo, laoabo) **lavabo** tan sucio.

Mi pelo quedó (mojado, moiado, mouado) **mojado** después de la guerra de agua.

Aquella es la sexta (oveja, oveia, oveua) **oveja** que se le escapa este año.

Me han dicho que me falta (calcio, calcjo, calcgo) **calcio** en los huesos.

Fuimos caminando hasta la pequeña (ermita, ermjta, ermgta) **ermita** de la montaña.

Se ve claramente en aquella (gráfica, gráfjca, gráfgca) **gráfica** el aumento de los impuestos.

Mi hermano me dio un fuerte (empujón, empuión, empueón) **empujón** que hizo que cayera al suelo.

El novio de Patricia es nuestro (dentista, dentjsta, dentgsta) **dentista** de toda la vida.

Irene limpió la sucia (tubería, tvbería, tzbería) **tubería** del cuarto de baño.

Sólo hicieron una única (revisión, reuisión, reoisión) **revisión** del coche antiguo.

En la reunión trataron la vieja (cuestión, cuestjón, cuestgón) **cuestión** de siempre.

Fui a hacerme una nueva (llave, llaue, llaoe) **llave** porque me robaron el bolso.

El primo de mi amiga parece (joven, jouen, joaen) **joven** pero está a punto de jubilarse.

Conocí a la profesora cuyo (novio, nouio, noeio) **novio** es deportista de élite.

No había probado nunca (caviar, cauiar, caoiar) **caviar** de primera calidad.

Mariano es el simpático (abuelo, abvelo, abzelo) **abuelo** de mi amiga.

Hemos visto al nuevo (testigo, testjgo, testpgo) **testigo** que declarará contra Jesús.

Allí han puesto una nueva (aduana, advana, adzana) **aduana** para cruzar la frontera.

Paula ha comprado pocas (chuletas, chvletas, chzletas) **chuletas** para todos los que somos.

Pedro es un claro (reflejo, refleio, refleao) **reflejo** de su padre.

Ayer te hablé de la gran (reserva, reserua, reseroa) **reserva** que hay en Santander.

Lola Revilla es nuestra (bruja, brvja, brzja) **bruja** favorita.

Begoña tiene una penosa (actitud, actitvd, actitzd) **actitud** con David.

Beatriz creó un elaborado (anuncio, anvncio, anzncio) **anuncio** para una marca muy conocida.

Es la segunda (tarjeta, tarieta, taraeta) **tarjeta** que le saca el árbitro.

Me vestí elegante para (desfilar, desfjlar, desfglar) **desfilar** junto a mi abuelo.

El novio de mi hermano parece (nativo, natjvo, natgvo) **nativo** pero nació en Australia.

No encontramos en nuestro (archivo, archjvo, archgvo) **archivo** ese documente del que hablas.

Tenemos pendiente una buena (revancha, reuancha, reoancha) **revancha** el próximo miércoles.

Felipe es demasiado (viajero, viaiero, viauero) **viajero** como para quedarse en casa.

La propuesta tenía gran riqueza (visual, vjsual, vgsual) **visual** y tuvo gran impacto.

Nadia se encontró una linda (tortuga, tortvga, tortzga) **tortuga** en el jardín.

Pepa empleó cierto (chantaje, chantaie, chantaoe) **chantaje** emocional para conseguir su objetivo.

Ayer fui a ver un divertido (musical, musjcal, musgcal) **musical** con muy buenos bailarines.

Le dieron un premio por el precioso (tatuaje, tatuaie, tatuaoe) **tatuaje** que había diseñado.

Mis vecinos se asombraron por la larga (serie, serje, serge) **serie** de robos en el edificio.

Mi tía hizo una inteligente (apuesta, apvesta, apzesta) **apuesta** sobre el partido.

El otro día compré una pequeña (pastilla, pastjlla, pastglla) **pastilla** que cura todos los males.

No sabía que existía aquella (caverna, cauerna, caoerna) **caverna** en lo alto de la montaña.

Ramón tiene un amplio (garaje, garaie, garaoe) **garaje** donde le caben todas sus herramientas.

Toni está en plena (pubertad, pvbertad, pzbertad) **pubertad** a sus trece años.

Ayer mi madre vio un pequeño (pájaro, páiaro, páearo) **pájaro** construyendo su nido.

No veo nuestro (futuro, futvro, futzro) **futuro** muy claro.

El fisioterapeuta le puso tanto (vendaje, vendaie, vendaoe) **vendaje** que ya no podía doblar la rodilla.

Pasamos por la gran (avenida, auenida, aoenida) **avenida** que cruza la ciudad.

Jorge lanzó un inmenso (suspiro, suspjro, suspgro) **suspiro** al saber que le había perdido para siempre.

Mi hermana diseñó un gran (tejado, teiado, teuado) **tejado** de vidrio para su chalet.

He visto un novedoso (artículo, artícvlo, artíczlo) **artículo** en la tienda de la esquina.

La razón para este (flojo, floio, floeo) **flojo** resultado fue la falta de ganas.

Nerea ha salido (movida, mouida, moaida) **movida** en la foto de grupo.

Verónica dice que es poco (evidente, euidente, eoidente) **evidente** el cambio climático.

Tengo demasiada (angustia, angvstia, angzstia) **angustia** como para comerme el postre.

4.6 Can I order a burger at rnacdonalds.com? Visual similarity effects of multi-letter combinations at the early stages of word recognition

Abstract

Previous research has shown that early in the word recognition process, there is some degree of uncertainty concerning letter identity and letter position. Here we examined whether this uncertainty also extends to the mapping of letter features onto letters, as predicted by the Bayesian Reader (Norris & Kinoshita, 2012, *Psychological Review*). Indeed, anecdotal evidence suggests that nonwords containing multi-letter homoglyphs (e.g., rn→m) such as docurnent can be confusable with their base word. We conducted two masked priming lexical decision experiments in which the words/nonwords contained a middle letter that was visually similar to a multi-letter homoglyph (e.g., docurnent [rn—m], presiclent [cl—d]). Three types of primes were employed: identity, multi-letter homoglyph, and orthographic control. We used two commonly used fonts: Tahoma in Experiment 1 and Calibri in Experiment 2. Results in both experiments showed faster word identification times in the homoglyph condition than in the control condition (e.g., documento–DOCUMENTO faster than docusnento–DOCUMENTO). Furthermore, the homoglyph condition produced nearly the same latencies as the identity condition. These findings have important implications not only at a theoretical level (models of printed word recognition) but also at an applied level (Internet administrators/users).

Keywords: lexical access; masked priming; visual similarity; models of word recognition

In Roman script, as in other alphabetic scripts, letters are the building blocks of words. When a printed word is presented, the initial stages of processing are devoted to identify the visual features (e.g., oriented curves/lines, intersections, terminations, among others) of each of the visual objects (i.e., letters) that comprise the word (e.g., the letters s-a-l-t in the word salt; see Figure 1). The activation from these visual feature detectors is sent to abstract letter detectors (i.e., salt and SALT would activate the same letter detectors), which in turn send activation to whole-word units—note that this process may involve both feedforward and feedback connections (Carreiras, Armstrong, Perea, & Frost, 2014). The "magic moment" in word recognition occurs when the level of activation of a given whole-word unit exceeds some threshold (see Balota, Yap, & Cortese, 2006; McClelland, Mirman, Bolger, & Khaitan, 2014).

Figure 1. Representation of the word salt in Calibri, indicating the width of each letter slot

Thus, as Norris and Kinoshita (2012) pointed out, during printed word recognition "the visual system must identify how many visual objects are present, their configuration (order), and their identity." (p. 521) Indeed, the cognitive processes that underlie the encoding of letter identification and letter position have received considerable attention in the literature on printed word recognition and reading (see Grainger, Dufau, & Ziegler, 2016, for review). Most researchers assume that there is some degree of uncertainty regarding letter identity and letter position in the early moments of word processing (e.g., see Davis, 2010; Gomez, Ratcliff, & Perea, 2008; Grainger & van Heuven, 2003; Norris, 2006). For instance, using Forster and Davis' (1984) masked priming technique (i.e., a technique devised to reflect the early stages of word processing), Marcet and Perea (2017c) found that word identification times on a target stimulus (e.g., DENTIST) were shorter when preceded by a visually similar one-letter replacement nonword prime (e.g., dentjst; note that j and i are visually similar) than when preceded by a visually dissimilar one-letter replacement nonword prime (e.g., dentgst) (see Kinoshita, Robidoux, Mills, & Norris, 2013; Perea, Duñabeitia, & Carreiras, 2008, for similar evidence using letter-like numbers [e.g., 4=A in M4TERI4L] and symbols [e.g., Δ = A in MΔTERIΔL]). These findings suggest that, at the earliest stages of word processing, the letter detector corresponding to the letter "A" can be activated not only by the sensory representation of the letter "A", but also by visually similar characters such as "H", "4", or "Δ". Likewise, word recognition times on a target stimulus (e.g., JUDGE) are shorter when preceded by a transposed-letter nonword prime (e.g., jugde) than when preceded by a replacement-letter nonword prime (e.g., jupte) (Perea & Lupker, 2003, 2004; see Johnson, Perea, & Rayner, 2007, for evidence during sentence reading using parafoveal previews). The robustness of masked transposed-letter priming effects (e.g., jugde→judge or cholocate→chocolate) is a demonstration that, early in processing, there is some degree of ambiguity regarding letter position.

Critically, much less attention has been dedicated to the perceptual front-end of word processing: how the visual objects that compose the words are mapped onto letters? As Finkbeiner and Coltheart (2009) indicated, "determining how readers extract letter identities from the highly variable featural information in the input is fundamental to attempts to understand the reading process." (p. 2) However, none of the current computational models of printed word recognition and reading makes any specific claims on the binding from letter feature to letters. This is so because: 1) the focus of these models is on already highly complex processes (i.e., the underpinnings of the letter and word levels); and 2) the "basic results" are assumed to be independent of the implementation of a detailed mapping between features and letters (see Davis, 2010, p. 725; McClelland & Rumelhart, 1981, p. 383). As an illustrative example, when introducing the SERIOL model of visual word recognition, Whitney (2001) stated the following: "we do not model the process of letter recognition; we take as given that a mechanism exists to bind the features of a letter together, culminating in activation of the correct letter" (p. 226-227).

For simplicity, the interactive activation model (McClelland & Rumelhart, 1981) and its successors (dual-route cascaded model: Coltheart, Rastle, Perry, Langdon, &

Ziegler, 2001; multiple read-out model: Grainger & Jacobs, 1996) assume discrete slots for letters that are fed by a feature-level channel on each letter position using the Rumelhart and Siple (1974) uppercase font (e.g. the word HAND would be encoded as ). The model does not make any claims on how the visual components of letters are put together, although a reasonable starting point is that the small gaps among letters act as boundaries (e.g., we may not know Georgian script, but we may easily deduce that the word ხაღამო [*night* in Georgian] is composed of six letters)[1]. Therefore, the orthographic coding scheme of the interactive activation model predicts an unequivocal mapping of letter features to letters (e.g., the letter features that compose H in HAND would not be merged with the letter features of A). However, as indicated earlier, there is a rich literature that has repeatedly shown that the processes underlying word recognition can be better understood assuming a noisy or incomplete signal of the visual input at the early moments of processing (Adelman, 2011; Davis, 2010; Gomez et al., 2011; Grainger et al., 2016; Norris, Kinoshita, & van Casteren, 2011).

Therefore, an open question is whether there is some degree of ambiguity in the initial mapping of letter features onto letters. Importantly, a leading model of visual word recognition (Bayesian Reader model, Norris & Kinoshita, 2012) makes specific predictions in this respect. Norris and Kinoshita (2012) claimed that, in the early moments of word processing, “there will be uncertainty about the identity of the objects, their location, and even whether the objects really exist or are insertions created by spurious noise in the system” (p. 521)—this ambiguity would be progressively resolved over time (i.e., JUGDE may be processed initially as JUDGE, but at some point the reader will notice the difference; see Vergara-Martínez, Perea, Gomez, & Swaab, 2013, for an analysis of the time course of the transposed-letter effect using evoked-related potentials). Thus, the Bayesian Reader model can successfully capture that the masked nonword prime dentjst is more effective at

[1] The story is (obviously) more complex for semi-cursive scripts (e.g., Arabic; see Yakup, Abliz, Sereno, & Perea, 2015). For instance, in the Arabic sentence “أخذ الولد دب صديقه” [the boy took the friend bear in Arabic] each word’s segments need to be adequately segmented into letters and words. The same case applies to reading cursive handwriting, in which the lack of uniformity across letters adds to the additional segmentation processes (e.g., see Barnhart & Goldinger, 2010; Perea, Marcet, Uixera, & Vergara-Martínez, 2017).

activating the word DENTIST than the control nonword dentgst (i.e., dentjst and dentist only differ in a visually similar letter) and that the masked nonword prime jugde is more effective at activating the word JUDGE than the control nonword jupte (i.e., jugde and judge share the same letters in different order). But more importantly for the present purposes, the Bayesian Reader model predicts that, early in word processing, there is also some degree of uncertainty with respect to the mapping of visual objects onto letters. As Norris and Kinoshita (2012) indicated, "in the same way that we assume that identity and order information accumulates gradually over time, we also assume that knowledge of which letters, or letter objects, are in the input also improves over time" (p. 524).

One way to test this assumption of the Bayesian Reader model is to examine whether or not visually presented words are segmented into letter units at the early stages of word processing (i.e., house: h-o-u-s-e). To tackle this issue, we took advantage of the fact that there are multi-letter combinations—the so-called "multi-letter homoglyphs"[2] —whose shapes may resemble individual letters (e.g., rn→m, cl→d, vv→w). While this type of confusion occurs in OCR engines (e.g., the Tesseract ORG engine [Smith, 2007] has a specific module to avoid "rn" being identified as "m"), we must keep in mind that human readers can rapidly read words composed of distorted characters (e.g., CAPTCHAs [Completely Automated Public Turing test to tell Computers and Humans Apart]; see Von Ahn, Maurer, McMillen, Abraham, & Blum, 2008) that pose problems to OCR engines (see Hannagan, Ktori, Chanceaux, & Grainger, 2012, for evidence of substantial masked repetition priming when using CAPTCHAs as primes). Thus, the research question could be put this way: Would the detectors of a given letter (e.g., "m") be activated early in processing when a word not containing this specific letter—but containing a multi-letter homoglyph (e.g., docurnent)—is briefly presented? This question is not only important at a theoretical level (i.e., it would help refine the perceptual feature-letter front-end of models of printed word recognition); at an applied level, the potential confusability across letters is a matter of serious concern when accessing Internet websites (Davis & Suignard,

[2] As defined in Wikipedia, "A homoglyph is one of two or more graphemes, characters, or glyphs with shapes that appear identical or very similar" (retrieved on 21 February, 2017)

2012; see also Bohm, 2014). As acknowledged in the Microsoft website when discussing security in Internet domain names, "rnicrosoft.com looks much like microsoft.com"[3], and this may lead to spoofing attacks (see Gabrilovich & Gontmakher, 2002; Krammer, 2006). Thus, leaving aside the theoretical implications of the processing of multi-letter homoglyphs, if the suspicion that these letter combinations are processed as one letter is confirmed empirically, great care should be taken to prevent scammers to imitate false identity via multi-letter homoglyphs—as in rnacdonals.com—in Internet websites.

In the present experiments, we selected 240 words composed of a middle letter that resembled a multi-letter homoglyph (e.g., rn and m [documemt-document]; cl and d [presiclent- president])—the multi-letter homoglyph vv was not used because the letter w is very infrequent in Spanish. As we were interested in examining the early stages of word recognition, we used the same procedure as in prior research on letter identity/position coding (i.e., masked priming lexical decision; see Marcet & Perea, 2017c; Perea & Lupker, 2004). On each trial, an uppercase target stimulus (e.g., DOCUMENTO [the Spanish for DOCUMENT]) was preceded by a 50-ms lowercase nonword prime created by replacing the critical letter (e.g., m) of the target word (documento) by its corresponding multi-letter homoglyph (docurnento) or by a lowercase nonword control prime created by replacing the letters "rn" with "sn" (docusnento).[4] To obtain an estimate of the degree that the multi-letter homoglyphs activate their visually similar equivalent letters, we also included a lowercase identity prime (documento).

The predictions are clear. If visually presented words are readily segmented into letter units at early stages of word processing, the letters "r" and "n" in docurnent would only activate their corresponding best-match letter units (i.e., "r" and "n"). As a result, the multi-letter homoglyph "rn" would not activate the letter "m" in docurnent to a greater degree than the control multi-letter combination "sn" in docusnent. Therefore, one would expect a similar advantage of the identity condition (document-

[3] Retrieved on 21 February, 2017 from https://msdn.microsoft.com/en-us/library/windows/desktop/dd374047(v=vs.85).aspx

[4] We acknowledge that there may be other options at creating the control condition. We employed "sn" as a control of the homoglyph "rn" because they two pairs kept the same syllabic structure and had similar bigram frequencies.

DOCUMENT) over the two replacement-letter conditions (documnent-DOCUMENT and docusnent–DOCUMENT). At a theoretical level, this outcome would support the idea that the small gaps around the visual objects mark the beginning/end of each letter, at least when using highly legible fonts; furthermore, this would pose some problems to those models that assume that, early in processing, there is some degree of uncertainty at assigning the word's constituent visual objects onto letter units. At an applied level, this outcome would suggest that the source of the alleged confusability of multi-letter homoglyphs (if any) does not arise early in processing. Alternatively, if there were some degree of uncertainty at assigning the stimulus' visual information to letters units early in processing (i.e., the letter "rn" in docurnento would activate the abstract unit "m" to some degree)—as would predict the Bayesian Reader model (Norris & Kinoshita, 2012), one would expect faster word identification times in the multi-letter homoglyph priming condition than in the control priming condition (i.e., docurnent–DOCUMENT < docusnent–DOCUMENT); indeed, in the extreme scenario, the multi-letter homoglyph condition could be processed as fast as the identity condition (see Marcet & Perea, 2017c; Perea et al., 2008; for evidence with visually similar one-letter different primes). This latter outcome would not only support the predictions of the Bayesian Reader model (Norris & Kinoshita, 2012), but it would make it necessary to refine the links between the feature and letter levels in models of printed word recognition—note that the Bayesian Reader model is silent as to how the visual objects are bound onto letters. (We defer a discussion how visual features are mapped onto letters to the General Discussion.) Furthermore, at an applied level, this outcome should be made known to Internet administrators to avoid users from being potential victims of identity thief in malicious websites—this may also lead the creation/use of fonts that minimize this potential confusability.

To assess the generality of the findings in an ecological setting, we employed two common fonts. In Experiment 1 we used Tahoma, which is the default font of the most popular social network (Facebook)—this font has already been used in masked priming experiments (e.g., Duyck & Warlop, 2009; Silvia, Jones, Kelly, & Zibaie, 2011). This font has a narrow inter-letter spacing, thus maximizing the chances to capture the effects from multi-letter homoglyphs (if any) during printed word recognition (e.g., documento–DOCUMENTO vs. docurnento–DOCUMENTO vs. docusnento–DOCUMENTO). In Experiment 2, we employed Calibri. This is the default font in the most popular office package (Microsoft Office) (see Chen, Peltola, Ranta, & Hietanen, 2016; Tan & Yap, 2016, for masked priming experiments using Calibri font). As Calibri has a wider inter-letter spacing than Tahoma (e.g., document–DOCUMENTO vs. docurnento–DOCUMENTO vs. docusnento–DOCUMENTO), it offers a useful scenario to test whether the effects of multi-letter homoglyphs are restricted to a special case of narrow-spaced fonts.

Experiment 1

Method

Participants

Thirty undergraduate psychology students from the Universitat de València (Spain), all of them native speakers of Spanish, took part in the experiment. All participants signed an informed consent form before starting the experiment.

Materials

The set of word stimuli was composed of two hundred and forty Spanish words extracted from the EsPal subtitle database (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras 2013). The average Zipf frequency was 4.39 (range: 2.98–6.11), the average number of letters was 7.8 (range: 5–12), and the average OLD20 was 2.1 (range: 1–7.8). All these words had the letters m or d in a middle position (e.g., DOCUMENTO [document]; PRESIDENTE [president]). Target words were presented in uppercase and were preceded by: (a) a lowercase identity prime (identity condition; documento–DOCUMENTO; presidente–PRESIDENTE); (b) a nonword lowercase prime in which the letter m/d from the base word was replaced by rn/cl (homoglyph condition; docurnento–DOCUMENTO; presiclente–PRESIDENTE); or (c) a nonword prime in lowercase, in which the letter initial letter of the multi-letter homoglyph was replaced by another letter that kept the same syllabic structure (e.g., rn→sn; mean bigram token frequency per million: 339 vs. 335, respectively, $p > 0.40$) (control condition; docusnento–DOCUMENTO; presiglente–PRESIDENTE). We also created a set of 240 nonwords matched on letter length, transition frequencies, and subsyllabic elements with the words using Wuggy (Keuleers & Brysbaert, 2010)—the added constraint was that the letter m/d should appear in a middle position (e.g., CLIMERO; VADRO). The prime-target manipulation for the nonword targets was the same as that for word targets. Prime-target pairs were rotated across the three priming conditions in a Latin square manner, thus resulting in three lists. The complete set of words/nonwords is available at http://www.uv.es/amarhe5/glyphs.pdf

Procedure

The experimental session took place individually in a quiet lab. A windows computer equipped with DMDX (Forster & Forster, 2003) was employed to present the stimuli and register the responses. Each trial started with a 500-ms pattern mask—a series of #'s—in the center of a CRT screen for 500 ms. Then, the mask was immediately replaced by a 50-ms lowercase prime, which in turn was substituted by a target stimulus in uppercase. The target stimulus remained on the screen until the participant responded or a 2-sec deadline had passed. Participants were instructed to press, as quickly/accurately as possible, a key labelled "sí" (yes) if the letter string formed a legitimate word in Spanish or a key labelled "no" if the letter string did not form a word. The stimuli were presented in 16-pt Tahoma. Each participant received a randomized order of trials. There were sixteen practice trials before the 240 experimental trials. The session lasted for around 18 minutes.

Results and Discussion

Error responses were omitted from the latency analyses (2.4% for words and 6.3% for nonwords). To remove anticipatory responses, correct latencies faster than 250 ms were also excluded from the analyses (1 data point; i.e., less than 0.01% of the data).

The deadline for responding was 2 sec, so that there could not be response times (RTs) longer than 2000 ms. The averages of each of the three prime-target conditions (identity, homoglyph, control) for each dependent variable—mean correct RT and accuracy—are shown in Table 1. Words and nonwords were analyzed separately because masked form priming is typically restricted to word targets.

Table 1. Mean lexical decision times (in ms) and accuracy (in parentheses) for words and nonwords in Experiment 1

	Identity	Homoglyph	Control
Words	573 (.979)	576 (.975)	595 (.973)
Nonwords	719 (.937)	716 (.935)	727 (.940)

For the RT analyses, we employed linear mixed effects models that included Prime-Target relationship as a fixed factor, and subject and item as random factors. We used the maximal random structure model using the lmer package in R (Bates, Maechler, Bolker, & Walker, 2015): LME_RT = lmer(-1000/RT ~ primetype + (primetype +1|item) + (primetype +1|subject), data = RTdata)— as these models require that the underlying data follow approximately a normal distribution, RTs were transformed to decrease the positive skew of raw RTs. The three priming conditions were encoded in the model as -1, 0, +1 so that we could test the two planned comparisons: 1) homoglyph condition vs. control condition; and 2) identity condition vs. homoglyph condition. The lmerTest package in R (Kuznetsova, Brockhoff, & Christensen, 2016) was used to estimate the *p* values corresponding to the *t*-tests. Similar analyses were conducted on the accuracy data, except for the use of generalized linear models—accuracy for each response was encoded as 1 [correct] and 0 [incorrect]. For the interested readers, *F*1 and *F*2 ANOVAs yielded the same pattern of significant results as those reported here.

Word data. On average, responses to target words were approximately 19 ms faster in the homoglyph condition than in the control condition, $t = 4.67$, $\beta = 0.056$, $SE = 0.012$, $p < .001$. In addition, there was only a small 3-ms nonsignificant advantage of the identity condition over the homoglyph condition, $t = -1.45$, $\beta = 0.015$, $SE = 0.013$, $p =$

.26. (A post hoc analysis showed that this pattern of effects was virtually the same for the multi-letter homoglyphs rn/m and cl/d.) Accuracy was very high (0.976) and the statistical analyses did not show any significant effects (both *p*s > .46).

Nonword data. None of the effects approached significance in the latency or error data (all *p*s > .20).

Results showed faster word identification times when the prime was composed of a multi-letter homoglyph than when it was preceded by an orthographic control (i.e., docurnento–DOCUMENTO < docusnento–DOCUMENTO). Furthermore, the multi-letter homoglyph activated its corresponding visually similar letter to a very large degree, as deduced from the similar word identification times for the multi-letter homoglyph condition and the identity condition (i.e., documento–DOCUMENTO = docusnento–DOCUMENTO).

The question now is to what extent this pattern of data is due to specific characteristics of the font employed in the experiment. Keep in mind that Tahoma is characterized by a narrow spacing between letters. In Experiment 2, we employed the same materials/procedure as in Experiment 1 except that we employed Calibri. This font, being the default font in Microsoft Office, is currently one of the most prevalent fonts and, importantly, it has a wider inter-letter spacing than Tahoma. We acknowledge that another strategy could have been to increase inter-letter spacing in Tahoma. However, we must bear in mind that Tahoma was designed with a specific inter-letter spacing in mind. Finally, as the size of the effects could be smaller than those in Experiment 1, sample size was increased to 36 participants (i.e., 2880 data points in each priming condition).

Experiment 2

Method

Participants

Thirty-six new students from the same pool as in Experiment 1 participated in the experiment.

Materials and Procedure

The materials and procedure were the same as in Experiment 1, except that the font was 18-pt Calibri.

Results and Discussion

As in Experiment 1, incorrect responses (2.9% for words and 4.9% for nonwords) and RTs shorter than 250 ms (0 data points for words; 4 data point for nonwords [less than 0.05% of the data]) were excluded from the RT analyses. The mean correct RT and accuracy in each condition are shown in Table 2. The statistical tests paralleled those from Experiment 1.

Table 2. Mean lexical decision times (in ms) and accuracy (in parentheses) for words and nonwords in Experiment 2

	Identity	Homoglyph	Control
Words	604 (.977)	610 (.965)	620 (.970)
Nonwords	728 (.953)	733 (.947)	726 (.953)

Word data. Word identification times were, on average, 10 ms faster in the homoglyph condition than in the control condition, t = 2.40, β = 0.020, SE = 0.008, p = .018. Furthermore, the 6 ms advantage of the identity condition over the homoglyph condition was significant, t = -2.51, β = 0.021, SE = 0.008, p = .017. As in Experiment 1, accuracy was extremely high (0.971) and neither of the planned comparisons approached significance in the accuracy analyses (both *p*s > .24).

Nonword data. There were no signs of priming effects in the latency or error data (all *p*s > .19).

Results showed that the identity condition only produced slightly faster word identification times than the multi-letter homoglyph condition (6 ms; it was 3 ms in Experiment 1). In addition, we found an advantage of the multi-letter homoglyph priming condition over the orthographic control condition—note that it was somewhat smaller than in Experiment 1 (10 vs. 19 ms, respectively).

To examine the similarities and differences between the findings with Tahoma (Experiment 1) and Calibri (Experiment 2) fonts, we conducted a combined analysis of Experiments 1 and 2 with Experiment as a between-subjects factor. Results showed similar word response times for the identity and the multi-letter homoglyph conditions, $t = -1.35$, $\beta = 0.015$, $SE = 0.011$, $p = .18$—this pattern was similar in the two experiments, as deduced from the lack of a significant interaction, $t = -0.40$, $p > .68$. When examining the advantage of the homoglyph condition over the control condition ($t = 5.30$, $\beta = 0.056$, $SE = 0.011$, $p < .001$), the joint analysis showed that it was greater in Experiment 1 (Tahoma) than in Experiment 2 (Calibri), $t = -2.56$, $\beta = -0.036$, $SE = 0.014$, $p = .013$. Therefore, albeit to a slightly lesser degree, Calibri font is subject to letter confusability from multi-letter homoglyphs.[5]

[5] Response times for words were, on average, 20 ms faster in Experiment 1 than in Experiment 2, $t = 2.61$, $\beta = 0.110$, $SE = 0.042$, $p = .01$. Nonetheless, this difference should be taken with caution because this is a post-hoc analysis of between-subject data that were not collected with random assignment (i.e., we ran Experiment 1, and then Experiment 2). More important, as masked priming effects reflect a "savings" effect (see Gomez, Perea, & Ratcliff, 2013, for modeling evidence with the diffusion model), there is no theoretical reason why the overall difference in word response times would have affected the pattern of masked priming effects.

General Discussion

The words' constituent letters in printed Roman script are separated by small whitespaces that signal their boundaries (see Figure 1). For simplicity, models of printed word recognition inspired in the interactive activation model assume the existence of well-defined discrete slots for each letter (e.g., the visual features of H and A in HAND would be processed independently). Alternatively, the Bayesian Reader model (Norris & Kinoshita, 2012) posits that there is some degree of uncertainty at assigning visual objects to letters in the initial moments of processing. This latter assumption is consistent with anecdotal evidence that suggests that nonwords composed of multi-letter homoglyphs such as docurnent can be confusable with their base word. To examine whether nonwords composed of multi-letter homoglyphs such as docurnent activate their visually similar base words in the early stages of word processing, we conducted two masked priming experiments using two very common fonts: Tahoma (Experiment 1) and Calibri (Experiment 2)—note that Tahoma has a narrow inter-letter spacing. Results showed a response time advantage of the multi-letter homoglyph priming condition over the orthographic control condition in the two experiments (19 ms in Experiment 1; 10 ms in Experiment 2; i.e., docurnento–DOCUMENTO faster than docusnento–DOCUMENTO). Furthermore, the identity condition only showed a minimal advantage over the multi-letter homoglyph condition (a 3 ms difference in Experiment 1 and a [significant] 6 ms difference in Experiment 2). That is, in the early moments of processing, the perceptual system does not accurately perceive the whitespaces around the r and the n in docurnento (i.e., docurnento and documento generate a similar perceptual input). The greater effectiveness of multi-letter homoglyphs with the Tahoma than with the Calibri font probably reflects the fact that the visual features of nearby letters are closer with the Tahoma font (e.g., compare the homoglyph "rn" in docurnento [Tahoma] and docurnento [Calibri]). Taken together, these findings have important implications both at the theoretical level (i.e., how visual similarity extends across letters in models of printed word recognition) and the applied level (i.e., for Internet administrators/users and font designers).

At the theoretical level, the presence of faster responses in the multi-letter homoglyph condition than in the control condition with easily legible printed script reveals that, in the early moments of word processing, the cognitive processes responsible for visual word recognition are highly resilient to potentially noisy signal (e.g., the gap between r and n in rn), and this is the case even when the stimuli are presented in a visually familiar format (e.g., docurnent). Therefore, despite the presence of visual cues (i.e., whitespaces) between letters, there is still some ambiguity at assigning the words' visual objects to letters at the early moments of processing. This phenomenon adds to the presence of uncertainty concerning letter identity and letter position during the initial moments of printed word recognition (e.g., see Gomez et al., 2008; Norris et al., 2010). The flexibility at tolerating large shape variations across letter features and letters during orthographic processing probably arises from the fact that adult readers have extensive experience with very different forms of writing (e.g., handwriting) (Barnhart & Goldinger, 2010; Grainger et al., 2016; Hannagan et al., 2012). Indeed, unlike OCR engines, human readers can read distorted stimuli such as captchas (e.g., critics), partially mutilated words (e.g., hotel), or low-resolution faxes (e.g., associations) without much trouble (see Hannagan et al., 2012, for evidence of sizeable masked repetition priming effects when the primes were composed of captchas; see also Perea, Comesaña, Soares, & Moret-Tatay, 2012, for similar evidence with mutilated prime words).

How can models of printed word recognition account for the present findings? As acknowledged by McClelland et al. (2014), the interactive activation model—for simplicity— "assumes discrete slots for letters" (p. 1181). Therefore, as it stands, this model predicts similar word identification times for docurnent-DOCUMENT and docusnent–DOCUMENT, which in turn would be longer than the word identification times for document-DOCUMENT. Obviously, a similar reasoning applies to the other interactive-activation models of printed word recognition that also use the font designed by Rumelhart and Siple (1974). Nonetheless, the extension of the interactive activation model to auditory word recognition (i.e., the TRACE model), assumes "some spread of phonological features producing overlap between adjacent slots" (McClelland et al., 2014, p. 1187). If this idea were extended to the interactive activation model and its successors (i.e., using visual features instead of phonological features), this would mean that multi-letter homoglyphs could activate their visually similar letter representations, thus capturing the observed effects. However, this modification would also require a letter level more sophisticated than the Rumelhart and Siple (1974) uppercase font (see Mewhort & Johns, 1998, for criticism on the oversimplification in the letter-feature and letter levels in the coding scheme of the interactive-activation model). Importantly, the Bayesian Reader model (Norris & Kinoshita, 2012) can readily capture the observed pattern of findings because this model assumes that, in the first moments of processing, there is uncertainty when mapping visual features to letters. As Norris and Kinoshita (2012) indicated, “early in processing, there might be so much uncertainty as to how many letter objects are present that, for example, *care* might be as likely as a three-letter word.” (p. 527). Nonetheless, the current version of the Bayesian Reader model needs further refinement: for simplicity, it assumes that all letters are equally confusable and it does not make any specific claims concerning the mapping of visual objects onto letters.

Clearly, the present data call for a refinement of the perceptual front-end of models of printed word recognition. As Balota et al. (2006) put it, “what is the glue that puts the features together?” (p. 289) This question is related to a fundamental issue in visual perception: how the varying features from visual objects can be perceived as a whole (see Wolfe, 2012). A common view is that the “glue” that combines the letter features into letters is focal attention (i.e., conscious processing; see Treisman & Gelade, 1980, for discussion). Nonetheless, as Dehaene et al. (2004) proposed, conscious processing may not be a requirement when binding the visual components of letters or words, as this is a highly overlearned process that may involve dedicated neural pathways that combine the letter features into abstract letter units (see Keizer, Hommel, & Lamme, 2015, for a similar observation; see also Dehaene, Cohen, Sigman, & Vinckier, 2005, for a neural model of printed word recognition). Indeed, it has been claimed that one of the processing deficits of individuals with dyslexia is at binding the visual features of letters and words (see Pammer, 2014). While an answer to the binding problem in printed word recognition would undeniably be beyond the scope of the present study, the high degree of perceptual similarity between docurnent and document at the early stages of word recognition suggest that, as occurs with other visual objects, Gestalt principle of good continuation of form also apply to letter/word recognition (i.e., rn→m; see Rosa, Perea, & Enneson, 2016, for evidence of this principle when deleting visual features from letters in printed word recognition; see also Pelli et al., 2009, for discussion of Gestalt principles in letter identification). Further research should be conducted to determine in detail the role of visual similarity with multi-letter homoglyphs during visual word recognition and reading. As a reviewer pointed out, one potential avenue would be to manipulate the inter-letter spacing of the prime stimuli using the same font (e.g., docurnent-DOCUMENT vs. d o c u r n e n t-DOCUMENT)—importantly, this could combined with the recording of event-related potentials to unfold the time course of the effect. Another line of research could examine the processing of multi-letter homoglyphs in a more natural scenario: while participants read sentences and their eyes are monitored—this could be combined with a gaze contingent boundary change paradigm (Rayner, 1975) to assess the processing of multi-letter homoglyphs in the parafovea.

At an applied level, the present data offer empirical support to the suspicion that nonwords composed of multi-letter homoglyphs such as docurnent are perceptually very similar to their base words. That is, a domain name such as rnicrosoft.com could be easily misread as microsoft.com (or sarnsung.com instead of samsung.com; ibrn.com instead of ibm.com, etc.). Therefore, potentially malicious imposters can buy these domain names instead of the real names to let innocent users into thinking that they are on the proper website. The result is that naïve users may give away passwords and private information. How can Internet administrators avoid these potentially threatening issues? An initial obvious solution is to buy those domain names that may be potentially confusable with the real ones. This would involve not only those domain names that employ multi-letter homoglyphs (e.g., rnicrosoft.com) but also single-letter homoglyphs (e.g., 0 and O, as in MICR0S0FT.COM). A complementary option would be to design fonts that minimize this type of letter confusion when reading a domain name in a web browser (e.g., zero could be written as 0, as in Consolas font) together with a wide inter-letter spacing (e.g., r n i c r o s o f t . c o m would not be easily confusable with microsoft.com).

In summary, we found that, at the early moments of word processing, nonwords created by replacing a letter with a multi-letter homoglyph (e.g., m with rn, as in docurnent) are quite effective at activating their corresponding base words. At the theoretical level, this finding is a demonstration that there is some degree of ambiguity at mapping the visual objects that constitute the words onto letters, thus requiring more elaborated accounts of the links between the visual feature level and the letter levels in future implementations of models of printed word recognition. At an applied level, Internet users should be aware that malicious attackers might trick them with domain names that visually resemble the real websites (e.g., rnicrosoft.com) with the risk of exposing confidential information.

4.7 Are you taking the fastest route to the RESTAURANT? The role of the usual letter-case configuration of words in lexical decision

Abstract

Most words in books and digital media are written in lowercase. The primacy of this format has been brought out by different experiments showing that common words are identified faster in lowercase (e.g., molecule) than in uppercase (MOLECULE). However, there are common words that that are usually written in uppercase (street signs, billboards; e.g., STOP, PHARMACY). We conducted a lexical decision experiment to examine whether the usual letter-case configuration (uppercase vs. lowercase) of common words modulates word identification times. To this aim, we selected 78 molecule-type words and 78 PHARMACY-type words that were presented in lowercase or uppercase. For molecule-type words, the lowercase format elicited faster responses than the uppercase format, whereas this effect was absent for PHARMACY-type words. This pattern of results suggests that the usual letter configuration of common words plays an important role during visual word processing.

Key words: visual word recognition, letter-case, lexical decision

The Latin alphabet was first composed of uppercase letters, but eventually writers developed smaller versions of these letters that allowed them for faster handwriting. While originally the visual form of these lowercase letters was similar to that of the uppercase letters, some of these letters evolved into a different visual form (e.g., A→a; B→b; D→d; R→r) (see Kleve, 1994). At present, most words in Latinate languages are written in lowercase. Thus, it is not surprising that a number of word identification and text reading experiments have shown that common words are identified more quickly in lowercase than in uppercase (e.g., lexical decision: Paap, Newsome, & Noel, 1984; semantic categorization: Mayall & Humphreys, 1996; naming: Mayall & Humphreys, 1996; text reading: Tinker & Paterson, 1928).

The lowercase advantage is apparently at odds with a basic assumption of neural models of visual word recognition.[1] These models postulate that, early in processing, the elements that constitute the visual input are mapped onto case-invariant abstract letter units, which in turn are mapped onto whole-word abstract units (see Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger, Rey, & Dufau, 2008). In these models, the visual input provided by house and HOUSE—or even hOuSE—would similarly activate the same abstract representations during visual word processing. Evidence consistent with this interpretation comes from masked priming experiments: the size of masked repetition priming effects on uppercase target words is similar with lowercase primes (e.g., house-HOUSE), uppercase primes (HOUSE-HOUSE) and alternating-case primes (e.g., hOuSe-HOUSE) (e.g., Jacobs, Grainger, & Ferrand, 1995; Perea, Vergara-Martínez, & Gomez, 2015; see also Brysbaert, Speybroeck, & Vanderelst, 2009, for evidence with acronyms). Clearly, if letter-case modulated the initial contact with lexical entries, one would have expected smaller masked repetition priming for the lowercase and alternating-case compared to the uppercase priming conditions. Additional converging evidence comes from sentence reading experiments. Reingold, Yang, and Rayner (2010; see also Perea, Rosa, & Marcet, 2017) found that the duration of the initial of multiple fixations on a target word was shorter for high- than for low-frequency words, whereas it was uninfluenced by letter case. Therefore, even the effect of word-

[1] Contemporary computational models of visual word recognition only include, for simplicity, an uppercase font at the letter level (see Davis, 2010, for discussion).

frequency (i.e., a lexical effect) emerges on early measures during normal sentence reading, while the effect of letter-case does not.

The lowercase advantage in visual word recognition can be reconciled with the predictions of the above-cited models with an extra assumption: the effects of letter-case would arise at a post-access processing stage, probably when the visual input and the whole-word stored representations are combined to form a conscious percept (Besner, 1983; see also Herdman, Chernecki, & Norris, 1999; Perea et al., 2015; Van Orden & Goldinger, 1994). Long-term memory traces of words are partly built on the interaction with many more accounts of the lowercase than the uppercase version of the stimuli. Therefore, the more similar the visual input is with the long-term memory trace of a word, the easier the integration into a stable percept. Thus, hOuSe would be more difficult to integrate as a percept than HOUSE, which in turn would be more difficult to integrate than house. As a result, word identification times and eye fixation durations are longer for alternating-case than for uppercase words, and for uppercase words than for lowercase words (e.g., see Mayall & Humphreys, 1996, for behavioral evidence; see Perea et al., 2017; Reingold et al., 2010, for eye movement evidence).

Critically, if the lowercase advantage during word recognition and reading arises because this is the usual letter-case configuration of most words, one should obtain a lowercase disadvantage for those words whose usual letter-case configuration is uppercase. An excellent scenario to test this hypothesis is by using brand names, as they are generally written in the same case, either lowercase (e.g., adidas) or uppercase (e.g., IKEA). Consistent with this idea, Gontijo and Zhang (2007) employed a number of brand names that were usually written in uppercase (e.g., GUCCI) in a lexical decision experiment and found faster response times to uppercase than lowercase brand names (e.g., GUCCI faster than gucci). More recently, Perea et al. (2015) employed brand names usually written either in lowercase (adidas) or uppercase (IKEA) and asked participants whether the item was a brand name or not. Perea et al. (2015) found faster response times when the brand names were presented in their usual letter-case than when they were presented in their infrequent letter-case (i.e., adidas was recognized faster than ADIDAS; IKEA was recognized faster than ikea).

A similar advantage of the usual letter-case of words has been reported with acronyms (i.e., FBI is recognized faster than fbi; Seymour & Jack, 1978) and proper names (Mary is recognized faster than mary; Peressotti, Cubelli, & Job, 2003). While all these experiments suggest that the identification times of words are modulated by their usual letter-case, a potential shortcoming is that the mental representations of brand names, acronyms, and proper names may be different from that of common words (see Gontijo & Zhang, 2007).

The goal of the present lexical decision experiment was to examine whether word identification times are modulated by the usual letter-case configuration of common words. To that end, we selected a large number of common words that readers usually encounter in uppercase on billboards or store signs (e.g., PHARMACY, RESTAURANT, BINGO, CLOSED, MUSEUM, PARKING, THEATER; throughout this article, we refer to words that are usually encountered in uppercase as *PHARMACY-type* words). This was done on the basis of subjective ratings (see Methods) because case-sensitive frequencies via Google Books n-grams—or other procedures—underestimate the occurrence of the usual letter-case configuration of these words in everyday life (e.g., these computations do not take into account the frequency of encountering billboards or store signs). Then, we matched these PHARMACY-type words on an item-by-item basis with other common words of similar word-frequency and length that are usually encountered in lowercase (e.g., molecule; throughout this article, we refer to words that are usually encountered in lowercase as *molecule-type* words). The two types of words were presented in lowercase or uppercase (e.g., PHARMACY vs. pharmacy; MOLECULE vs. molecule) in a 2x2 factorial design.

The predictions of the experiment are straightforward: If the usual letter-case configuration of words influences word identification times, there should be an interaction between usual letter-case configuration and format presentation (lowercase, uppercase). Specifically, molecule-type words should show—as in previous research—a lowercase advantage. In contrast, PHARMACY-type words should show a lowercase disadvantage (as occurs with IKEA-type brand names) or a null effect of letter-case—note that unlike IKEA-type brand names, PHARMACY-type words are frequently found in lowercase (e.g., pharmacy).

Method

Participants

The sample was composed of thirty students of the University of Valencia, all native speakers of Spanish, who volunteered to take part in the experiment. None of them reported having reading difficulties. All participants signed a consent form before the experiment.

Materials

Firstly, we asked other colleagues and members of the lab to write down potential words whose usual letter-case configuration was uppercase (PHARMACY-type words). We selected 102 common words out of this initial screening. Secondly, we selected 102 common words whose usual letter configuration was lowercase (molecule-type words). These words were matched with the PHARMACY-type words on word-frequency, number of letters, and number of orthographic neighbors from the Spanish database EsPal (Duchon, Perea, Sebastián-Gallés, Martí, & Carreiras 2013) using the software Match (van Casteren & Davis, 2007). As there are no reliable sources of the case-sensitive word-forms in everyday life, we obtained ratings from ten naïve university students on a 1-7 Likert scale (1 = almost always in lowercase; 7 = almost always in uppercase) to assess the familiarity of each of the two types of pre-selected words in lowercase or uppercase. To ensure that the PHARMACY-type words were rated as typically presented in uppercase, we excluded from the final set those words whose average was less than 4.9 out of 7 (24 excluded words; note that this also implied excluding their corresponding pairs in the set of the molecule-type words). This criterion allowed us to select a total of 78 PHARMACY-type words (mean rating: 6.0; range: 4.9-6.9). To make sure that the molecule-type words were typically presented in lowercase, we replaced three molecule-type words whose average ratings were higher than 2.5 out of 7 (mean rating: 1.3; range: 1.0-2.5). Thus, the final set of stimuli was composed of 156 words (78 PHARMACY-type words and 78 molecule-type words). These two sets of words were matched on word-frequency per million (35.8 vs. 33.2), number of letters (7.59 vs. 7.54), and number of orthographic neighbors (2.8 vs. 2.6) (all *p*s > .5). In addition, the frequency of the individual letters was similar for the two sets of words, $\chi^2(25) = 31.1$, $p = .19$. A set of 156 legal pseudowords was created with Wuggy (Keuleers & Brysbaert, 2010) to act as foils in the lexical decision task. Two stimuli lists were created in order to counterbalance the printed-stimulus letter-case across participants: if PHARMACY were presented in uppercase in List 1, it would be presented in lowercase in List 2. All participants responded to 156 words and 156 pseudowords, half of which were in lowercase and the other half in uppercase. The list of words and pseudowords is presented in the Appendix.

Procedure

The experiment was conducted individually using a computer equipped with DmDX software (Forster & Forster, 2003) in a quiet lab. Participants were told that they would be presented with strings of letters that could either form a Spanish word or not, and that their task was to press the “Sí” (Yes) button for words and the “No” button for nonwords. Participants were also instructed to make the responses as fast as possible while trying not to make mistakes. In each trial, the stimulus (word/nonword) was preceded by a 500-ms fixation point (+). The stimulus remained on the computer screen until the participant responded or a 2100 ms deadline had elapsed—in this latter case the response would be coded as incorrect but no response time (RT) was assigned. The 312 experimental trials were preceded by 16 practice trials similar to the experimental trials.

Results

For the analysis of the correct lexical decision times, we excluded those trials with extremely short RT values (less than 250 ms; 2 data points)—note that the upper limit was set by the maximum duration of each trial: 2100 ms. Overall, there were 4503 data points for the word stimuli in the latency data (#trials [4680] – timeouts – error responses). The average correct RTs and error rates in each condition are displayed in Table 1. The inferential RT analyses was carried out with linear mixed effects models (lme4 and lmerTest packages in R)—as RT distributions typically show a positive skew, the RTs were inverse-transformed to approach a normal distribution. For the word stimuli, the fixed factors were usual letter-case configuration and format presentation—the levels of the factors were encoded as -.5 and .5. We employed the maximal random structure model that converged—the model was: LME_RT = -1000/RT ~ configuration * format + (format + 1 | item) + (format + 1 | subject). The models of the analyses on the accuracy data (0 [incorrect] vs. 1 [correct]) employed the function *glmer* (family=binomial) instead of *lmer*. For the pseudoword data, the only factor in the analyses was format presentation. It may be worth noting here that the analyses of variance across participants' and items' means with untransformed data revealed the same results as those reported here.

Table 1. Mean correct lexical decision times (in ms) and percent error (in parenthesis) across Usual case configuration and Format presentation in the experiment

	Format Presentation		
	Lowercase	Uppercase	Uppercase-Lowercase
Usual case configuration			
Uppercase	586 (3.2)	591 (2.8)	5 (-0.4)
Lowercase	606 (4.7)	634 (4.2)	28 (-0.5)

Note: The mean correct RTs and error rates for the lowercase and uppercase pseudowords were 734 and 4.8% and 736 and 5.1%, respectively.

Word data. The analyses of lexical decision times on words showed that, on average, lowercase words were responded to faster than uppercase words, t = 3.08, b = .032, SE = 0.011, p = .005, and that, on average, PHARMACY-type words were responded to faster than molecule-type words, t = 3.55, b = .068, SE = 0.019, p < .001. More important, we found a significant interaction between the two factors, t = 2.74, b = .051, SE = 0.018, p = .006. This interaction showed that, for molecule-type words, response times were on average 28 ms faster when presented in lowercase than in uppercase, *t* = 3.79, *b* = .057, *SE* = 0.015, $p < .001$, whereas there were no signs of an effect of letter-case for PHARMACY-type words (a 5 ms advantage for the lowercase stimuli), $t < 1$, $p > .64$.

To examine in further detail the influence of letter-case on word recognition times, we conducted vincentile analyses of the RT distributions (see Gomez & Perea, 2014, for a similar procedure). Specifically, we computed the .1, .3, .5, .7, and .7 quantiles for each participant and then averaged the values for each quantile over the participants. As can be seen in Figure 1, there was a robust lowercase advantage for molecule-type words that increased in the higher quantiles (11, 14, 18, 36, and 59 ms at the .1, .3, .5, .7, and .9 quantiles, respectively). In contrast, there were no signs of an effect of letter-case for PHARMACY-type words across quantiles (-5, 1, 8, 5, and 12 ms at the .1, .3, .5, .7, and .9 quantiles, respectively).

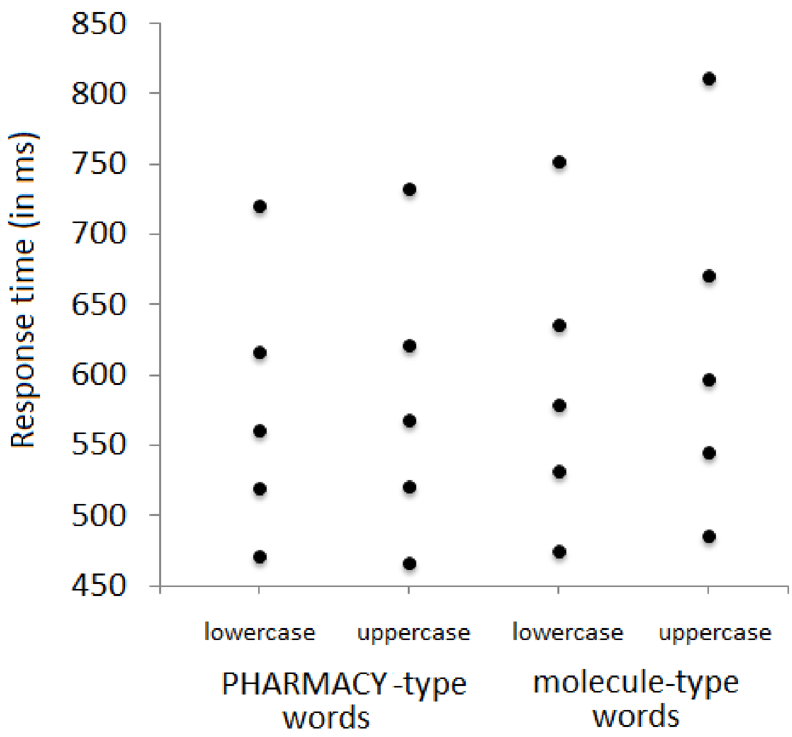


Figure 1. Group response time distributions for the four experimental conditions in the experiment. The dots represent the .1, .3, .5, .7, and .9 quantiles.

The analyses of the accuracy rates only showed that participants committed more errors on molecule-type words than on PHARMACY-type words, *t* = -1.98, *b* = .397, *SE* = 0.200, *p* = .047. The other effects did not approach significance.

Nonword data. The analyses on the effect of the printed-stimulus letter-case on latencies/errors on nonwords did not reveal any significant effects neither for latency nor for accuracy (both *p*s > .15).

Discussion

We designed a lexical decision experiment to examine whether the usual letter-case configuration (uppercase vs. lowercase) of common words modulates word identification times. To that end, we selected a set of common words that are often encountered in uppercase (e.g., PHARMACY) or lowercase (e.g., molecule) and presented them in uppercase or lowercase. Results showed a substantial 28-ms lowercase advantage for molecule-type words. In contrast, PHARMACY-type words produced similar word identification times regardless of letter-case (see Figure 1). Therefore, the usual letter configuration of letter-case plays a role during the identification of common words.

Before discussing the implications of this dissociation for models of word recognition, it is important to comment on an apparently unexpected outcome: despite the fact the PHARMACY-type and molecule-type words were matched on an item-by-item basis in word-frequency and other relevant variables, word identification times were, on average, faster for PHARMACY-type than molecule-type words—this difference occurred to a larger degree for the words presented in uppercase (a 43 ms difference), $t = 4.12$, $b = .093$, $SE = 0.023$, $p < .001$ than in lowercase (a 20 ms difference), $t = 1.91$, $b = .042$, $SE = 0.022$, $p = .060$. A potential explanation for the faster responses to PHARMACY-type words relies on the idea that the frequency of PHARMACY-type items is underestimated in current lexical databases. The reason is that we encounter PHARMACY-type words in everyday life (e.g., when looking at street signs, billboards, etc.), but these occurrences are not reflected in lexical databases (i.e., they are based on word counts in movie subtitles, web documents, or books). If this is so, one could argue that the lack of an effect of letter-case for PHARMACY-type words could be some form of floor effect: frequent words are responded more rapidly than less frequent words and this might reduce or eliminate the effect of letter-case.[2]

To examine this explanation, we analyzed the effect of letter-case as a function of word frequency in the PHARMACY-type words. Accordingly, we selected the 30 words with the highest word-frequency values (mean: 85.4 per million, range: 14.5-321.1) and the 30 words with the lowest word-frequency values (mean: 1.9 per million; range: 0.2-6.3). Results showed that the effect of letter-case was absent for the less frequent words (3 ms; 608 ms [lowercase] vs. 611 ms [uppercase]) and the more frequent words (6 ms; 571 ms [lowercase] vs. 577 ms [uppercase])—unsurprisingly, we found a sizeable effect of word-frequency (t = 3.55, b = .093, SE = 0.026, p < .001). Thus, the lack of an effect of letter-case for PHARMACY-type words in the current experiment was not due to a floor effect. We also carried out a parallel analysis for the molecule-type words. In this case, the effect of letter-case was sizeable and similar in magnitude for the less frequent words (28 ms; 639 ms [lowercase] vs. 667 ms [uppercase]) and the more frequent words (24 ms; 585 ms [lowercase] vs. 609 ms [uppercase])—again, the effect of word-frequency was robust (t = 4.44, b = .140, SE = 0.032, p < .001). Taken together, these findings are consistent with previous additive effects of letter-case and word-frequency in word recognition and sentence reading experiments (see Perea et al., 2017, for discussion).[3]

The current results generalize previous findings with brand names, acronyms, and proper names to a more standard scenario: common words. A remaining question is why PHARMACY-type words did not show a lowercase disadvantage—the data showed a negligible 5 ms effect in the unexpected direction. How can we reconcile this null effect with the findings reported by Perea et al. (2015) with brand names? In the Perea et al. (2015) experiment the lowercase advantage for adidas-type brand names

[2] We thank an anonymous reviewer for suggesting this alternative explanation.

[3] A second explanation for the advantage of PHARMACY-type words is that these words might benefit from a familiarity advantage when presented individually, as in word recognition experiments (i.e. PHARMACY-type words may be more typically encountered in isolation than the molecule-type words). One way to test this possibility is to embed these two types of words in sentences. If this interpretation is true, the differences between PHARMACY-type words and molecule-type words sets of words should vanish during sentence reading. An examination of these overall differences between PHARMACY-type and molecule-type words is beyond the scope of the current paper.

was larger than the lowercase disadvantage for IKEA-type brand names (43 vs. 26 ms). To explain this finding, Perea et al. (2015) argued that while adidas-type words are hardly seen in uppercase, IKEA-type words are occasionally seen in lowercase (e.g., in the website of IKEA: www.ikea.com). In the present experiment, PHARMACY-type words are certainly encountered quite often in uppercase—as deduced from the familiarity ratings on each letter-case, but still the number of occurrences of the lowercase form (i.e., pharmacy) is quite frequent in written text. For instance, in Google Book n-gram counts, pharmacy is more frequent than PHARMACY (in 2008: 0.000289 vs. 0.000005%, respectively), whereas IKEA is much more frequent than ikea (0.0000285 vs. 0.0000002%, respectively). To further examine this issue in the present scenario, we obtained the frequencies of all molecule-type words and PHARMACY-type words when presented in lowercase and uppercase in Google Books n-gram counts (from 2000-2008). These data showed that when presented in lowercase, molecule-type words were more likely to be encountered in books than PHARMACY-type words (the averages were 3.2e-05% vs. 2.2e-05%, respectively, p = 0.017), whereas when written in uppercase, molecule-type words were less likely to be encountered in books than PHARMACY-type words (2.3e-07% vs. 3.4e-07%, respectively, p = .073)—note that this latter difference should be greater in everyday life because PHARMACY-type words are often encountered in billboards or store signs that are not taken into account in a Google Book search.

The present findings have implications for models of visual word recognition. Whilst there is ample consensus that readers have an early access to abstract letter/word units, it remains to be explained why common words are read faster in lowercase than in uppercase across a variety of tasks ranging from laboratory word identification tasks to sentence/text reading. Here we have provided evidence that the effects of letter-case in visual word recognition can be explained as due to a post-access stage that is sensitive to the typical letter-case configuration of the word (see Besner, 1983; Herdman et al., 1999). That is, when integrating the visual input with the stored representations, readers may use an estimate of the familiarity of the usual letter-case configuration to make their responses in lexical decision or—in a reading scenario—decide whether there is enough evidence to make a forward saccade to the following word (e.g., Perea et al., 2017, found more refixations on uppercase than on lowercase words). This mechanism can also explain the lowercase advantage of those words that are typically written in lowercase and the lowercase disadvantage of those words that are archetypically written in uppercase (e.g., brand names like IKEA; acronyms like FBI). To examine this interpretation, it is important to examine the shape of the RT distributions in the framework of the diffusion model (see Gomez & Perea, 2014). If the lowercase advantage occurs at a decisional stage (i.e., greater familiarity/wordness for lowercase than for uppercase words), the effect would grow in the higher quantiles of the RT distribution—as occurs with the effect of word-frequency (e.g., see Gomez & Perea, 2014). Instead, if the lowercase advantage occurs at early encoding processes (e.g., inter-letter spacing; see Perea & Gomez, 2012), the effect would be reflected as shifts of the RT distributions (see Gomez & Perea, 2014, for a dissociation of encoding and decision processes in lexical decision). Figure 1 shows that, for molecule-type words, the lowercase advantage is substantially greater in the higher quantiles of the RT distribution (11 ms at the .1 quantile and 59 ms at the .9 quantile). This pattern is consistent with the idea of higher familiarity/wordness of the lowercase format for molecule-type words in the decision process.

To sum up, the present lexical decision experiment showed that while a lowercase advantage is apparent for most common words (e.g., molecule is identified faster than MOLECULE), this effect vanishes for those words that are often encountered in uppercase (e.g., PHARMACY). Therefore, the typical letter-case configuration modulates the identification of common words, hence generalizing previous findings using acronyms or brand names. Future research should examine in detail how letter-case configuration affects the recognition of recently learned words.

PHARMACY-type words: entrada; liquidación; garaje; facultad; exposición; abierto; congreso; seguridad; ayuntamiento; mercado; hostal; muebles; aviso; recepción; atención; horario; locutorio; tabacos; frutería; salida; librería; urgencias; prohibida; ferretería; oferta; papelería; tintorería; teatro; bingo; farmacia; cerrado; droguería; silencio; camping; academia; disponible; master; rebajas; óptica; información; parking; colegio; estanco; taller; cine; ambulancia; novedades; bazar; autovía; peluquería; cafetería; ortopedia; menú; ascensor; sanidad; dental; vende; aseos; emergencia; alarma; transportes; pastelería; museo; vestuario; urgente; horno; restaurante; hotel; notario; taxi; clínica; circo; hospital; gratis; conserjería; cajero; cervecería; extintor
molecule-type words: mirada; informático; cuñado; bandera; tendencia; contexto; sencilla; situación; consecuencia; sentido; pétalo; tanques; cable; invisible; defensa; botella; educadora; pestaña; cenicero; sitio; cirujano; bicicleta; elegancia; estantería; hambre; flequillo; cremallera; división; miope; molécula; latina; alcachofa; respeto; zumbido; actuación; comentarios; jugada; sobres; flecha; realidad; cerrojo; animal; marisco; vecina; niño; zapatillas; cansancio; coser; pañuelo; adversidad; escondite; cartulina; riñón; molestia; columna; suegra; mosca; nevar; curiosidad; excusa; estudiante; meticuloso; común; laberinto; anciano; botín; convivencia; árbol; insecto; aguja; sobrino; huevo; frecuencia; puñado; contestador; juerga; servilleta; masticar
Pseudowords: ustrido; toquibación; pocije; laraltad; irganición; ituente; cospruso; mejucidal; ayertacienta; rorzado; hustol; vieldes; ucaco; remapsión; adarsión; hocirio; bomudoria; latacos; fraficío; zafoda; bifrinía; argescias; grohetido; tirrademía; otorda; gapefonía; testocucía; beafra; bergo; tarmicia; cellida; frochenía; silansia; zampong; amalecio; lasgonobla; zásler; cefijes; óplaca; eslusmación; gunting; cotejia; eslarso; larrer; ceco; antuliscia; mosodales; tavar; eulocío; galuguinía; zatelonía; oslojedio; zanú; ascanror; rasadad; luntal; cusde; usian; enampencia; alirza; trunsgonles; gontebería; suvea; cestoaria; umpante; hermo; centoirante; hofol; silerio; fexi; clísaca; cinso; hempatal; pratus; cinsorpería; capuna; murnenería; exlantor; ricida; vaceifación; cuvida; entirtar; ajecenión; cantixto; sansalla; milueción; moncizuencia; vintudo; gálilo; linques; zabla; grulancia; detanca; llacuro; eturaleca; pesliña; momajera; vitia; besjeque; esgaurape; elipiscia; peragüinzo; hasdre; egazultar; frocifario; bimisián; belde; solízuta; talana; almarrafa; cengeto; zundado; istiación; agariascia; pujafa; nobros; blerra; ceadidol; cellopa; asazal; mararno; cenuna; sizo; compastián; etrofules; pilvo; gañuelo; adsanridad; somiálopo; brepiluro; neñón; zolastio; colonra; zuepra; susca; mucir; cumiosidod; encuza; citolinación; selirulozo; casún; alebesión; rusecor; lodín; canvisiscia; éndol; antecio; egupo; robrano; huino; brerioncia; jucilo; aporbicilis; nepusa; moljaridad; nilalete

4.8 Can letter position encoding be modified by visual perceptual elements?

Abstract

A plethora of studies has revealed that letter position coding is relatively flexible during word recognition (e.g., the transposed-letter [TL] pseudoword CHOLOCATE is frequently misread as CHOCOLATE). A plausible explanation of this phenomenon is that letter identity and location are not perfectly bound as a consequence of the limitations of the visual system. Thus, a complete characterization of letter position coding requires an examination of how letter position coding can be modulated by visual perceptual elements. Here we conducted three lexical decision experiments with transposed-letter and replacement-letter pseudowords that manipulated the visual characteristics of the stimuli. In Experiment 1, each syllable was presented either in a different color or monochromatically (e.g., CHOLOCATE vs. CHOLOCATE) with the transposition occurring across syllables. In Experiment 2, the critical letters had a consistent contrast or not (e.g., CHOLOCATE vs. CHOLOCATE). In Experiment 3, the stimuli were presented either simultaneously or serially, letter by letter (i.e., as occurs in braille reading). Results showed that whereas coloring differently each syllable only produced a small nonsignificant reduction of the transposed-letter effect, the other two manipulations: presenting the two critical letters with an altered contrast and presenting the letters one at a time reduced, but did not eliminate, the magnitude of the transposed-letter effect relative to the regular format. While these findings are consistent with models that postulate an early perceptual locus of the transposed letter effect, the robustness of the transposed-letter effect suggests that letter position coding also has an orthographic abstract component.

Keywords: word recognition; letter position coding; lexical decision

The effortless way that readers go from a written word to the activation of a lexical unit is an intriguing and widely studied phenomenon. In spite of the automatic character of this process, there are multiple factors that enable its existence. The present study focuses on the perceptual and representational aspects of letter position coding by exploring the interplay of visual information with orthographic-lexical representations.

In all writing systems, the location of components (e.g., letters in the case of alphabetic systems) conveys relevant information. For example, the Spanish words *ALERGIA* (*allergy*) and *ALEGRIA* (*happiness*) share all letters in almost all positions, even if they are semantically unrelated. Given this feature of alphabetic systems, perhaps the simplest account of letter position coding is that the identity of the letters and their location are strictly bound to each other. In fact, seminal theories of visual word recognition (e.g., the Interactive Activation Model [IAM], McClelland & Rumelhart, 1981) assumed positions-specific orthographic representations (also known as "slot coding"). Importantly, the aim of the IAM was not to explain letter position coding; hence the position specific representation was a simplification rather than a theoretical claim. The same can be said about the IAM's descendants (dual-route cascaded model: Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; multiple read-out model: Grainger & Jacobs, 1996; CDP+ model: Perry, Ziegler, & Zorzi, 2007).

The evidence against letter identity and letter position being rigidly bound is robust and pervasive. As Chambers (1979) and O'Connor and Forster (1981) originally showed, pseudowords created by transposing two letters from a word (e.g., *JUGDE*, *CHOLOCATE*) can be easily misread as the base word. Since then, a large number of experiments have consistently reported that lexical decisions to transposed-letter pseudowords (e.g., *JUGDE*) are substantially longer and more error-prone than the lexical decisions to replacement-letter pseudowords (e.g., *JUPTE*; see Perea & Lupker, 2004). Likewise, for the target word *JUDGE*, the masked transposed-letter prime *jugde* is more effective than the masked replacement-letter prime *jupte* (Perea & Lupker, 2004); indeed, *jugde* is nearly as effective as the identity prime *judge* (Forster, Davis, Schoknecht, & Carter, 1987) and it provides with nearly as much parafoveal preview advantage during sentence reading (Johnson, Perea, & Rayner, 2007; see also Pagán, Paterson, Blythe, & Liversedge, 2015, for further evidence of transposed-letter effects during reading). This pattern is not restricted to the Roman alphabet: letter/character transposition effects have been reported in other writing systems (e.g., Chinese: Gu & Li, 2015; Hebrew: Velan & Frost, 2011; Arabic: Perea, Abu Mallouh, & Carreiras, 2010; Japanese Kana: Perea & Pérez, 2009; Korean Hangul: Lee & Taft, 2009; Thai: Perea, Winskel, & Ratitamkul, 2012). Furthermore, these effects are pervasive not only in adult skilled readers but also in developing readers (e.g. see Paterson, Read, McGowan, & Jordan, 2014).

The plethora of evidence for the so-called transposed-letter (TL) similarity effects has motivated theorists to develop an explanation for their prevalence. Two explanations for these effects are plausible; we refer to them as: 1) perceptual system based; and 2) orthographic representation based.

Perceptual system based accounts. An explanation of why letter position coding is so flexible is based on models of visual attention (e.g., Logan's, 1996, CODE model of visual attention). The basic assumption is that letters in words are objects subject to position uncertainty as a result of the limitations of the visual system (LTRS model: Adelman, 2011; spatial coding model: Davis, 2010; overlap model: Gomez, Ratcliff, & Perea, 2008; overlap open-bigram model, Grainger, Granier, Farioli, Van Assche, & van Heuven, 2006; Bayesian Reader model: Norris, Kinoshita, & van Casteren, 2010). For example, the letters *G* and *D* in *JUGDE* activate not only their own letter positions, but also nearby letter positions. As a result, the transposed-letter pseudoword *JUGDE* would activate its base word (*JUDGE*) to a greater degree than the replacement-letter pseudoword *JUPTE*.

Orthographic representation based accounts. An alternative account of letter transposition effects, which is specific to letter strings, assumes the existence of a "relative position map" level composed by open bigrams (i.e., pairs of ordered letters not necessarily adjacent) situated between the level of abstract letter units and the level of whole-word units in an interactive activation framework (open bigram model: Grainger & van Heuven, 2003; see also SERIOL model, Whitney, 2001). In open bigram models, the transposed-letter *JUGDE* would activate *J-U-G-D-E* at the level of letter units and *JU-JG-JD-JE-UG-UD-UE-GD-GE-DE* at the level of relative position map. As open bigrams have excitatory connections to the level of whole-word units, the transposed-letter pseudoword JUGDE would activate its base word *JUDGE* (they share all bigrams but one, *GD*/*DG*) to a larger degree than the replacement-letter pseudoword *JUPTE* (they only share three open bigrams, *JU*-*JE*-*UE*).

The two accounts described above are not mutually exclusive (e.g., see Adelman, 2011; Grainger et al., 2005, for hybrid models of visual word recognition that include both location uncertainty and open bigrams). While there might be abstract representations of orthographic features that contribute to TL effects, these effects might also be affected by visual perceptual processes. Therefore, we believe that a comprehensive characterization of letter position coding requires a careful examination of whether (and if so, how) this process can be modulated by visual perceptual elements. Importantly, previous research has reported an interaction between visual and orthographic-lexical factors when encoding letter identity. Grainger, O'Regan, Jacobs, and Segui (1992) found that the neighborhood frequency effect (e.g., the identification of *spice*—which has the higher frequency neighbor *space*—being slower than that of a word with no higher frequency neighbors like *sauce*) was substantially reduced when participants fixated on the disambiguating letter (i.e., *i* in spice) than when they fixated on other letters. Thus, the effect of neighborhood frequency (i.e., a phenomenon that involves the encoding of letter identities) is modulated by a visual attention element: whether the reader fixates the disambiguating letter or not. A remaining question is whether the transposed-letter effect (i.e., a phenomenon that involves the encoding of letter order) can be modulated by visual perceptual elements.

The main goal of the present series of experiments was to examine the role of three visual elements in the process of letter position coding during word recognition. As in the classic letter transposition experiments of Chambers (1979) and O'Connor and Forster (1981), we employed a single-presentation lexical decision task. The key comparison was between the transposed-letter pseudowords and their corresponding replacement-letter pseudowords. Specifically, the transposed-letter effect was computed as the difference in mean latency and in response accuracy between transposed-letter pseudowords (e.g., *CHOLOCATE*) and replacement-letter pseudowords (e.g., *CHOTONATE*). The idea is that the greater the similarity between the TL-pseudoword and its base word, the greater the magnitude of the transposed-letter effect. In all cases, the transposition/replacement involved two non-adjacent internal consonants from different syllables (e.g. *CHOLOCATE* [TL-pseudoword], *CHORONATE* [RL-pseudoword]; in Spanish *CHOCOLATE* is composed of four syllables [*cho-co-la-te*]).

In Experiment 1, the whole stimulus was presented in the same color—as is usually the case in word recognition and reading experiments—or with each syllable in a different color (e.g., *CHOLOCATE* vs. *CHOLOCATE*). The rationale behind this manipulation is that color is a useful perceptive cue that helps to distinguish the parts of a whole (see Goldfarb & Treisman, 2011, for a review). Indeed, color produces a different grouping of the elements that constitute the words (see Chetail & Mathey, 2009; Häikiö, Hyönäa, & Bertram, 2015; Perea, Tejero, & Winskel, 2015; Pinna & Deiana, 2014; Printzmetal, Hoffman, & Vest, 1991; Prinzmetal, Treiman, & Rho, 1986). In a series of influential experiments conducted by Prinzmetal et al. (1986, 1991), participants were briefly presented a word or a pseudoword in which the first two/three letters were in one color and the others in another color. When asked to indicate the color of a target letter, participants were more accurate when the letter had the same color as its syllabic unit than when not (e.g., more accurate responses for the color of *T* in *AZTEC* than in *AZTEC*). Similarly, Chetail and Mathey (2009) and Häikiö et al. (2015) showed that alternate coloring is a useful cue to emphasize the syllabic boundaries in lexical decision and sentence reading, respectively. In the context of a perceptual account of letter position coding, one might argue that using different colors across syllables in TL-pseudowords (e.g., *CHOLOCATE*) would induce the segmentation of the letter string into four objects (*CHO*-*LO*-*CA*-*TE*). As the critical letters *L* and *C* in the TL pseudoword *CHOLOCATE* would belong to different perceptual groups, this would diminish their location uncertainty relative to the case in which the critical letters belong to the same perceptual group (e.g., the monochromatic TL pseudoword *CHOLOCATE*). Therefore, if color is an effective segmentation cue when processing syllables in letter strings, the magnitude of the transposed-letter effect would be smaller for *CHOLOCATE* than for *CHOLOCATE*.

In Experiment 2, the materials were the same as in Experiment 1, but the manipulation involved stimuli with a consistent contrast for all letters (*CHOLOCATE*, *CHORONATE*) vs. stimuli in which the transposed/replaced letters have an altered contrast (*CHOLOCATE*, *CHORONATE*). Previous research has shown that this manipulation facilitates the perceptual grouping of letters in words (e.g., see Perea & Acha, 2009, for evidence during sentence reading). The idea is that the altered contrast of the letters *L* and *C* in *CHOLOCATE* would enjoy a special status during processing relative to the letters *L* and *C* in a consistent contrast (*CHOLOCATE*). As the sequence *L_C* from the transposed-letter pseudoword *CHOLOCATE* is not shared with the base word, *CHOLOCATE* would be less similar to its base word than the TL pseudoword *CHOLOCATE*, thus resulting in a smaller transposed-letter effect.

In Experiment 3, we examined whether a letter-by-letter presentation of the stimuli would reduce the transposed-letter effect. The idea was to keep conditions somewhat similar to braille reading. At an abstract level of processing, recent research has shown similarities between braille and sighted readers. Fischer-Baum and Englebretson (2016) showed that braille readers are sensitive to sublexical structures when identifying written words and these effects "extend beyond the serial recognition of a single cell at a time" (p.170). That is, the sublexical orthographic processes in braille readers are comparable to their sighted peers when reading an alphabetic script—indeed, braille readers also activate the "visual word form area" when reading (see Reich, Szwed, Cohen, & Amedi, 2011). But the critical point here is that, unlike visual presentations, in which all letters from a word are available at the same time, braille reading proceeds serially, on a letter-by-letter basis (see Marcet, Jiménez, & Perea, 2016, for a recent review on braille reading). Thus, in braille reading, letter position could be directly encoded from the serial (along the temporal dimension) way in which letters are attained. If so, letter position coding should be much less flexible in the tactile than in the visual modality. In a lexical decision experiment, Perea, García-Chamorro, Martín-Suesta, and Gomez (2012) compared the magnitude of letter transposition effects (transposed-letter pseudowords [*CHOLOCATE*] vs. replacement-letter pseudowords [*CHOTONATE*]) in the visual modality (sighted readers) and the tactile modality (braille readers). While sighted readers showed a large letter transposition effect (i.e., substantially longer response times and more errors to *CHOLOCATE* than to *CHOTONATE*), braille readers only showed a small nonsignificant trend in the error rates (see also Perea, Jiménez, Martín-Suesta, & Gomez, 2015, for evidence in a sentence reading task). In Experiment 3, the stimulus' constituent letters were presented simultaneously or serially one letter at a time. If readers encode with less perceptual uncertainty the order of the letters when they are presented serially one-by-one, the magnitude of the transposed-letter effect should be smaller in the serial format than in the simultaneous format.

In sum, the present lexical decision experiments were designed to study the interaction between visual and orthographic-lexical factors when encoding letter position coding in a word recognition task. While we acknowledge that the results from these experiments cannot be a final arbiter on the relative contribution of the perceptual vs. representational components to TL similarity effects, there are some patterns of data that would rule out some versions of the accounts described above: If the visual perceptual manipulations fail to modulate the TL effect, an explanation of such effect that relies solely on the characteristics of the visual system would be difficult to defend. According to such accounts, perceptual highlighting or serial reading should improve location coding. Alternatively, if the visual perceptual manipulations completely erase the TL effect, the idea of an encapsulated module of abstract representation (e.g., a layer of open bigrams between the letter and whole-word levels) would be untenable. Finally, from an applied perspective, if the uncertainty at letter position coding is modified by visual factors, this may help design the appropriate remediation strategies for those individuals with letter position dyslexia (see Kezilas, Kohnen, McKague, & Castles, 2014).

Experiment 1: Changing the colors across syllables

Method

Participants

Twenty-eight participants from the Complutense and the Polytechnic University of Madrid, all of them native speakers of Spanish and with normal (corrected-to-normal) vision, took part voluntarily in the experiment. In this and subsequent experiments, participants signed a consent form before the experiment.

Materials

The set of stimuli was composed of 240 words and 240 pseudowords—they were extracted from the Carreiras, Vergara, and Perea (2007) experiment. The 240 pseudowords had been created by transposing/replacing two non-adjacent consonants from different syllables of a base word (e.g., *CHOLOCATE* and *CHOTONATE* from the base word *CHOCOLATE*). (In the Carreiras et al., 2007, experiment, they included pseudowords created by transposing/replacing two non-adjacent consonants vs. vowels—here we only included consonant transpositions/replacements.) The letter transposition/replacements did not occur in the initial syllable. The mean frequency of the base words was 23 per million (range: 1-147), the mean number of orthographic neighbors was 0.5 (range: 0-5) and the mean length was 8.9 letters (range: 7-11) in the B-Pal Spanish database (Davis & Perea, 2005). The 240 words had a mean frequency of 31 per million (range: 4-251) and the mean length was 8.9 (range 7-11). The colors of the multicolored words and pseudowords were: first syllable RGB: 171-41-51 (red); second syllable RGB: 75-160-52 (green); third syllable RGB: 166-106-46 (brown); fourth syllable RGB (blue): 58-92-154; and (when applicable) fifth syllable RGB: 192-20-192 (violet). Half of the items (words and pseudowords) were presented with different colors across syllables and the other half were presented in the same color across all letters— each of the four colors used for the multicolored condition was utilized in an equal number of the monochromatic strings. To rotate the stimuli across the four conditions, we created four counterbalanced lists in a Latin square manner.

Procedure

The session took place individually in a sound-attenuated room. We employed the DMDX software (Forster & Forster, 2003) to present the stimuli and register the participants' responses. The sequence of a given trial was as follows: 1) A fixation point (+) was presented at the center of the CRT screen for 500 ms; and 2) A target stimulus (always in uppercase) was presented on the screen until the participant responded—or until 2100 ms had passed. Participants were asked to decide as quickly as possible if the letter string was a Spanish word by pressing the M key for words or the Z key for nonwords while trying to keep a low error rate. Each participant received a different random ordering of stimuli. Sixteen practice trials preceded the 240 experimental trials. The whole experimental session lasted approximately 20 minutes.

Results and Discussion

We excluded from the correct RT analyses those latencies beyond the 250-2000 ms cutoffs (0.04% for words and 0.19% for pseudowords). The average mean correct RTs and error rates per condition are presented in Table 1. The RT and accuracy data were analyzed using linear mixed effects and generalized linear mixed effects (*lme4* package in R; Bates, Maechler, Bolker, & Walker, 2015). For the RTs, we employed the -1000/RT transformation so that the resulting data distribution would be closer to the Gaussian distribution. For the pseudoword data, the fixed factors were Type of pseudoword (letter transposition/replacement) and Color (monochromatic/multicolor), whereas for the word data the only fixed factor was Color (monochromatic/multicolor). For each model, we employed the maximal random structure model that successfully converged—each fixed factor was zero-centered in the models.

Table 1. Mean lexical decision times (in ms) and percent error on pseudowords in Experiment 1

	Transposed-letter Pseudoword		Replacement-Letter Pseudoword		Transposed-Letter Effect	
	RT	ER	RT	ER	RT	ER
Monocolor	957	29.7	872	8.3	85	21.4
Multicolor	946	25.5	857	7.1	89	18.4

Note: The mean RTs and error rates for the monocolor and multicolor words were 765 vs. 790 ms, and 6.5 vs. 4.8%, respectively.

Pseudoword data. The analyses of the latency data showed that, on average, lexical decision responses were faster to replacement-letter pseudowords than to transposed-letter pseudowords, t = 13.81, p < .001. Neither the difference between multicolor and monochromatic pseudowords nor the interaction between the two factors approached significance, both ps > .25.

The analyses of the accuracy data showed that participants responded more accurately to replacement-letter pseudowords than to transposed-letter pseudowords, z = -21.71, p < .001. In addition, participants responded more accurately to multicolor pseudowords than to monochromatic pseudowords, z = 2.71, p = .007. The size of the transposed-letter effect was similar for monochromatic and multicolor pseudowords (0.214 vs. 0.184, respectively), as deduced by the lack of interaction between the two factors, z < 1, p > .40.

Word data. The analyses of the RT data showed that monochromatic words were responded to, on average, 25 ms faster than multicolor words, t = 4.29, p < .001. The analyses on the accuracy data showed that participants were more accurate with monochromatic words than with multicolor words (0.952 vs. 0.935), z = -2.97, p = .003.

This experiment showed a sizeable transposed-letter effect in both response times and accuracy (i.e., slower and less accurate responses to transposed-letter pseudowords than to replacement-letter pseudowords), thus replicating earlier research (e.g., Carreiras et al., 2007; Lupker, Perea, & Davis, 2008; Perea & Lupker, 2004). But the critical question was whether perceptual grouping—using syllables of different color—modulated this effect. Whilst results showed an effect of the perceptual manipulation on word stimuli (e.g., responses to words were faster for monochromatic than for multicolor words), there were no clear hints of a modulating effect of the perceptual grouping manipulation on the size of the transposed-letter effect in the accuracy rates: the effect was only 3% smaller for the multicolor pseudowords than for the monochromatic pseudowords (see Table 1). This null effect of color on the magnitude of TL effects is consistent with the Friedmann and Rahamim (2014) study—they measured the number of letter migration errors (e.g., slat being misread as salt) with multicolor (coloring each letter in a different color; e.g., slat) vs. black monochromatic words in a small sample (N = 5) of individuals with letter position dyslexia.

In Experiment 2, we employed a manipulation of perceptual grouping that was potentially more powerful than in Experiment 1. Instead of changing the color across syllables, the manipulation focused exclusively on the critical letters that were transposed/replaced in the pseudoword stimuli, thus making those letter more salient: these letters were presented in altered contrast or not (e.g., *CHOLOCATE* vs. *CHOLOCATE*). For control purposes, we employed a parallel manipulation for the word stimuli (e.g., *DOCUMENTO* vs. *DOCUMENTO*).

Experiment 2: altered contrast of the critical letters

Method

Participants

Twenty-eight students from the University of Valencia, all of them native speakers of Spanish and with normal (corrected-to-normal) vision, took part voluntarily in the experiment.

Materials

The set of 240 words and 240 pseudowords was the same as in Experiment 1. The difference was that either all letters were presented with the same contrast or two internal consonant letters—the ones that were transposed/replaced in the pseudoword stimuli—had an altered contrast (e.g., *CHOLOCATE* vs. *CHOLOCATE*). For the word stimuli, we also applied the contrast manipulation to two internal consonant letters (e.g., *DOCUMENTO* vs. *DOCUMENTO*).

Procedure

The structure of the trials and the experimental sessions was the same as in Experiment 1.

Results and Discussion

As in Experiment 1, correct RTs beyond the 250-2000 ms cutoff (0.06% for words and 0.16% for pseudowords) were omitted from the latency analyses. The mean correct lexical decision times and error rates per condition are displayed in Table 2. The statistical analyses paralleled those in Experiment 1 except that Color was replaced with Contrast (altered vs. consistent stimuli) as a fixed factor.

Table 2. Mean lexical decision times (in ms) and percent error on pseudowords in Experiment 2

	Transposed-letter Pseudoword		Replacement-Letter Pseudoword		Transposed-Letter Effect	
	RT	ER	RT	ER	RT	ER
Regular	949	28.9	829	5.8	120	23.2
Highlighted	930	19.2	821	4.6	109	14.6

Note: The mean RTs and error rates for regular and highlighted words were 751 vs. 798 ms, and 3.9 vs. 4.5%, respectively.

Pseudoword data. The latency data showed that, on average, responses were faster to replacement-letter pseudowords than to transposed-letter pseudowords, $t = -21.33$, $p < .001$, and that pseudowords with altered contrast were responded to, on average, 13.5 ms more rapidly than the pseudowords with consistent contrast, $t = 2.61$, $p < .009$. The interaction between the two factors was not significant, $t = -1.45$, $p > .14$.

The accuracy data revealed that participants were more accurate with replacement-letter pseudowords than with transposed-letter pseudowords, $z = 21.41$, $p < .001$. Participants were also more accurate with the pseudowords with altered contrast than with the pseudowords with consistent contrast, $z = -5.25$, $p = .007$. But the most important finding was that the magnitude of the transposed-letter effect was smaller for those pseudowords with altered contrast than for the pseudowords with consistent contrast (0.146 vs. 0.231, respectively), as deduced from the significant interaction between the two factors, $z = 2.42$, $p = .015$.

Word data. The latency data showed that participants responded more quickly to regular words than to words with consistent contrast, $t = -9.42$, $p < .001$. The analyses on the accuracy data did not show any differences between the words with altered vs. consistent contrast (0.961 vs. 0.955, respectively), $z < 1$, $p = .71$.

As in Experiment 1, the processing of the word stimuli was affected by the perceptual manipulation (i.e., word response times were slower for words with altered contrast than for regular words). As measured by response latencies, the transposed letter effect was not significantly modulated by the contrast manipulation; however, the key finding is that, as measured by error rate, the transposed-letter similarity effect was substantially reduced for the pseudowords with altered contrast (14.6% in the altered-contrast format vs. 23.2% in the consistent-contrast format, respectively)—note that the magnitude of the effect for the regular format was very similar to that of monochromatic stimuli in Experiment 1 (i.e., 21.4%).

Therefore, we found that a visual perceptual element such as altering the contrast of the critical letters (e.g., *CHOLOCATE* vs. *CHOLOCATE*) can modulate letter position coding. However, the magnitude of the TL effect was still reasonably large in the altered-contrast condition. To examine whether the TL effect could be erased by visual perceptual factors, we conducted yet another experiment with a potentially more extreme manipulation: the word/pseudoword's constituent letters were presented simultaneously (i.e., as in the typical word recognition experiments) or were presented serially one-by-one as occurs when reading in braille—note that while braille readers do not show TL similarity effects in lexical decision (Perea et al., 2012), they are sensitive to the sublexical structure of words (Fischer-Baum & Englebretson, 2016).

Experiment 3: letter-by-letter [serial] reading

Methods

Participants

Fifty-six undergraduate students from the DePaul University, all of them native speakers of English and with normal (corrected-to-normal) vision, took part in the experiment.

Materials

The set of stimuli was extracted from the Lupker, Perea, and Davis (2008) experiments and was composed of 80 words and 80 pseudowords. As in Experiments 1 and 2, these pseudowords had been created by transposing/replacing two non-adjacent consonants from different syllables of a base word (e.g., *CHOLOCATE* and *CHOTONATE* from the base word *CHOCOLATE*). (Lupker et al., 2008, also created pseudowords with transposed/replaced vowels—here we only employed those stimuli based on consonant transpositions/replacements.) The mean frequency of the base words was 14.30 per million (range: 1-101.96), the mean number of orthographic neighbors was 0.338 (range: 0-2) and the mean length was 7.3 letters (range: 6-8) in the English Lexicon Project subtitle database (Balota et al., 2007). The 80 words had a mean frequency of 61.97 per million (range: 3.96-625.14) and the mean length was 7.3 (range 6-9). Half of the items (words and pseudowords) were presented with all the letters simultaneously (immediate format [i.e., the standard format]) and the other half were presented one successive letter at a time (serial format [i.e., to simulate braille reading conditions]). The stimuli were rotated across the four conditions to create four counterbalanced lists following a Latin square method.

Procedure

The instructions and general organization of the experimental sessions was parallel to that employed in Experiments 1 and 2. The trial structure (see Figure 1) was somewhat different to the previous two experiments, as the letters from the printed stimuli were presented either simultaneously (immediate format) or letter by letter one at a time for 200 ms in its relative position (serial format). The deadline to make a response was increased to 3500 ms because of the slow rate of presentation in the serial format.

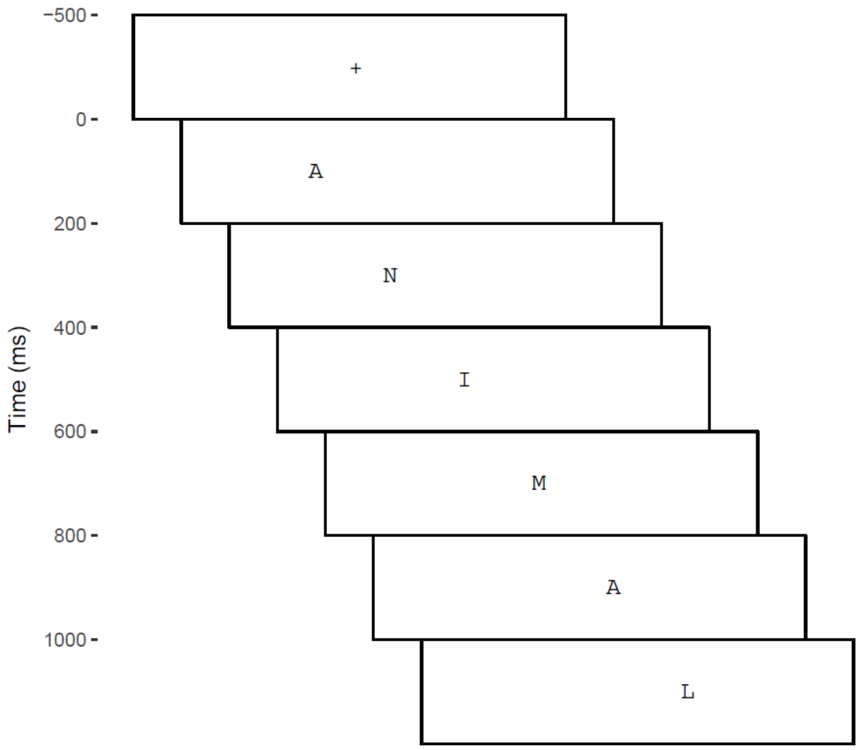


Figure 1. Schematic depiction of the procedure in Experiment 3.

Results and Discussion

Correct RTs beyond the 250-3500 ms cutoff (less than 0.01% for words and pseudowords) were omitted from the RT analyses. The mean correct RTs and error rates per condition are presented in Table 3. The statistical analyses were analogous to those in Experiment 1, except that Color was replaced with presentation format (Immediate vs. Serial) as a fixed factor.

Table 3. Mean lexical decision times (in ms) and percent error on pseudowords in Experiment 3

	Transposed-letter Pseudoword		Replacement-Letter Pseudoword		Transposed-Letter Effect	
	RT	ER	RT	ER	RT	ER
Immediate	1183	31.8	1000	9.6	183	22.1
Serial	2115	44.7	2040	16.8	75	27.9

Note: The mean RTs and error rates for the words in the immediate and serial formats were 804 vs. 1874 ms, and 1.9 vs. 17.2%, respectively.

Pseudoword data. The analyses of the RT data showed that responses were faster to replacement-letter pseudowords than to transposed-letter pseudowords, $t = -8.43$, $p < .001$, and that responses were faster in the immediate format than in the serial format, $t = 18.65$, $p < .001$. Critically, the interaction between the two factors was significant, $t = -7.34$, $p < .001$: the transposed-letter effect was smaller in the serial format, $t = -3.10$, $p = .003$, than in the immediate format (75 vs. 183 ms, respectively), $t = -9.24$, $p < .001$.

The analyses on the accuracy data showed more accurate responses with replacement-letter pseudowords than with transposed-letter pseudowords, $z = 13.77$, $p < .001$, and more accurate responses in the immediate format than in the serial format, $z = -6.23$, $p < .001$. There were no signs of an interaction between the two factors, $z = -0.54$, $p = .59$.

Word data. The RT data showed that participants responded faster when all the letters were presented simultaneously than when presented serially one at a time, $t = -32.96$, $p < .001$. The analyses on the accuracy data also showed an advantage of the immediate over the serial format, $z = -7.61$, $p < .001$.

The present experiment showed that magnitude of the transposed-letter effect in the RT data was reduced in the serial letter-by-letter format than in the standard, immediate format (75 vs. 183 ms, respectively)—note that this was so despite the fact that the overall latencies were much greater in the serial format, hence this is not a scaling effect. That is, readers encode more precisely letter order when the constituent letters of the stimuli are presented serially than when presented simultaneously. However, unlike braille reading (Perea et al., 2012), the transposed-letter effect was sizeable in the serial letter-by-letter format. A reason for this discrepancy is that while in braille reading, participants have control on how long the fingers sense each letter (e.g., low-frequency words receive longer scanning times than high-frequency words), in the visual modality each letter is presented for a limited (and constant) exposure duration. We acknowledge that, to make to two tasks more equivalent, the braille experiment would have to present the letters also at a fixed rate.

General Discussion

The present work examined whether visual elements could modify the process of letter position coding during visual word recognition. We conducted three experiments that manipulated three visual perceptual elements in a single-presentation lexical decision task with transposed-letter and replacement-letter pseudowords: using different colors for each syllable (Experiment 1), using a different contrast for the critical letters (Experiment 2), and simultaneous vs. letter-by-letter presentation (Experiment 3). Experiment 1 showed that coloring differently each syllable only produced a negligible reduction of the transposed-letter effect relative to the regular format. In addition, Experiments 2 and 3 revealed that using a different contrast for the two critical letters (e.g., L and C in the transposed-letter pseudoword CHOLOCATE) and presenting the letters serially one at a time (e.g., C, then H, then O, then L…) reduced substantially the magnitude of the transposed-letter effect relative to the standard presentation. Therefore, visual elements can modify how letter order is encoded during lexical access.

Perhaps the first-order result is that the transposed letter effect in the lexical decision task is quite robust and seemingly impossible to eliminate. A more nuanced examination of our results indicate that, consistent with those models that assume a perceptual locus of letter position coding, transposed-letter effects can be modulated by visual perceptual elements. This is consistent with prior evidence showing that location uncertainty of objects in space is not restricted to letters: they have been found for strings of digits (García-Orza, Perea, & Muñoz, 2010), strings of symbols (García-Orza et al., 2010), strings of non-alphanumeric objects (García-Orza, Perea, & Estudillo, 2011), and also for musical notes in a staff (Perea, García-Chamorro, Centelles, & Jiménez, 2013). Likewise, transposed-letter effects have also been found with preliterate children (Perea, Jiménez, & Gomez, 2016) and with non-human species (baboons: Ziegler et al., 2013). A further demonstration of the importance of visual elements in transposed-letter effects is that they do not arise in the tactile modality: lexical decision times and error rates to *CHOLOCATE* and *CHOTONATE* are remarkably similar in braille reading (see Perea et al., 2012).

As mentioned in the Introduction, some patterns of results would be inconsistent with particular versions of the accounts of letter position coding. The modulation of the transposed-letter effect in Experiments 2 and 3 is consistent with the view that letter transposition effects have an early visual perceptual locus. Hence, the "strong" version of the orthographic coding theory (i.e., transposition effects are purely based on an abstract code via "open bigrams") can be ruled out. Conversely, the robustness of the transposed-letter effect when the critical pair of letters had an altered contrast or when letters were presented serially one at a time suggests that an important component of letter position coding is at an abstract orthographic level, thus ruling out the "strong" version of the perceptual account of letter transposition effects.

Therefore, as occurs with other factors in orthographic-lexical processing, it may be more accurate to talk about the various loci of letter position coding rather than a unique locus (e.g., see Knobel, Finkbeiner, & Caramazza, 2008, for evidence of several loci of the word-frequency effect). Indeed, several accounts of letter position coding assume both an early perceptual effect common to other visual objects and a late letter-specific effect due to the activation of abstract representations—typically in the form of open bigrams (Adelman, 2011; Grainger et al., 2005; Grainger & Ziegler, 2011). An obvious advantage of hybrid accounts of letter position coding is that they can simultaneously accommodate the presence of letter transposition effects for non-letter strings—which a "strong" open bigram model cannot capture— and the existence of greater transposition effects for letter strings than for other types of alphanumeric objects (e.g., digits, symbols)—which a “strong” perceptual account cannot capture. Indeed, using a same-different perceptual matching task, Massol, Duñabeitia, Carreiras, and Grainger (2013) found transposition effects for strings of letters, digits and symbols, but the magnitude of the effect was greater for the strings of letters than for digits or symbols. Massol et al. (2013) suggested that this pattern reflected both “generic positional noise” which applies to all types of objects and “letter-specific position-coding mechanism” which applies exclusively to letter strings. The present experiments provide converging evidence to this hybrid account of letter position coding, with the advantage that we employed a lexically-based task (i.e., a lexical decision task rather than a same-different task) with letter strings—keep in mind that strings of letters follow different neural paths than strings of symbols or digits (see Schubert, 2017, for review).

In summary, we have demonstrated that visual perceptual elements (i.e., altering the contrast of the critical letters [e.g., CHOLOCATE] and presenting the letters serially one at a time) may diminish the transposed-letter effect in lexical decision. This finding is consistent with those models of word recognition that postulate a perceptual locus of letter position coding. Nonetheless, the reduced but substantial transposed-letter effect even with the altered-contrast format or with serial presentations suggests that another major component of the transposed-letter effect is at an abstract orthographic level. Characterizing these abstract orthographic representations is far beyond the scope of the present study, and our data cannot shed light on this issue.

4.9 ¿Pueden los juegos mejorar la habilidad lectora?

Resumen

Investigaciones recientes han mostrado que las habilidades lectoras pueden ser moduladas mediante el entrenamiento en juegos/videojuegos. Dado que un déficit en atención visual puede ser causante de la dislexia, el entrenamiento en videojuegos puede mejorar la atención visual, lo cual puede ayudar al tratamiento de la dislexia. Pero también un juego de mesa como es el Scrabble puede mejorar las habilidades lectoras: los jugadores expertos de Scrabble tienen unas destrezas ortográfico-léxicas más eficientes que los no expertos. Trabajos futuros han de centrarse en examinar qué beneficios aporta el entrenamiento mediante juegos/videojuegos en la mejora del aprendizaje lector.

Palabras clave: atención; cerebro; dislexia; entrenamiento cognitivo; juegos; lectura; videojuegos

Aparte del aspecto lúdico, muchos juegos ofrecen mejorar, o mantener en el caso de personas mayores, diversas habilidades cognitivas. En nuestro caso, más que ocuparnos del impacto cognitivo de los juegos de “gimnasia cerebral” (véase Anguera y col., 2013), nos centraremos en dos líneas de investigación recientes que examinan cómo el entrenamiento en juegos puede mejorar las habilidades lectoras.

Se ha propuesto que una dificultad lectora como la dislexia se puede deber a un déficit de atención visual (Franceschini y col., 2013). Como demostraron Green y Bavelier (2003), la atención visual se puede moldear con la experiencia: los jugadores de videojuegos de acción tienen mayores niveles de atención visual que los individuos no expertos. Este hallazgo se ha obtenido también mediante el entrenamiento en videojuegos de acción empleando un diseño pre-post (Green y Bavelier, 2003). Para examinar si estas mejoras se pueden trasladar a un ámbito aplicado, Franceschini y col. (2013) entrenaron a un grupo de niños con dislexia en un minijuego de acción del videojuego *Rayman Raving Rabbids* que requería una alta atención visual debido a la imprevisibilidad de los elementos, mientras que a otro grupo de niños con dislexia se les entrenó en un minijuego de no acción del mismo videojuego (véase la Figura 1). Hubo nueve sesiones de entrenamiento de 80 minutos (12 horas en total), y se registró el tiempo de lectura de un texto antes y después del entrenamiento.

Figura 1. Esquema del procedimiento en el experimento de Franceschini et al. (2013). El videojuego de acción precisaba de velocidad en las respuestas conllevando una alta atención a carga perceptiva dada la imprevisibilidad temporal o espacial de los elementos. Cada una de las nueve sesiones de entrenamiento duraba 80 minutos.

A diferencia del grupo control, el grupo experimental mostró tiempos de lectura más rápidos tras el entrenamiento que antes (véase Figura 2). Franceschini y col. (2013) concluyeron que un entrenamiento atencional mediante videojuegos de acción produce una mejora de las habilidades lectoras (véase Gori, Seitz, Ronconi, Franceschini. y Facoetti. 2016, para una replicación).

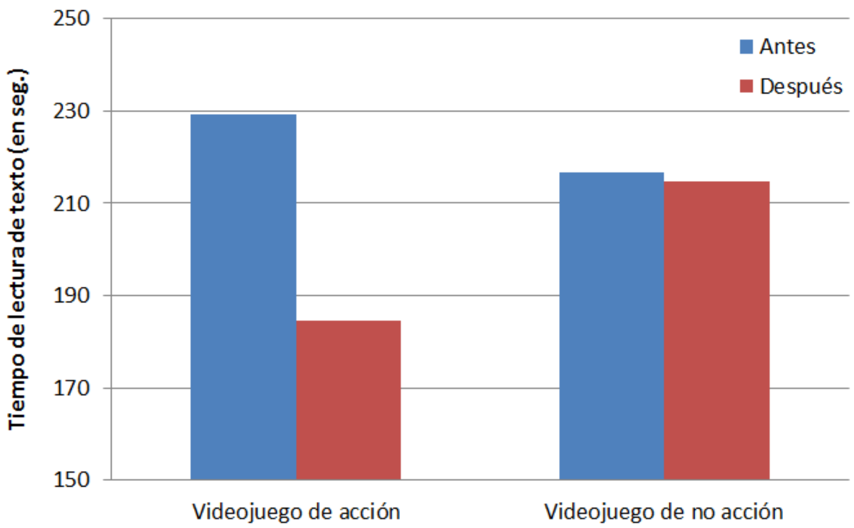


Figura 2. Tiempos de lectura de un texto (en segundos) antes y después del entrenamiento en el experimento de Franceschini et al. (2013).

Otra línea de investigación se ha centrado en cómo la práctica continuada en un popular juego de mesa (Scrabble) modula la forma en la que procesamos las palabras escritas. Varios estudios recientes han mostrado que los jugadores expertos de Scrabble muestran diferencias respecto a no expertos en tareas de identificación de palabras como la decisión léxica—en esta tarea se presenta una cadena de letras y los participantes han de indicar rápidamente si es una palabra o no. Hargreaves, Pexman, Zdrazilova y Sargious (2011) encontraron que los jugadores expertos de Scrabble tienen más facilidad en la lectura vertical de las palabras que los no expertos. Adicionalmente, Hargreaves et al. (2011) encontraron que un efecto de carácter semántico como el de concreción (identificación más rápida de una palabra concreta como *MESA* que de una palabra abstracta como *AMOR*) es menor en jugadores expertos que en no expertos. Dado que la finalidad del Scrabble es formar palabras con una mayor cantidad de puntos posible, sin reparar en su significado, éste es secundario para los jugadores expertos. Un trabajo de neuroimagen funcional realizado por Protzner y col. (2015) corroboró esta hipótesis. A diferencia de los no expertos, los jugadores expertos en Scrabble empleaban, durante una tarea de decisión léxica, áreas cerebrales asociadas con la memoria de trabajo y la percepción visual más que áreas cerebrales relacionadas con el acceso al significado.

En nuestro laboratorio (Perea, Marcet y Gomez, 2016), examinamos si los jugadores expertos de Scrabble codifican la posición de las letras de manera diferente a los no expertos. Empleamos una tarea de decisión léxica en la que se transponían/reemplazaban letras en palabras. Investigaciones previas (Perea y Lupker, 2004) han mostrado que las pseudopalabras formadas por la transposición de dos letras (PRIVAMERA) son perceptualmente muy parecidas a las palabras reales, produciendo más errores y tiempos de reacción mayores que las pseudopalabras creadas por remplazamiento (PRICATERA) (véase la Figura 3).

Figura 3. Condiciones en la tarea de decisión léxica ("¿Forma el estímulo una palabra real?") del experimento de Perea et al. (2016)

En nuestro estudio encontramos que los expertos cometieron menos errores y tenían tiempos de reacción más rápidos que los no expertos, una diferencia que se hizo más patente en las pseudopalabras creadas por transposición de letras como PRIVAMERA (Figura 4). Por tanto, la destreza en el procesamiento ortográfico-léxico que tienen los expertos en Scrabble se traduce en una codificación más precisa de la identidad y posición de las letras. Una pregunta para futuros trabajos es si el papel preponderante de la información ortográfica-léxica en los expertos de Scrabble pudiera afectar negativamente a la comprensión lectora.

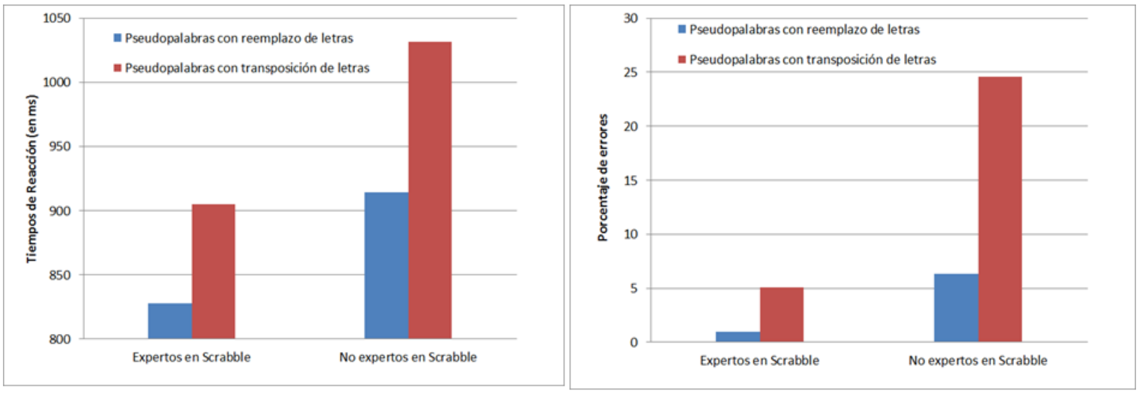


Figura 4. Tiempos de reacción (en ms) y porcentaje de errores para pseudopalabras creadas por transposición/reemplazo de letras en jugadores expertos y no expertos de Scrabble en el experimento de Perea et al. (2016)

En definitiva, las habilidades adquiridas mediante juegos/videojuegos modulan el reconocimiento visual de palabras. Por una parte, las mejoras atencionales derivadas de los videojuegos de acción proporcionan un procedimiento efectivo y de bajo coste para la intervención en niños con dislexia. Por otra parte, las destrezas ortográfico-léxicas que tienen los expertos en Scrabble revelan una reorganización funcional de los sustratos neuronales y las redes cerebrales encargadas del procesamiento lingüístico. Trabajos futuros han de examinar cómo esta reorganización funcional puede tener implicaciones para nuestra comprensión del aprendizaje lector.

4.10 ¿Comprarías ropa de DOLCE & BANANA? Similitud visual y percepción de marcas

Resumen

Las imitaciones de logotipos y nombres de productos, empresas o páginas web representan una realidad cotidiana en nuestra sociedad. Por ello, es importante examinar cómo reconocemos logotipos y marcas para evitar ser engañados por productos falsos o webs fraudulentas. En este artículo presentamos dos trabajos recientes en tal sentido, en un ámbito que une la psicología cognitiva y el marketing. En el primero, mostramos la dificultad de identificar un logotipo, muy familiar, entre logotipos falsos. En el segundo, mostramos cómo nuestro sistema perceptivo tiene dificultades para reconocer correctamente las palabras de direcciones web fraudulentas que son visualmente similares a la original (p.ej., www.rnicrosoft.com).

Palabras clave: cerebro; internet; lectura; lenguaje; marketing; percepción

A día de hoy no nos extraña ver imitaciones de productos (p.ej., bolsos o zapatillas de marca, camisetas de fútbol, etc.) a la venta en las calles de nuestras ciudades por mucho menos dinero de su valor real. Muchos consumidores compran productos falsificados, incluso cuando son conscientes de que no son los auténticos. Este hecho ha convertido al comercio de falsificaciones en una industria multimillonaria. Aunque algunos consumidores busquen activamente productos falsificados, entre otras cosas debido a que tienen un precio mucho más bajo que el producto original, otros consumidores desean un producto auténtico. Estos últimos a menudo son engañados y acaban comprando un producto falsificado por no poder diferenciar un logotipo falso de uno real. En este sentido, las empresas luchan para que otros no se aprovechen del éxito de sus productos, protegiéndose con patentes que impiden el registro de otras marcas y logotipos visualmente similares que puedan llevar al engaño. Un ejemplo reciente ocurrió cuando se intentó registrar en España la marca John Lennon, pero no se pudo al existir John Lemon como una marca de cervezas. De manera similar, es fácil encontrarse con webs fraudulentas que se parecen a las originales en nombre, diseño, etc. con el objetivo de obtener datos personales de los usuarios (Moreno-Fernández, Blanco, Garaizar y Matute, 2017).

Las investigaciones sobre cómo reconocemos marcas y logotipos representan un ámbito que está en auge y suponen un punto de unión entre la psicología cognitiva y el marketing (Perea, Jiménez, Talero y López-Cañada, 2015; van Horen y Pieters, 2012). A continuación describimos dos trabajos recientes, uno sobre logotipos y otro sobre nombres de marcas, que ejemplifican la facilidad que pueden tener los imitadores de marcas para hacer creer a los compradores que un producto es original cuando realmente se trata de una copia.

El logotipo de Apple ha sido catalogado como uno de los logotipos más conocidos en el mundo. Por tanto, se podría esperar que las personas pudieran identificar dicho logotipo y diferenciarlo de posibles imitaciones sin demasiadas dificultades. Sin embargo, como mostraron Blake, Nazarian y Castel (2015), las personas tienen dificultades en distinguir el logotipo verdadero de Apple de las imitaciones. En uno de sus experimentos, los participantes habían de identificar el logotipo de Apple entre un conjunto de ocho posibles logotipos con pequeñas modificaciones: forma de la manzana, dirección de la hoja u orientación del logotipo.

Menos de la mitad de personas (un 47%) fueron capaces de identificar correctamente el logotipo. Blake y colaboradores (2015) sugirieron que, dada la familiaridad y sencillez del logotipo de Apple, se puede generar una cierta saturación atencional que resulte en una escasa atención a los detalles del logotipo. Estas dificultades en distinguir el logotipo de una marca pueden volverse en nuestra contra, dado que podemos creer falsamente que un producto es original cuando realmente estamos ante una imitación.

Si hablamos de páginas de Internet, es de gran importancia saber a ciencia cierta que el dominio al que estamos accediendo es seguro. Para no caer en el engaño hay que discriminar correctamente si se trata de una página web auténtica o no. Una estrategia que siguen muchas direcciones web fraudulentas es contener palabras con homoglifos por combinación de letras, es decir, pares de letras que se parezcan visualmente a la original (p.ej., rn→m www.sarnsung.com, rnicrosoft.com). Para examinar el papel de los homoglifos en los primeros momentos del acceso al léxico, Marcet y Perea (2017c) realizaron dos experimentos con la técnica de presentación enmascarada del estímulo-señal (véase la Figura 1). En sus experimentos, cada palabra-test podía ir precedida brevemente por: 1) una palabra idéntica (documento-DOCUMENTO; presidente-PRESIDENTE); 2) una pseudopapabra que contenía un homoglifo por combinación de letras (documento-DOCUMENTO; presiclente-PRESIDENTE); o 3) un control ortográfico en el que se sustituyó la primera de las letras de la combinación (p.ej., rn→sn) (docusnento-DOCUMENTO; presiglente-PRESIDENTE). Si en los primeros momentos de procesamiento los homoglifos se procesan como las letras originales, los tiempos de identificación de las palabras serían más rápidos en la condición con homoglifos que en la condición de control. Además, se esperarían tiempos de respuesta similares en las condiciones de homoglifos y de identidad.

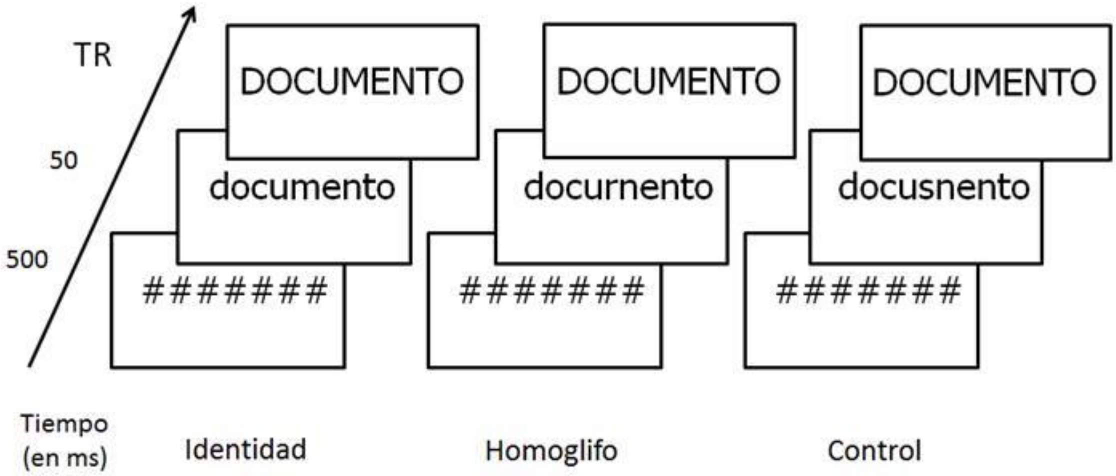


Figura 1. Ejemplo de ensayo con la técnica de presentación enmascarada del estímulo-señal empleada por Marcet y Perea (2017). La tarea de los participantes era decidir, lo más rápido posible intentando no cometer errores, si el estímulo-test en mayúsculas era palabra o no (es decir, una decisión léxica). Las variables dependientes son el tiempo de reacción (TR) y la precisión.

El primer experimento, realizado con una fuente de letra muy habitual (Tahoma, fuente por defecto en Facebook) confirmó ambas predicciones (véase la Figura 2).

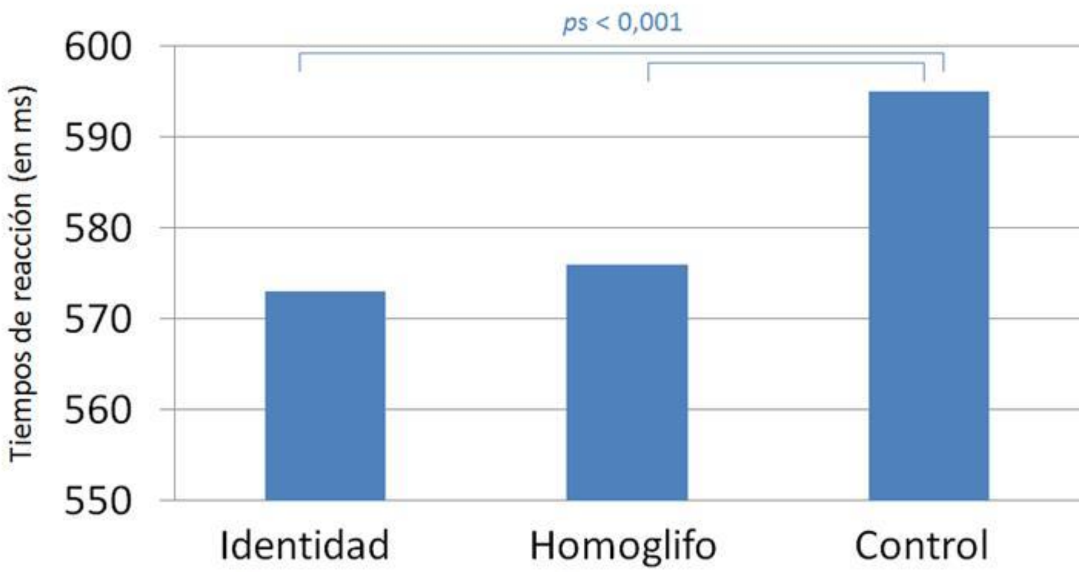


Figura 2. Tiempos medios de identificación de las palabras-test (en milisegundos) en cada una de las condiciones experimentales del Experimento 1 de Marcet y Perea (2017).

Dichos resultados muestran que los usuarios de Internet deberían ser conscientes del riesgo de ser engañados con nombres de dominios visualmente parecidos a los reales (p.ej., www.sarnsung.com). ¿Cómo podría modificarse la barra de direcciones de los navegadores de internet para minimizar dichos riesgos? Como señalaron Marcet y Perea (2018a), un elemento importante para minimizar los efectos de similitud de los homoglifos por combinación de letras es aumentar espaciado entre caracteres. En el segundo experimento emplearon una fuente con un espaciado algo mayor (Calibri, fuente por defecto en MS-Word) y los efectos de similitud visual, si bien seguían existiendo, fueron sensiblemente menores.

En definitiva, la imitación está muy extendida en todo tipo de marcas: diseño de sitios web, publicidad, logotipos, tiendas y productos. Las investigaciones anteriormente descritas y las que puede haber en un futuro sobre cómo se perciben las falsificaciones, pueden contribuir a controlar la competencia, preservar la integridad de los productos y determinar qué imitadores están cometiendo fraude, para poder así luchar contra la industria de la falsificación y reforzar las leyes que regulan la protección de las marcas.

5. CONCLUSIONES

Después de una breve revisión metodológica sobre la lectura en sus diversas modalidades, hemos realizado varias series de experimentos sobre los procesos cognitivos que se llevan a cabo durante el reconocimiento visual de palabras y la lectura, en particular durante los primeros momentos de procesamiento. Dichos experimentos han mostrado que aunque el sistema cognitivo es capaz de activar representaciones léxicas abstractas, la similitud visual y la familiaridad de la forma de la palabra juegan un papel modulador en los primeros momentos de la identificación de palabras. La aproximación a este tema ha sido realizada a través de diferentes técnicas, con el objetivo de obtener una visión global de los fenómenos bajo estudio: 1) tareas conductuales en las que se recogen los tiempos de reacción; 2) tareas de lectura de frases en las que se registran las duraciones de la fijaciones oculares; y 3) tareas de lectura en las que se recogen correlatos electrofisiológicos asociados a procesos cognitivos. Finalmente, se han examinado las repercusiones prácticas de los hallazgos obtenidos en dichos experimentos.

En los apartados siguientes indicaremos, en primer lugar, un breve resumen de los efectos que produce la similitud visual de letras, tanto en los primeros momentos del reconocimiento visual de palabras, como durante la lectura, y de cómo y cuándo se llega de lo perceptivo a lo abstracto y los factores que lo modulan dependiendo del colectivo en cuestión (individuos normo-lectores vs. sordos) y de las estrategias que éstos utilizan. En segundo lugar, indicaremos las repercusiones que tienen estos resultados para los modelos teóricos de reconocimiento visual de palabras y lectura. Finalmente, en tercer lugar, expondremos las posibles implicaciones a nivel práctico y educativo de los hallazgos.

5.1 Efectos de similitud visual

Gracias al uso de diferentes técnicas y tareas realizadas en los experimentos anteriormente descritos, hemos podido analizar los procesos más tempranos y automáticos comprobando así, que nuestro sistema perceptivo puede confundirse fácilmente en los primeros momentos de procesamiento. Para llegar a estas conclusiones hemos mostrado que en los primeros momentos de procesamiento foveal y parafoveal, existe cierto grado de incertidumbre en el código ortográfico para aquellas letras que son visualmente similares a otras. Esto también lo hemos corroborado al rastrear el curso del tiempo de los efectos de la similitud visual de letras, analizando los correlatos electrofisiológicos.

Estos hallazgos sugieren que los modelos de reconocimiento visual de palabras escritas deberían implementarse empleando niveles más refinados en cuanto a las características y los niveles de las letras se refiere. En experimentos como los de Marcet y Perea (2017c) se encontró una ventaja de los primes visualmente similares sobre los visualmente disimilares en los estadios tempranos del procesamiento de las palabras que no podía ser predicha por el modelo de activación interactiva (McClelland y Rumelhart, 1981). Así como en los experimentos llevados a cabo por Marcet y Perea (2018a) donde encontraron que, en los primeros momentos del procesamiento, las pseudopalabras creadas reemplazando una letra por un homoglifo de varias letras (por ejemplo, "m" con "rn," como en docurnento) son bastante efectivas activando sus correspondientes palabras base. Estos experimentos siguen en la línea de implementar modelos que aporten explicaciones más elaboradas sobre la relación entre las características visuales y los niveles de las letras. Este cierto grado de incertidumbre a la hora de identificar una letra en los primeros estadios el procesamiento, también fue obtenido con potenciales relacionados con eventos en el trabajo de Gutiérrez, Marcet y Perea (2018), en el que no se observaron diferencias en la ventana 230-350 ms para palabras que contenían una letra reemplazada por una letra visualmente similar (dentjsta-DENTISTA) pero sí que se encontraron mayores amplitudes de onda negativa en la condición visualmente disimilar (dentgsta-DENTISTA). Estos efectos de similitud visual no se restringen a tareas de reconocimiento visual de palabras, sino que también ocurren durante la lectura de frases cuando se registran los movimientos oculares. Empleando la técnica contingente de presentación parafoveal (Rayner, 1975), Marcet y Perea (2018b) encontraron que los tiempos de fijación para una palabra-test como *dentista* fueron más rápidos cuando se hallaba precedida en la parafóvea por un estímulo visualmente similar (dentjsta) que cuando éste estímulo era visualmente disimilar (dentgsta). Por tanto, los hallazgos durante una lectura de frases mediante presentación parafoveal replican los obtenidos en la tarea de decisión léxica con presentación foveal.

Como hemos visto anteriormente, los experimentos de decisión léxica con priming enmascarado han mostrado que existe una retroalimentación de los niveles más altos de procesamiento durante la codificación ortográfica. Para minimizar estos efectos léxicos de arriba-abajo Perea, Marcet y Vergara-Martínez (2016a) emplearon una tarea que incumbía los procesos ortográficos preléxicos: una tarea de priming enmascarado con la tarea igual-diferente. Para las respuestas igual, los resultados mostraron que los pares de palabras visualmente iguales disfrutan una ventaja en los tiempos de identificación sobre los pares de palabras que coincidían nominalmente pero no visualmente (p.e., ALTAR-ALTAR más rápido que altar-ALTAR), un efecto que ocurre en la misma magnitud con las pseudopalabras. Dado que la ventaja de ALTAR-ALTAR sobre altar-ALTAR no ocurre en tareas de corte léxico, este hallazgo restringe la interacción entre los mecanismos ascendentes y descendentes en los modelos de identificación visual de palabras. Es decir, si bien hay un acceso rápido a representaciones abstractas durante la identificación visual de palabras, la retroalimentación de niveles más altos de procesamiento puede ayudar a lograr representaciones abstractas más estables (véase Perea, Marcet. Lozano y Gomez, 2018, para evidencia de procesos automáticos con la técnica de priming enmascarado).

La mayoría de modelos de identificación visual de palabras predicen que una palabra en mayúsculas o minúsculas activa igualmente a su palabra correspondiente. Sin embargo, diversos experimentos han mostrado una ventaja de minúsculas en tareas de lectura e identificación de palabras. Para examinar el lugar donde se encuentra esta ventaja, Perea, Rosa y Marcet (2017) compararon el patrón de los movimientos oculares al leer frases en minúsculas frente a la lectura de frases en mayúsculas. Se encontró una mayor facilitación de lectura en las frases en minúscula, posiblemente por una mayor familiaridad ya que estamos más acostumbrados a leer frases en minúscula que en mayúsculas. Sin embargo, hay palabras comunes que normalmente se escriben en mayúsculas (p.e., RESTAURANTE, FARMACIA). Para examinar si la configuración habitual de letras (mayúscula o minúscula) modula los tiempos de identificación en palabras, Perea, Marcet y Vergara-Martínez (2018) realizaron un experimento de decisión léxica con 78 palabras comúnmente escritas en minúsculas (molécula) y 78 palabras escritas comúnmente en mayúsculas (FARMACIA). Como era de esperar, el formato en minúsculas obtuvo tiempos más rápidos que el formato en mayúsculas, mientras que este efecto no se observó en el caso de las palabras en mayúsculas. Este patrón de resultados sugiere que la configuración habitual de letras de palabras comunes juega un papel importante durante procesamiento visual de textos.

En cuanto a la complejidad de la lectura de palabras manuscritas, Perea, Marcet, Uixera, y Vergara-Martínez (2018) registraron los movimientos oculares durante la lectura de oraciones escritas a mano. De entre las oraciones que se presentaban en el experimento, nos encontramos con frases escritas a mano con una caligrafía fácil, frases escritas a mano con una caligrafía difícil o frases impresas. Los resultados mostraron que, si bien las oraciones escritas a mano tienen un costo de lectura importante en comparación con las oraciones impresas, no lo hay en las etapas iniciales del proceso léxico, ni en la frecuencia de las palabras. Estos hallazgos suscitan la necesidad de investigar acerca de cómo los procesos de nivel superior se ven afectados por la entrada visual ruidosa de las frases escritas a mano. Habitualmente, cuando escribimos a mano y en minúsculas una frase, unimos las letras que componen las palabras. Esta letra cursiva también ha sido creada como fuente tipográfica para textos escritos a ordenador. Manso de Zuniga, Humphreys y Evett (1991) afirmaron que hay una etapa temprana de codificación de "normalización cursiva" al procesar palabras escritas con letras conectadas. Para probar esta afirmación, Roldán, Marcet y Perea (2018) realizaron un experimento con una tarea de decisión léxica en el que las palabras se presentaban con letras separadas o conectadas. Los resultados mostraron tiempos de respuesta más rápidos para las palabras compuestas por letras separadas que para las palabras compuesta por letras conectadas. Estos datos ofrecen apoyo empírico a la investigación de Manso de Zúñiga et al. (1991) y tienen implicaciones teóricas en cuanto al papel de la "normalización cursiva" en los modelos de reconocimiento visual de palabras.

Si hablamos de cómo el cerebro codifica el orden de las letras más que su identidad, como en el caso de los efectos de transposición de letras (p.e., CHOLOCATE activa CHOCOLATE), no encontraremos unanimidad entre los expertos. Un grupo de modelos explica los efectos de transposición de letras en función de la incertidumbre perceptiva a la hora de asignar posiciones a las letras dentro de una palabra, mientras que otro grupo de modelos los explica mediante la activación de "bigramas abiertos" a nivel ortográfico. Para diferenciar ambos modelos Perea, Marcet y Gomez (2015) recapitularon una serie de experimentos como el de Perea, Jiménez, Martín-Suesta y Gomez (2015) en el que encuentran tiempos de lectura mayor en la modalidad táctil (braille) que en la visual (tinta) cuando las frases no contenían palabras transpuestas que cuando sí que tenían, y otro tipo de experimentos en los que se presentan palabras transpuestas en alfabetos desconocidos para el lector como el de Perea, Winskel, Abu Mallouh, Barnes y Gomez (2015) que consistía en decir si las palabras que aparecían eran iguales o diferentes. Los participantes cometieron un número mayor de errores ante los pares con letras transpuestas que ante los pares con letras sustituidas, resultados que apoyan a los modelos que asumen que existe incertidumbre perceptiva al codificar la posición de las letras en las palabras. En sintonía con lo anteriormente nombrado, Marcet, Perea, Baciero y Gomez (2018) para disminuir el tamaño del efecto de letras transpuestas, hicieron dos tipos de manipulación: 1) resaltando los bigramas transpuestos y 2) presentando las letras en serie una por una. Aunque dicho efecto no logró desaparecer, sí que disminuyó sustancialmente de tamaño. Estos hallazgos sugieren que existe otro componente fundamental a un nivel ortográfico abstracto.

Finalmente, los efectos de transposición de letras son mayores para las transposiciones de consonantes que para las de vocales en lectores adultos, debido posiblemente a un mayor procesamiento fonológico que ortográfico (Perea y Acha, 2009; Perea y Lupker, 2004). Para poner a prueba esta hipótesis, Comesaña, Soares, Marcet y Perea (2016) realizaron un experimento con escolares en el que no se encontraron signos de priming fonológico enmascarado. Con este colectivo de escolares, Comesaña et al. (2016) encontraron un efecto de transposición de letras similar para consonantes y vocales, mientras que se replicó la interacción obtenida por Perea y Lupker (2004) con lectores adultos—que sí muestran efectos de priming fonológico. Por tanto, el estatus de las letras como consonantes/vocales no juega un papel en la codificación de la posición de las letras, sino más bien en un estadio posterior de corte fonológico.

5.2 Repercusión para los modelos teóricos de identificación de palabras y lectura

El modelo de activación interactiva (McClelland & Rumelhart, 1981), con los parámetros establecidos por defecto, no predice los efectos de similitud visual obtenidos en los experimentos realizados en esta tesis. Este hecho posiblemente sea por la falta de especificación en el nivel de los parámetros visuales (véase Rosa, Perea y Enneson, 2016, para una discusión más extensa).

El modelo que mejor se ajusta a los resultados obtenidos es el Bayesian Reader (Norris y Kinoshita, 2012). En este modelo, se asume una incertidumbre perceptiva en los primeros momentos de procesamiento de palabras, tanto en la codificación de la identidad como de la posición de las letras que las componen, que se va resolviendo en los siguientes estadios. Este modelo encaja perfectamente con los resultados de los experimentos conductuales y de potenciales relacionados a eventos que hemos expuesto, ya que esa incertidumbre aparece a nivel ortográfico para ir posteriormente desapareciendo. Además, este modelo también predice y explica los efectos de trasposición, hecho que no sucede en el modelo de activación interactiva.

Un elemento importante para poder conocer con precisión cómo la información visual de las palabras escritas activa representaciones abstractas es mediante la rotación de las letras. En el modelo neural de reconocimiento visual de palabras propuesto por Dehaene, Cohen, Sigman y Vinckier (2005), se indicaba que las unidades responsables de codificar las letras de las palabras verían entorpecida su labor cuando las letras se presentaran con una rotación superior a 45 grados. Para examinar esta predicción, Perea, Marcet y Fernández-López (2018) realizaron un experimento de priming enmascarado de repetición con la tarea de decisión léxica en la que las palabras se presentaban en formato marquée (es decir, cada letra debajo de la anterior) o rotadas 90 grados. Los resultados mostraron efectos claros de priming de repetición enmascarada en ambos formatos, lo que pone algunos problemas al supuesto del modelo de Dehaene et al. (2005) acerca de que las neuronas responsables del procesamiento de letras se encuentran parcialmente impedidas cuando las letras se presentan rotadas.

Finalmente, si bien en esta tesis no se ha realizado explícitamente un trabajo de modelado, en otros trabajos sí que se han efectuado ajustes con modelos matemáticos en tareas de reconocimiento visual de palabras. En particular, Perea, Marcet, Vergara-Martínez y Gomez (2016) realizaron un experimento de decisión léxica en el que examinaron los efectos de repetición para palabras y pseudopalabras. Para palabras, se encontró un efecto facilitador de repetición, mientras que para pseudopalabras, se encontró un efecto inhibidor de repetición. Estos resultados fueron simulados con el modelo de difusión (véase Gomez, 2012, Perea, Devis, Marcet y Gomez, 2016, para una revisión), asumiendo que las respuestas en la tarea de decisión léxica tienen un componente de familiaridad, que facilita las respuestas "sí" a las palabras repetidas pero que, a su vez, dificulta las respuestas "no" a las pseudopalabras repetidas.

5.3 Aplicaciones prácticas

De los estudios anteriormente presentados y de otros realizados en nuestro laboratorio, podemos resaltar diferentes estrategias para una mayor comprensión de los textos escritos. Tal y como señalan Perea, Marcet, Jiménez y Tejero (2015), la utilización del color en la delimitación de palabras ayudaría al aprendizaje de una segunda lengua que se escriba sin espacios entre palabras, como el chino. También, la utilización de un código de colores puede ayudar al procesamiento de los elementos gramaticales que facilite el reconocimiento de las distintas categorías gramaticales que a su vez, puedan facilitar la lectura de textos al proporcionar un apoyo visual que dé información adicional acerca de su significado. Siguiendo esta línea, para conocer si la facilitación del color en chino afecta también a los nativos de este idioma Perea y Wang (2017) realizaron tres experimentos en los que los participantes, niños y adultos nativos de China, habían de leer en voz alta dos textos. En uno de los textos, todas las palabras se presentaban en el mismo color y en el otro, las palabras adyacentes tenían colores diferentes. El resultado clave fue que los niños de segundo de Primaria leían más rápidamente los textos con colores alternados que los textos estándar monocolor. Por tanto, en lectores principiantes de chino, la coloración alternada de las palabras en un texto produce una lectura más ágil que el formato estándar. Pero la utilización de colores no son las únicas claves visuales que nos pueden agilizar el proceso lector.

Otra manipulación que se puede realizar para una lectura más ágil de los textos, es aumentar el espaciado entre letras (p.e., c a m i n o vs. camino; Perea y Gomez, 2012a, 2012b). Durante la lectura de textos, Perea, Giner, Marcet y Gomez (2016) encontraron que los tiempos de fijación sobre cada palabra eran más breves cuando las letras de las palabras de texto tenían un ligero incremento del espaciado frente al texto estándar. Sin embargo, los tiempos totales de lectura fueron similares en ambas condiciones debido a que la condición con espaciado extra produjo un mayor número de fijaciones. Como indicaron Perea et al. (2016), sería interesante conocer si el espaciamiento entre letras juega un papel más importante durante la lectura en individuos con dislexia que en lectores expertos. Aunque la literatura reporta un efecto facilitador de aumentos extras en el espaciamiento entre letras para personas con dislexia, estos experimentos se llevaron a cabo mediante tareas que requerían explícitamente la activación de códigos fonológicos como es la lectura en voz alta. Para que estos resultados fueran más concluyentes sería conveniente realizar experimentos de movimientos oculares utilizando una tarea de lectura silenciosa.

Aparte de las diferentes modificaciones que se pueden hacer a un texto para facilitar la lectura como son el colorear las palabras o el aumentar el espaciado entre palabras, también se puede llevar a cabo un entrenamiento para minimizar las confusiones en procesamiento ortográfico-léxico de las palabras. En el experimento de Perea, Marcet, Gomez (2016) se demostró que los jugadores expertos de Scrabble mostraban un efecto de letras transpuestas notablemente menor en comparación con las personas que no juegan a Scrabble de forma profesional. Esto implica que los parámetros responsables de la flexibilidad en los esquemas de codificación ortográfica son modulados por la experiencia. Esto podría ayudar a los niños que están aprendiendo a leer y a las personas que tengan dificultades en la lectura en cuanto al proceso de codificación de identidad/posición de las letras durante el reconocimiento visual de palabras, lo que conllevaría mejores resultados en la lectura de textos.

Otra población que se puede beneficiar de los hallazgos procedentes de la psicología cognitiva durante la lectura es la población sorda. En el caso de los lectores sordos, independientemente de su capacidad lectora, su codificación fonológica es deficiente o está ausente en las primeras etapas del procesamiento visual de textos. Para poner a prueba esta idea, Perea, Marcet, y Vergara-Martínez (2016) realizaron un experimento con priming de repetición enmascarado en el que se observaron diferencias en el reconocimiento de palabras entre los lectores oyentes y sordos. Al no beneficiarse estos últimos del procesamiento de arriba-abajo a partir de información fonológico-léxica, se observó que los lectores sordos gozaban de una ventaja de procesamiento en la identidad física sobre la identidad nominal no sólo en pseudopalabras –como ocurre en oyentes– sino también en palabras (GEDA-GEDA más rápido que geda-GEDA; REAL-REAL más rápido que real-REAL). Claramente, se necesita más investigación para entender completamente las similitudes y diferencias en el procesamiento visual de textos entre lectores sordos y oyentes, y poder así utilizar las técnicas más convenientes en la enseñanza de la lectura a personas sordas.

En esta línea, recientemente Gutiérrez-Sigut, Vergara, Marcet y Perea (2018) encontraron evidencia de activación automática temprana de códigos fonológicos en lectores sordos en un experimento de priming enmascarado al obtener una magnitud de priming fonológico enmascarado similar a los oyentes (koral-CORAL < toral-CORAL), al menos cuando la asincronía estimular entre la señal y el test era de 100 ms—Perea et al. (2016) emplearon solamente 50 ms que posiblemente no fue suficiente para la activación fonológica en personas sordas. Por lo tanto, estos hallazgos son consistentes con aquellos relatos que asumen que la fonología es una parte automática de la identificación de palabras en ortografías transparentes. Estos resultados están en consonancia con la idea de que el acceso al léxico para las personas sordas depende más de la información visual y ortográfica que para los oyentes. Por tanto, las estrategias educativas que se lleven a cabo con personas sordas deben distar de las que se realicen con personas oyentes, ya que para ellos es clave la información visual y ortográfica.

Para concluir, los experimentos descritos en esta tesis han arrojado luz sobre los procesos cognitivos que se llevan a cabo durante los primeros momentos de procesamiento en el reconocimiento visual de palabras y durante la lectura. A través de diferentes técnicas, se mostrado que la similitud visual y la familiaridad en cuanto a la forma de la palabra modula la identificación de palabras en los primeros estadios del procesamiento incluso aunque el sistema cognitivo sea capaz de activar representaciones léxicas abstractas. Creemos además que los hallazgos descritos en esta tesis pueden tener no solamente implicaciones de corte teórico sino que pueden ser empleadas en el contexto escolar.

6. REFERENCIAS

Abboud, S., Maidenbaum, S., Dehaene, S. y Amedi, A. (2015). A number-form area in the blind. *Nature Communications*, *6*, 6026. doi:10.1038/ncomms7026

Acha, J. y Perea, M. (2010). Does kaniso activate CASINO? *Experimental Psychology, 57*, 245–251. doi:10.1027/1618-3169/a000029

Adelman, J. S. (2011). Letters in time and retinotopic space. *Psychological Review, 118*, 570–582. doi:10.1037/a0024811

Angele, B., Slattery, T. J. y Rayner, K. (2016). Two stages of parafoveal processing during reading: Evidence from a display change detection task. *Psychonomic Bulletin & Review, 23*, 1241–1249. doi:10.3758/s13423-015-0995-0

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., ... y Gazzaley, A. (2013). Video game training enhances cognitive control in older adults. *Nature, 501*, 97–101.

Aranyanak, I. y Reilly, R. G. (2013). A system for tracking braille readers using a Wii Remote and a refreshable braille display. *Behavior Research Methods*, *45*, 216–228. doi:10.3758/s13428-012-0235-8

Balota, D. A., Yap, M. J., Hutchison, K. A., Cortese, M. J., Kessler, B., Loftis, B., … y Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods, 39*, 445–459. doi:10.3758/bf03193014

Balota, D., Yap, M. J. y Cortese, M. J. (2006). Visual word recognition: The journey from features to meaning (A travel update). In M. Traxler & M. A. Gernsbacher (Eds.), *Handbook of psycholinguistics* (2nd edition) (pp. 285–375). Amsterdam: Academic Press.

Barnhart, A. S. y Goldinger, S. D. (2010). Interpreting chicken- scratch: Lexical access for handwritten words. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 906–923. doi:10.1037/a0019258

Bates, D., Maechler, M., Bolker, B. y Walker, S. (2014). *lme4: Linear mixed-effects models using Eigen and S4*. R package version 1.1–5. Retrieved from http://CRAN.Rproject.org/package=lme4

Bates, D., Maechler, M., Bolker, B. y Walker, S. (2015). Fitting Linear Mixed-Effects models using lme4. *Journal of Statistical Software, 67*, 1–48. doi:10.18637/jss.v067.i01

Bates, D., Maechler, M., Bolker, B., Walker, S. (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67, 1–48. doi:10.18637/jss.v067.i01

Bélanger, N. N., Baum, S. R. y Mayberry, R. I. (2012). Reading difficulties in adult deaf readers of French: Phonological codes, not guilty! *Scientific Studies of Reading, 16*, 263–285.

Bélanger, N. N., Mayberry, R. I., y Rayner, K. (2013). Orthographic and phonological preview benefits: Parafoveal processing in skilled and less-skilled deaf readers. *Quarterly Journal of Experimental Psychology, 66*, 2237–2252.

Bertelson, P., Mousty, P. y Radeau, M. (1992). The time course of braille word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *18*, 284–297.

Besner, D. (1983). Basic decoding components in reading: Two dissociable feature extraction processes. *Canadian Journal of Psychology, 37*, 429–438. doi:10.1037/h0080739

Bicknell, K. y Levy, R. (2010). A rational model of eye movement control in reading. In J. Hajič (Ed.), *Proceedings of the 48th Annual Meeting of the Association for Computational Linguistics* (pp.1168–1178). Uppsala, Sweden: Association for Computational Linguistics. doi:10.1037/e520602012-979

Blais, C., Fiset, D., Jolicoeur, P., Arguin, M., Bub, D. N. y Gosselin, F. (2009). Reading between eye saccades. *PLOS ONE, 4*(7), e6448. doi:10.1371/journal.pone.0006448

Blake, A. B., Nazarian, M. y Castel, A. D. (2015). The Apple of the mind's eye: Everyday attention, metamemory, and reconstructive memory for the Apple logo. *Quarterly Journal of Experimental Psychology, 68*, 858–865.

Bohm, T. (2014). Letter and symbol misrecognition in highly legible typefaces for general, children, dyslexic, visually impaired and ageing readers. *Information Design Journal, 21*, 34–50. doi:10.1075/idj.21.1.05boh

Bouma, H. (1971). Visual recognition of isolated lower-case letters. *Vision Research, 11*, 459–474. doi:10.1016/0042-6989(71)90087-3

Brysbaert, M., Speybroeck, S. y Vanderelst, D. (2009). Is there room for the BBC in the mental lexicon? On the recognition of acronyms. *Quarterly Journal of Experimental Psychology, 62*, 1832–1842. doi:10.1080/17470210802585471

Bürklen, K. (1932). *Touch reading of the blind* (F. K. Merry, Trans.). Nueva York: American Foundation for the Blind, Inc. (Original in 1917).

Carreiras, M., Armstrong, B. C., Perea, M. y Frost, R. (2014). The what, when, where, and how of visual word recognition. *Trends in Cognitive Sciences, 18*, 90–98. doi:10.1016/j.tics.2013.11.005

Carreiras, M., Perea, M. y Mallouh, R. A. (2012). Priming of abstract letter representations may be universal: The case of Arabic. *Psychonomic Bulletin & Review, 19*, 685–690. doi:10.3758/s13423-012-0260-8

Carreiras, M., Perea, M., Gil-López, C., Abu Mallouh, R. y Salillas, E. (2013). Neural correlates of visual vs. abstract letter processing in Roman and Arabic scripts. *Journal of Cognitive Neuroscience, 25*, 1975–1985. doi:10.1162/jocn_a_00438

Carreiras, M., Vergara, M. y Perea, M. (2007). ERP correlates of transposed-letter similarity effects: Are consonants processed differently from vowels? *Neuroscience Letters, 419*, 219–224. doi:10.1016/j.neulet.2007.04.053

Chambers, S. M. (1979). Letter and order information in lexical access. *Journal of Verbal Learning and Verbal Behavior, 18*, 225–241. doi:10.1016/s0022-5371(79)90136-1

Chen, T., Peltola, M. J., Ranta, L. J. y Hietanen, J. K. (2016). Affective priming by eye gaze stimuli: behavioral and electrophysiological evidence. *Frontiers in Human Neuroscience, 10*, 619. doi:10.3389/fnhum.2016.00619

Chetail, F. y Mathey, S. (2009). Activation of syllable units during visual recognition of French words in Grade 2. *Journal of Child Language, 36*, 883–894. doi:10.1017/s0305000908009197

Coltheart, M., Rastle, K., Perry, C., Langdon, R. y Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256. doi:10.1037/0033-295x.108.1.204

Coltheart, M., Rastle, K., Perry, C., Langdon, R. y Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*, 204–256. doi:10.1037/0033-295x.108.1.204

Comisión Braille Española. (2015). *La didáctica del braille más allá del código: Nuevas perspectivas en la alfabetización del alumnado con discapacidad visual*. Madrid: ONCE.

Craik, F. I. M. y Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior, 11*, 671–684. doi:10.1016/s0022-5371(72)80001-x

Cutter, M. G., Drieghe, D. y Liversedge, S. P. (2015). How is information integrated across fixations in reading? In A. Pollatsek and R. Treiman (Eds.), *The Oxford Handbook of Reading* (pp. 245–260). New York: Oxford University Press. doi:10.1093/oxfordhb/9780199324576.013.11

Davis, C. J. (2010). The spatial coding model of visual word identification. *Psychological Review, 117*, 713–758. doi:10.1037/a0019738

Davis, C. J. y Perea, M. (2005). BuscaPalabras: A program for deriving orthographic and phonological neighborhood statistics and other psycholinguistic indices in Spanish. *Behavior Research Methods, 37*, 665–671. doi:10.3758/bf03192738

Davis, M. y Suignard, M. (2012). *Unicode security considerations*. Technical Report 36, Unicode Technical Report. Available at http://www.unicode.org/reports/tr36/

Dehaene, S., Cohen, L., Sigman, M. y Vinckier, F. (2005). The neural code for written words: a proposal. *Trends in Cognitive Sciences, 9*, 335–341. doi:10.1016/j.tics.2005.05.004

Dehaene, S., Jobert, A., Naccache, L., Ciuciu, P., Poline, J.-B., Le Bihan, D. y Cohen, L. (2004). Letter binding and invariant recognition of masked words: Behavioral and neuroimaging evidence. *Psychological Science, 15*, 307–313. doi:10.1111/j.0956-7976.2004.00674.x

Delorme, A. y Makeig, S. (2004). EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9–21. doi:10.1016/j.jneumeth.2003.10.009

Duchon, A., Perea, M., Sebastián-Gallés, N., Martí, A. y Carreiras, M. (2013). EsPal: One-stop shopping for Spanish word properties. *Behavior Research Methods, 45*, 1246–1258. doi:10.3758/s13428-013-0326-1

Duñabeitia, J. A., Perea, M. y Carreiras, M. (2009). Eye movements when reading words with $YMβOL$ and NUM83R5: There is a cost. *Visual Cognition, 17*, 617–631. doi:10.1080/13506280902764489

Duyck, W. y Warlop, N. (2009). Translation priming between the native language and a second language. *Experimental Psychology, 56*, 173–179. doi:10.1027/1618-3169.56.3.173

Engbert, R., Nuthmann, A., Richter, E. M. y Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*, 777–813. doi:10.1037/0033-295X.112.4.777

Fischer-Baum, S. y Englebretson, R. (2016). Orthographic units in the absence of visual processing: Evidence from sublexical structure in braille. *Cognition, 153*, 161–174. doi:10.1016/j.cognition.2016.03.021

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research, 27*, 203–233. doi:10.1023/A:1023202116609

Forster, K. I. y Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory y Cognition, 10*, 680–698. doi:10.1037/0278-7393.10.4.680

Forster, K. I. y Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments y Computers, 35*, 116–124. doi:10.3758/bf03195503

Forster, K. I., Davis, C., Schoknecht, C. y Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology*, *39A*, 211–251. doi:10.1080/14640748708401785

Franceschini, S., Gori, S., Ruffino, M., Viola, S., Molteni, M. y Facoetti, A. (2013). Action video games make dyslexic children read better. *Current Biology, 23*, 462–466.

Friedmann, N. y Rahamim, E. (2012). What can reduce letter migrations in letter position dyslexia? *Journal of Research in Reading, 37*, 297–315. doi:10.1111/j.1467-9817.2011.01525.x

Gabrilovich, E. y Gontmakher, A. (2002). The homograph attack. *Communications of the ACM, 45,* 128. doi:10.1145/503124.503156.

García-Orza, J., Perea, M. y Estudillo, A. (2011). Masked transposition effects for simple vs. complex non-alphanumeric objects. *Attention, Perception, & Psychophysics, 73*, 2573–2582. doi:10.3758/s13414-011-0206-7

García-Orza, J., Perea, M. y Muñoz, S. (2010). Are transposition effects specific to letters? *Quarterly Journal of Experimental Psychology, 63*, 1603–1618. doi:10.1037/e520562012-240

Goldfarb, L. y Treisman, A. (2011). Does a color difference between parts impair the perception of a whole? A similarity between simultanagnosia patients and healthy observers. *Psychonomic Bulletin & Review, 18*, 877–882. doi:10.3758/s13423-011-0123-8

Gomez, P. y Perea, M. (2014). Decomposing encoding and decisional components in visual-word recognition: A diffusion model analysis. *Quarterly Journal of Experimental Psychology, 67*, 2455–2466. doi:10.1080/17470218.2014.937447

Gomez, P., Perea, M. y Ratcliff, R. (2013). A diffusion model account of masked vs. unmasked priming: Are they qualitatively different? *Journal of Experimental Psychology: Human Perception and Performance, 39*, 1731–1740. doi:10.1037/a0032333

Gomez, P., Ratcliff, R. y Perea, M. (2008). The overlap model: A model of letter position coding. *Psychological Review, 115*, 577–600. doi:10.1037/a0012667

Gontijo, P. F. G. y Zhang, S. (2007). The mental representation of brand names: Are brand names a class by themselves? In T. M. Lowrey (Ed.), *Psycholinguistic phenomena in marketing communications* (pp. 23–37). Hillsdale, NJ: Erlbaum.

Gori, S., Seitz, A. R., Ronconi, L., Franceschini, S. y Facoetti, A. (2016). Multiple Causal Links Between Magnocellular–Dorsal Pathway Deficit and Developmental Dyslexia. *Cerebral Cortex, 26*, 4356–4369.

Grainger, J. (2008). Cracking the orthographic code: An introduction*. Language and Cognitive Processes, 23*, 1–35. doi:10.1080/01690960701578013

Grainger, J. (2018). Orthographic processing: A “mid-level” vision of reading. *Quarterly Journal of Experimental Psychology, 71*, 335–359. doi:10.1080/17470218.2017.1314515

Grainger, J. y Holcomb, P. J. (2009). Watching the word go by: On the time-course of component processes in visual word recognition. *Language and Linguistics Compass, 3*, 128–156. doi:10.1111/j.1749-818x.2008.00121.x

Grainger, J. y Jacobs, A.M. (1996). Orthographic processing in visual word recognition: A multiple read-out model. *Psychological Review, 103*, 518–565. doi:10.1037/0033-295x.103.3.518

Grainger, J. y van Heuven, W. J. B. (2003). Modeling letter position coding in printed word perception. In P. Bonin (Ed.), *Mental lexicon: Some words to talk about words* (pp. 1–23). Hauppauge, NY: Nova Science.

Grainger, J. y Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology, 2*, 54. doi:10.3389/fpsyg.2011.00054

Grainger, J., Dufau, S. y Ziegler, J. C. (2016). A Vision of Reading. *Trends in Cognitive Sciences, 20*, 171–179. doi:10.1016/j.tics.2015.12.008.

Grainger, J., Granier, J.-P., Farioli, F., Van Assche, E. y van Heuven, W. J. B. (2006). Letter position information and printed word perception: The relative-position priming constraint. *Journal of Experimental Psychology: Human Perception and Performance, 32*, 865–884. doi:10.1037/0096-1523.32.4.865

Grainger, J., O’Regan, J. K., Jacobs, A. M. y Segui, J. (1989). On the role of competing word units in visual word recognition: The neighborhood frequency effect. *Perception & Psychophysics, 45*, 189–195. doi:10.3758/bf03210696

Grainger, J., O'Regan, J. K., Jacobs, A. M. y Segui, J. (1992). Neighborhood frequency effects and letter visibility in visual word recognition. *Perception & Psychophysics, 51*, 49–56. doi:10.3758/bf03205073

Grainger, J., Rey, A. y Dufau, S. (2008). Letter perception: From pixels to pandemonium. *Trends in Cognitive Sciences, 12*, 381–387. doi:10.1016/j.tics.2008.06.006

Green, C. S. y Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534–537.

Gregg, J., & Inhoff, A. W. (2016). Misperception of orthographic neighbors during silent and oral reading. *Journal of Experimental Psychology: Human Perception and Performance, 42*, 799–820. doi:10.1037/xhp0000193

Gu, J. y Li, X. (2015). The effects of character transposition within and across words in Chinese reading. *Attention, Perception, & Psychophysics, 77*, 272–281. doi:10.3758/s13414-014-0749-5

Guthrie, D. y Buchwald, J. S. (1991). Significance testing of difference potentials. *Psychophysiology, 28*, 240–244. doi:10.1111/j.1469-8986.1991.tb00417.x

Gutiérrez-Sigut, E., Marcet, A. y Perea, M. (2018). Tracking the time course of letter visual-similarity effects during word recognition: A masked priming ERP investigation. Bajo revision en la revista *Cognitive, Affective, and Behavioral Neuroscience.*

Gutiérrez-Sigut, E., Vergara-Martínez, M. y Perea, M. (2017). Early use of phonological codes in deaf readers: An ERP study. *Neuropsychologia, 106*, 261–279. doi:10.1016/j.neuropsychologia.2017.10.006

Häikiö, T., Hyönä, J. y Bertram, R. (2015). The role of syllables in word recognition among beginning Finnish readers: Evidence from eye movements during reading. *Journal of Cognitive Psychology, 27*, 562–577. doi:10.1080/20445911.2014.982126

Hannagan, T., Ktori, M., Chanceaux, M. y Grainger, J. (2012). Deciphering CAPTCHAs: What a Turing test reveals about human cognition. *PLoS ONE, 7*, e32121. doi:10.1371/journal.pone.0032121

Hannan, C. K. (2006). Review of research: Neuroscience and the impact of brain plasticity on braille reading. *Journal of Visual Impairment & Blindness*, *100*, 397–

413. Hughes, B. (2011). Movement kinematics of the braille-reading finger. *Journal of Visual Impairment and Blindness*, *105*, 370–381.

Hargreaves, I. S., Pexman, P. M., Zdrazilova, L. y Sargious, P. (2011). How a hobby can shape cognition: Visual word recognition in competitive Scrabble players. *Memory & Cognition, 40*, 1–7.

Healy, A. F. y Drewnowski, A. (1983). Investigating the boundaries of reading units: Letter detection in misspelled words. *Journal of Experimental Psychology: Human Perception and Performance, 9*, 413–426. doi:10.1037/0096-1523.9.3.413

Herdman, C. M., Chernecki, D. y Norris, D. (1999). Naming cAsE aLtErNaTeD words. *Memory & Cognition, 27*, 254–266. doi:10.3758/bf03211410

Herrera, L. y Defior, S. (2005). Una aproximación al procesamiento fonológico de los niños prelectores: Conciencia fonológica, memoria verbal a corto plazo y denominación. *Psyckhe, 14*, 81–95

Hohenstein, S. y Kliegl, R. (2014). Semantic preview benefit during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40*, 166–190. doi:10.1037/a0033670

Holcomb, P. J. y Grainger, J. (2006). On the time course of visual word recognition: An event-related potential investigation using masked repetition priming. *Journal of Cognitive Neuroscience, 18*, 1631–1643. doi:10.1162/jocn.2006.18.10.1631

Hughes, B., McClelland, A. y Henare, D. (2014). On the Nonsmooth, Nonconstant Velocity of Braille Reading and Reversals. *Scientific Studies of Reading*, *18*, 94–113

Hyönä, J., Bertram, R. y Pollatsek, A. (2004). Are long compound words identified serially via their constituents? Evidence from an eye movement-contingent display change study. *Memory & Cognition, 32*, 523–532. doi:10.3758/bf03195844

Jacobs, A. M., Grainger, J. y Ferrand, L. (1995). The incremental priming technique: A method for determining within-condition priming effects. *Perception & Psychophysics, 57*, 1101–1110.

Johnson, R. L., Perea, M. y Rayner, K. (2007). Transposed-letter effects in reading: Evidence from eye movements and parafoveal preview. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 209–229. doi:10.1037/0096-1523.33.1.209

Keizer, A. W., Hommel, B. y Lamme, V. A. F. (2014). Consciousness is not necessary for visual feature binding. *Psychonomic Bulletin & Review, 22*, 453–460. doi:10.3758/s13423-014-0706-2

Keuleers, E. y Brysbaert, M. (2010). Wuggy: A multilingual pseudoword generator. *Behavior Research Methods, 42*, 627–633. doi:10.3758/brm.42.3.627

Kezilas, Y., Kohnen, S., McKague, M. y Castles, A. (2014). The locus of impairment in English developmental letter position dyslexia. *Frontiers in Human Neuroscience, 8*, 1–14. doi:10.3389/fnhum.2014.00356

Kinoshita, S. y Lagoutaris, S. (2010). Priming by numb3r5 does not involve top-down feedback. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 36*, 1422–1440. doi:10.1037/a0020609

Kinoshita, S., Robidoux, S., Guilbert, D. y Norris, D. (2015). Context-dependent similarity effects in letter recognition. *Psychonomic Bulletin and Review, 22*, 1458–1464. doi:10.3758/s13423-015-0826-3

Kinoshita, S., Robidoux, S., Mills, L. y Norris, D. (2013). Visual similarity effects on masked priming. *Memory & Cognition, 42*, 821–833. doi:10.3758/s13421-013-0388-4

Kiyonaga, K., Grainger, J., Midgley, K. y Holcomb, P. J. (2007). Masked cross-modal repetition priming: An event-related potential investigation. *Language and Cognitive Processes, 22*, 337–376. doi:10.1080/01690960600652471

Kleve, K. (1994). The Latin Papyri in Herculaneum. In A. Bülow-Jacobsen (Ed.), *Proceedings of the 20th International Congress of Papyrologists* (pp. 382-383). Copenhagen: Museum Tusculanum Press.

Knobel, M., Finkbeiner, M. y Caramazza, A. (2008). The many places of frequency: Evidence for a novel locus of the lexical frequency effect in word production. *Cognitive Neuropsychology, 25*, 256–286. doi:10.1080/02643290701502425.

Krammer, V. (2006). Phishing Defense against IDN Address Spoofing Attacks. In *Proceedings of the 4th Annual Privacy Security Trust Conference 2006* (PST 2006) (pp. 275–284). New York: ACM Press. doi:10.1145/1501434.1501473.

Ktori, M. y Pitchford, N. J. (2008). Effect of orthographic transparency on letter position encoding: A comparison of Greek and English monoscriptal and biscriptal readers. *Language and Cognitive Processes, 23*, 258–281. doi:10.1080/01690960701536797

Kuznetsova, A., Brockhoff, P. B. y Christensen, R. H. B. (2016). *lmerTest: Tests for random and fixed effects for linear mixed effect models (lmer objects of lme4 package)*: R package version 2.0-33. Retrieved from http://CRAN.R-project.org/package=lmerTest

LaBerge, D. y Samuels, S. J. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6*, 293–323. doi:10.1016/0010-0285(74)90015-2

Laszlo, S. y Federmeier, K. D. (2014). Never seem to find the time: evaluating the physiological time course of visual word recognition with regression analysis of single-item event-related potentials. *Language, Cognition and Neuroscience, 29*, 642–661. doi:10.1080/01690965.2013.866259

Lederberg, A. R., Schick, B. y Spencer, P. E. (2013). Language and literacy development of deaf and hard-of-hearing children: successes and challenges. *Developmental Psychology, 49*, 15–30.

Lee, C. H. y Taft, M. (2009). Are onsets and codas important in processing letter position? A comparison of TL effects in English and Korean. *Journal of Memory and Language, 60*, 530–542. doi:10.1016/j.jml.2009.01.002

Legge, G. E., Madison, C. M. y Mansfield, J. S. (1999). Measuring braille reading speed with the MNREAD test. *Visual Impairment Research*, *1*, 131–145. doi:10.1076/vimr.1.3.131.4438

Lien, M.-C., Allen, P. y Martin, N. (2014). Processing visual words with numbers: Electrophysiological evidence for semantic activation. *Psychonomic Bulletin and Review, 21*, 1056–1066. doi:10.3758/s13423-014-0581-x

Logan, G. D. (1996). The CODE theory of visual attention: An integration of space-based and object-based attention. *Psychological Review, 103*, 603–649. doi:10.1037/0033-295x.103.4.603

Lopez-Calderon, J. y Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. *Frontiers in Human Neuroscience, 8*, 213. doi:10.3389/fnhum.2014.00213

Lupker, S. J., Perea, M. y Davis, C. J. (2008). Transposed-letter effects: Consonants, vowels and letter frequency. *Language and Cognitive Processes, 23*, 93–116. doi:10.1080/01690960701579714

Madec, S., Rey, A., Dufau, S., Klein, M. y Grainger, J. (2012). The time course of visual letter perception. *Journal of Cognitive Neuroscience, 24*, 1645–1655. doi: 10.1162/jocn_a_00178

Marcet, A. y Perea, M. (2017a). ¿Comprarías ropa de DOLCE & BANANA? Similitud visual y percepción de marcas. *Ciencia Cognitiva, 11*:3, 67–70.

Marcet, A. y Perea, M. (2017b). ¿Pueden los juegos mejorar la habilidad lectora? *Ciencia Cognitiva, 11*, 26–29.

Marcet, A. y Perea, M. (2017c). Is nevtral NEUTRAL? Visual similarity effects in the early phases of written-word recognition. *Psychonomic Bulletin and Review*. doi:10.3758/s13423-016-1180-9

Marcet, A. y Perea, M. (2018a). Can I order a burger at rnacdonalds.com? Visual similarity effects of multi-letter combinations at the early stages of word recognition. Journal of Experimental Psychology: Learning, Memory, & Cognition, 44, 699–706. doi:10.1037/xlm0000477

Marcet, A. y Perea, M. (2018b). Visual letter similarity effects during sentence reading: Evidence from the boundary technique Bajo revision en la revista *Acta Psychologica*.

Marcet, A., Jiménez, M. y Perea, M. (2016). Why braille reading is important and how to study it. *Culture and Education, 28*, 811–825. doi:10.1080/11356405.2016.1230295

Marcet, A., Perea, M., Baciero, A. y Gomez, A. (2018). Can letter position encoding be modified by visual perceptual elements? *Quarterly Journal of Experimental Psychology*. doi: 10.1177/1747021818789876

Marcet, A., Vergara-Martínez, M. y Perea, M. (2016). Buscando las claves de la lectura en personas sordas. *Ciencia Cognitiva, 10:2*, 36–39.

Massol, S., Duñabeitia, J. A., Carreiras, M. y Grainger J. (2013). Evidence for letter-specific position coding mechanisms. *PLOS ONE, 8*(7), e68460. doi:10.1371/journal.pone.0068

Mayall, K. y Humphreys, G. W. (1996). Case mixing and the task-sensitive disruption of lexical processing. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*, 278–294. doi:10.1037/0278-7393.22.2.278.

McClelland, J. L. y Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88*, 375–407. doi:10.1037/0033-295x.88.5.375

McClelland, J. L., Mirman, D., Bolger, D. J. y Khaitan, P. (2014). Interactive activation and mutual constraint satisfaction in perception and cognition. *Cognitive Science, 38*, 1139–1189. doi:10.1111/cogs.12146

McConkie, G. W. y Zola, D. (1979). Is visual information integrated across successive fixations in reading? *Perception & Psychophysics, 25*, 221–224. doi:10.3758/bf03202990

Millar, S. (1997). *Reading by touch*. Nueva York: Routledge.

Molinaro, N., Duñabeitia, J. A., Marìn-Gutiérrez, A. y Carreiras, M. (2010). From numbers to letters: Feedback regularization in visual word recognition. *Neuropsychologia, 48*, 1343–1355. doi:10.1016/j.neuropsychologia.2009.12.037

Moreno-Fernández, M. M., Blanco, F., Garaizar, P. y Matute, H. (2017). Fishing for phishers. Improving Internet users' sensitivity to visual deception cues to prevent electronic fraud. *Computers in Human Behavior, 69*, 421–436,

Mousty, P. y Bertelson, P. (1985). A study of braille reading, 1: Reading speed as a function of hand usage and context. *Quarterly Journal of Experimental Psychology*, *37A*, 217–233. doi:10.1080/14640748508400931

Mueller, S. T. y Weidemann, C. T. (2012). Alphabetic letter identification: Effects of perceivability, similarity, and bias. *Acta Psychologica, 139*, 19–37. doi:10.1016/j.actpsy.2011.09.014

Neely, P. M. (1977). Implementation independent arithmetic: Speculation for discussion. *Software: Practice and Experience, 7*, 461–468. doi:10.1002/spe.4380070404

New, B. y Grainger, J. (2011). On letter frequency effects. *Acta Psychologica, 138*, 322–328. doi:10.1016/j.actpsy.2011.07.001

New, B., Araujo, V. y Nazzi, T. (2008). Differential processing of consonants and vowels in lexical access through reading. *Psychological Science, 19*, 1223–1227. doi:10.1111/j.1467-9280.2008.02228.x

Noblet, A., Ridelaire, H. y Sylin, G. (1985). Equipment for the study of operating processes in braille Reading. *Behavior Research Methods, Instruments and Computers*, *17*, 107–111. doi:10.3758/BF03200904

Norris, D. (2006). The Bayesian reader: Explaining word recognition as an optimal Bayesian decision process. *Psychological Review, 113*, 327–357. doi:10.1037/0033-295x.113.2.327

Norris, D. y Kinoshita, S. (2012). Reading through a noisy channel: Why there's nothing special about the perception of orthography. *Psychological Review, 119*, 517–545. doi:10.1037/a0028450

Norris, D., Kinoshita, S. y van Casteren, M. (2010). A stimulus sampling theory of letter identity and order. *Journal of Memory and Language, 62*, 254–271. doi:10.1016/j.jml.2009.11.002

O'Connor, R. E. y Forster, K. I. (1981). Criterion bias and search sequence bias in word recognition. *Memory & Cognition, 9,* 78–92. doi:10.3758/bf03196953

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 97–113. doi:10.1016/0028-3932(71)90067-4

Paap, K. R., Newsome, S. L. y Noel, R. W. (1984). Word shape's in poor shape for the race to the lexicon. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 413–428. doi:10.1037/0096-1523.10.3.413

Pagán, A., Paterson, K. B., Blythe, H. I. y Liversedge, S. P. (2015). An inhibitory influence of transposed-letter neighbors on eye movements during reading. *Psychonomic Bulletin & Review, 23*, 278–284. doi:10.3758/s13423-015-0869-5

Pammer, K. (2014). Temporal sampling in vision and the implications for dyslexia. *Frontiers in Human Neuroscience, 7*. doi:10.3389/fnhum.2013.00933

Paterson, K. B., Read, J., McGowan, V. A. y Jordan, T. R. (2014). Children and adults both see "pirates" in "parties": Letter-position effects for developing readers and skilled adult readers. *Developmental Science, 18*, 335–343. doi:10.1111/desc.12222

Pelli, D. G., Majaj, N. J., Raizman, N., Christian, C. J., Kim, E. y Palomares, M. C. (2009). Grouping in object recognition: The role of a Gestalt law in letter identification. *Cognitive Neuropsychology, 26*, 36–49. doi:10.1080/13546800802550134

Perea, M. y Acha, J. (2009). Space information is important for reading. *Vision Research, 49*, 1994–2000. doi:10.1016/j.visres.2009.05.009

Perea, M. y Gomez, P. (2012a). Increasing interletter spacing facilitates encoding of words. *Psychonomic Bulletin and Review, 19*, 332–338. doi:10.3758/s13423-011-0214-6

Perea, M. y Gomez, P. (2012b). Subtle increases in interletter spacing facilitate the encoding of words during normal reading. *PLoS ONE 7*(10): e47568. doi:10.1371/journal.pone.0047568

Perea, M. y Lupker, S. J. (2003). Does jugde activate COURT? Transposed-letter similarity effects in masked associative priming. *Memory & Cognition, 31*, 829–841. doi:10.3758/bf03196438

Perea, M. y Lupker, S. J. (2004). Can CANISO activate CASINO? Transposed-letter similarity effects with nonadjacent letter positions. *Journal of Memory and Language, 51*, 231–246. doi:10.1016/j.jml.2004.05.005

Perea, M. y Panadero, V. (2014). Does viotin activate violin more than viocin? On the use of visual cues during visual-word recognition. *Experimental Psychology, 61*, 23-29. doi:10.1027/1618-3169/a000223

Perea, M. y Pérez, E. (2009). Beyond alphabetic orthographies: The role of form and phonology in transposition effects in Katakana. *Language and Cognitive Processes, 24*, 67–88. doi:10.1080/01690960802053924

Perea, M., Abu Mallouh, R. y Carreiras, M. (2010). The search of an input coding scheme: Transposed-letter priming in Arabic. *Psychonomic Bulletin & Review, 17*, 375–380. doi:10.3758/pbr.17.3.375

Perea, M., Abu Mallouh, R., Mohammed, A., Khalifa, B. y Carreiras, M. (2016). Do diacritical marks play a role at the early stages of word recognition in Arabic? *Frontiers in Psychology, 7*, 1255. doi:10.3389/fpsyg.2016.01255

Perea, M., Comesaña, M., Soares, A.P. y Moret-Tatay, C. (2012). On the role of the upper part of words in lexical access: Evidence with masked priming. *Quarterly Journal of Experimental Psychology, 65*, 911–925. doi:10.1080/17470218.2011.636151

Perea, M., Devis, E., Marcet, A. y Gomez, P. (2016). Are go/no-go tasks preferable to two-choice tasks in response time experiments with older adults? *Journal of Cognitive Psychology, 28*, 147–158. doi: 10.1080/20445911.2015.1107077

Perea, M., Duñabeitia, J. A. y Carreiras, M. (2008). R34D1NG W0RD5 W1TH NUMB3R5. *Journal of Experimental Psychology: Human Perception and Performance, 34*, 237–241. doi:10.1037/0096-1523.34.1.237

Perea, M., Duñabeitia, J. A., Pollatsek, A. y Carreiras, M. (2009). Does the brain regularize digits and letters to the same extent? *Quarterly Journal of Experimental Psychology, 62*, 1881–1888. doi:10.1080/17470210902923374

Perea, M., García-Chamorro, C., Centelles, A. y Jiménez, M. (2013). Position coding effects in a 2D scenario: The case of musical notation. *Acta Psychologica, 143*, 292–297. doi:10.1016/j.actpsy.2013.04.014

Perea, M., García-Chamorro, C., Martín-Suesta, M. y Gómez, P. (2012). Letter position coding across modalities: The case of braille readers. *PLoS ONE*, *7*(10), e45636. doi:10.1371/journal.pone.0045636

Perea, M., Giner, L., Marcet, A., & Gomez, P. (2016). Does extra interletter spacing help text reading in skilled adult readers? *Spanish Journal of Psychology, 19*, e26, doi: 10.1017/sjp.2016.28

Perea, M., Jiménez, M. y Gomez, P. (2015). Do young readers have fast access to abstract lexical representations? Evidence from masked priming. *Journal of Experimental Child Psychology, 129*, 140–147.

Perea, M., Jiménez, M. y Gomez, P. (2016). Does location uncertainty in letter position coding emerge because of literacy training? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 42*, 996–1001. doi:10.1037/xlm0000208

Perea, M., Jiménez, M., Martín-Suesta, M. y Gomez, P. (2015). Letter position coding across modalities: Braille and sighted reading of sentences with jumbled words. *Psychonomic Bulletin & Review, 22*, 531–536. doi:10.3758/s13423-014-0680-8

Perea, M., Jiménez, M., Martín-Suesta, M. y Gómez, P. (2015). Letter position coding across modalities: Braille and sighted reading of sentences with jumbled words. *Psychonomic Bulletin and Review*, *22*, 531–536. doi:10.3758/s13423-014-0680-8

Perea, M., Jiménez, M., Talero, F. y López-Cañada, S. (2015). Letter-case information and the identification of brand names. *British Journal of Psychology, 106*, 162–173. doi:10.1111/bjop.12071

Perea, M., Marcet, A. y Fernández-López, M. (2018). Does letter rotation slow down orthographic processing in word recognition? *Psychonomic Bulletin and Review*. doi:10.3758/s13423-017-1428-z

Perea, M., Marcet, A. y Gomez, P. (2015). ¿Por qué poedmos leer fácilmnete las paalbras con lertas trasnpuetsas? *Ciencia Cognitiva, 9*, 49-52.

Perea, M., Marcet, A. y Gomez, P. (2016). How do Scrabble players encode letter position during reading? *Psicothema, 28*, 7–12.

Perea, M., Marcet, A. y Vergara-Martínez, M. (2016a). Does top-down feedback modulate the encoding of orthographic representations during visual-word recognition? *Experimental Psychology, 63*, 278–286. doi:10.1027/1618-3169/a000327

Perea, M., Marcet, A. y Vergara-Martínez, M. (2016b). Phonological-lexical feedback during early abstract encoding: The case of deaf readers. *PLoS ONE, 11*(1), e0146265.

Perea, M., Marcet, A. y Vergara-Martínez, M. (2018). Are you taking the fastest route to the RESTAURANT? The role of the usual letter-case configuration of words in lexical decision. *Experimental Psychology*, 65, 98–104. doi:10.1027/1618-3169/a000391

Perea, M., Marcet, A. y Acha, J. (2018). Does consonant-vowel skeletal structure play a role early in lexical processing? Evidence from masked priming. *Applied Psycholinguistics*, *39*, 169–186. doi:10.1017/S0142716417000431

Perea, M., Marcet, A., Jiménez, M. y Tejero, P. (2015). Los colores como claves perceptivas durante la lectura. *Ciencia Cognitiva, 9:2*, 40–42.

Perea, M., Marcet, A., Uixera, B. y Vergara-Martínez, M. (2017). Eye movements when reading sentences with handwritten words. *Quarterly Journal of Experimental Psychology*. doi:10.1080/17470218.2016.1237531

Perea, M., Marcet, A., Vergara-Martínez, M. y Gomez, P. (2016). On the dissociation of word/nonword repetition effects in lexical decision: An evidence accumulation account. *Frontiers in Psychology, 7*, 215. doi:10.3389/fpsyg.2016.00215

Perea, M., Marcet. A., Lozano, M. y Gomez, P. (2018). Is masked priming modulated by memory load? A test of the automaticity of masked identity priming in lexical decision. *Memory and Cognition*. doi:10.3758/s13421-018-0825-5

Perea, M., Rosa, E. y Marcet, A. (2017). Where is the locus of the lowercase advantage during sentence reading? *Acta Psychologica, 177*, 30–35. doi:10.1016/j.actpsy.2017.04.007

Perea, M., Tejero, P. y Winskel, H. (2015). Can colours be used to segment words when reading? *Acta Psychologica, 159*, 8–13. doi:10.1016/j.actpsy.2015.05.005

Perea, M., Vergara-Martínez, M. y Gomez, P. (2015). Resolving the locus of cAsE aLtErNaTiOn effects in visual word recognition: Evidence from masked priming. *Cognition, 142*, 39–43. doi:10.1016/j.cognition.2015.05.007

Perea, M., Winskel, H. y Ratitamkul, T. (2012). On the flexibility of letter position coding during lexical processing: The case of Thai. *Experimental Psychology, 59*, 68–73. doi:10.1027/1618-3169/a000127

Peressotti, F., Cubelli, R. y Job, R. (2003). On recognizing proper names: The orthographic cue hypothesis. *Cognitive Psychology, 47*, 87–116. doi:10.1016/S0010-0285(03)00004-5

Perry, C., Ziegler, J. C. y Zorzi, M. (2007). Nested incremental modeling in the development of computational theories: The CDP+ model of reading aloud. *Psychological Review, 114*, 273–315. doi:10.1037/0033-295x.114.2.273

Pinna, B. y Deiana, K. (2014). New conditions on the role of color in perceptual organization and an extension to how color influences reading. *Psihologija, 47*, 319–351. doi:10.2298/psi1403319p

Pollatsek, A. y Well, A. D. (1995). On the use of counterbalanced designs in cognitive research: A suggestion for a better and more powerful analysis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 785–794. doi:10.1037/0278-7393.21.3.785

Pollatsek, A., Lesch, M., Morris, R. K. y Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word identification and reading. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 148–162. doi:10.1037/0096-1523.18.1.148

Prinzmetal, W., Hoffman, H. y Vest, K. (1991). Automatic processes in word perception: An analysis from illusory conjunctions. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 902–923. doi:10.1037/0096-1523.17.4.902

Prinzmetal, W., Treiman, R. y Rho, S. H. (1986). How to see a reading unit. *Journal of Memory and Language, 25*, 461–475. doi:10.1016/0749-596x(86)90038-0

Protzner, A. B., Hargreaves, I. S., Campbell, J. A., Myers-Stewart, K., van Hees, S., Goodyear, B. G., … y Pexman, P. M. (2016). This is your brain on Scrabble: Neural correlates of visual word recognition in competitive Scrabble players as measured during task and resting-state. *Cortex, 75*, 204–219.

Pylkkänen, L. y Okano, K. (2010). The nature of abstract orthographic codes: Evidence from masked priming and magnetoencephalography. *PloS ONE, 5*(5), e10793.

Ratcliff, R. (1978). A theory of memory retrieval. *Psychological Review, 85*, 59–108. doi:10.1037/0033-295x.85.2.59

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*, 65–81. doi:10.1016/0010-0285(75)90005-5

Rayner, K., McConkie, G. W. y Ehrlich, S. (1978). Eye movements and integrating information across fixations. *Journal of Experimental Psychology: Human Perception and Performance, 4*, 529–544. doi:10.1037/0096-1523.4.4.529

Rayner, K., McConkie, G. W. y Zola, D. (1980). Integrating information across eye movements. *Cognitive Psychology, 12*, 206–226. doi:10.1016/0010-0285(80)90009-2

Rayner, K., Pollatsek, A., Ashby, J. y Clifton, J. C. (2012). *Psychology of reading*. New York: Psychology Press.

Rayner, K., Well, A. D., Pollatsek, A. y Bertera, J. H. (1982). The availability of useful information to the right of fixation in reading. *Perception & Psychophysics, 31*, 537–550. doi:10.3758/bf03204186

Real Academia Española. (2014). *Diccionario de la lengua española* (23ª Ed.). Madrid, España: Autor.

Reich, L., Szwed, M., Cohen, L. y Amedi, A. (2011). A ventral visual stream reading center independent of visual experience. *Current Biology*, *21*, 363–368. doi:10.1016/j. cub.2011.01.040

Reichle, E. D. (2015, August). *Über-Reader: Computational Modeling of Reading: The "Whole Burrito"*. Paper presented at the 18th European Conference on Eye Movements, Vienna, Austria.

Reichle, E. D., Pollatsek, A., Fisher, D. L. y Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review*, *105*, 125–157. doi:10.1037/ 0033-295X.105.1.125

Reichle, E. D., Rayner, K. y Pollatsek, A. (2003). The E-Z Reader model of eye-movement control in reading: Comparisons to other models. *Behavioral and Brain Sciences, 26,* 445–476. doi:10.1017/s0140525x03000104

Reingold, E. M., Yang, J. y Rayner, K. (2010). The time course of word frequency and case alternation effects on fixation times in reading: Evidence for lexical control of eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 1677–1683. doi:10.1037/a0019959.

Roldán, M., Marcet, A. y Perea, M. (2018). Is there a cost at encoding words with joined letters during visual word recognition? *Psicológica. 40*, 138–150. doi:10.2478/psicolj-2018-0012

Rosa, E., Perea, M. y Enneson, P. (2016). The role of letter features in visual-word recognition: Evidence from a delayed segment technique. *Acta Psychologica*, *169*, 133–142. doi:10.1016/j.actpsy.2016.05.016

Rumelhart, D. E. y McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: II. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review, 89*, 60–94. doi:10.1037/0033-295x.89.1.60

Rumelhart, D. E. y Siple, P. (1974). Process of recognizing tachistoscopically presented words. *Psychological Review, 81*, 99–118. doi:10.1037/h0036117

Ryles, R. (1996). The impact of braille reading skills on employment, income, education, and reading habits. *Journal of Visual Impairment and Blindness*, *90*, 219–226

Schubert, T. M. (2017). Why are digits easier to identify than letters? *Neuropsychologia, 95*, 136–155. doi:10.1016/j.neuropsychologia.2016.12.016

Segui, J. y Grainger, J. (1990). Priming word recognition with orthographic neighbors: Effects of relative prime-target frequency*. Journal of Experimental Psychology: Human Perception and Performance, 16*, 65–76. doi:10.1037/0096-1523.16.1.65

Seymour, P. H. y Jack, M. V. (1978). Effects of visual familiarity on "same" and "different" decision processes. *Quarterly Journal of Experimental Psychology, 30*, 455–469. doi:10.1080/ 00335557843000052

Silvia, P. J., Jones, H. C., Kelly, C. S. y Zibaie, A. (2011). Masked first name priming increases effort-related cardiovascular reactivity. *International Journal of Psychophysiology, 80*, 210–216. doi:10.1016/j.ijpsycho.2011.03.009

Simpson, I. C., Mousikou, P., Montoya, J. M. y Defior, S. (2012). A letter visual-similarity matrix for Latin-based alphabets. *Behavior Research Methods, 45*, 431–439. doi:10.3758/s13428-012-0271-4

Slattery, T. J. (2009). Word misperception, the neighbor frequency effect, and the role of sentence context: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance, 35*, 1969–1975. doi:10.1037/a0016894

Slattery, T. J., Angele, B. y Rayner, K. (2011). Eye movements and display change detection during reading. *Journal of Experimental Psychology: Human Perception and Performance, 37*, 1924–1938. doi:10.1037/a0024322

Smith, R. (2007). An overview of the Tesseract OCR engine. In *Proceedings of the Document Analysis and Recognition, IEEE* (Vol. 2, pp. 629-633).

Staub, A., White, S. J., Drieghe, D., Hollway, E. C. y Rayner, K. (2010). Distributional effects of word frequency on eye fixation durations. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 1280–1293. doi:10.1037/a0016896

Stevens, M. A. y Brysbaert, M. (2016, January 27). *Power in language research*. Retrieved from osf.io/d2cye

Tan, L. C. y Yap, M. J. (2016). Are individual differences in masked repetition and semantic priming reliable? *Visual Cognition, 24*, 182–200. doi:10.1080/13506285.2016.1214201

Tinker, M. A. y Paterson, D. G. (1928). Influence of type form on speed of reading. *Journal of Applied Psychology, 12*, 359–368. doi:10.1037/h0073699.

Treisman, A. M. y Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136. doi:10.1016/0010-0285(80)90005-5

van Casteren, M. y Davis, M. H. (2007). Match: A program to assist in matching the conditions of factorial experiments. *Behavior Research Methods, 39*, 973–978. doi:10.3758/bf03192992

Van Horen, F. y Pieters, R. (2012). When high-similarity copycats lose and moderate-similarity copycats gain: The impact of comparative evaluation. *Journal of Marketing Research, 49*, 83–91.

Van Orden, G. C. y Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 1269–1291. doi:10.1037/0096-1523.20.6.1269

Velan, H. y Frost, R. (2011). Words with and without internal structure: What determines the nature of orthographic and morphological processing? *Cognition, 118*, 141–156. doi:10.1016/j.cognition.2010.11.013

Vergara-Martínez, M., Gomez, P., Jiménez, M. y Perea, M. (2015). Lexical enhancement during prime-target integration: ERP evidence from matched-case identity priming. *Cognitive, Affective, and Behavioral Neuroscience, 15*, 492–504.

Vergara-Martínez, M., Perea, M., Gomez, P. y Swaab, T. Y. (2013). ERP correlates of letter identity and letter position are modulated by lexical frequency. *Brain and Language, 125*, 11–27. doi:10.1016/j.bandl.2012.12.009

Von Ahn, L., Maurer, B., McMillen, C., Abraham, D. y Blum, M. (2008). reCAPTCHA: Human-Based Character Recognition via Web Security Measures. *Science, 321*, 1465–1468. doi:10.1126/science.1160379

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8*, 221–243. doi:10.3758/bf03196158

Wiley, R. W., Wilson, C. y Rapp, B. (2016). The effects of alphabet and expertise on letter perception. *Journal of Experimental Psychology: Human Perception and Performance, 42*, 1186–1203. doi:10.1037/xhp0000213

Winskel, H. y Perea, M. (2013). Consonant/vowel asymmetries in letter position coding during normal reading: Evidence from parafoveal previews in Thai. *Journal of Cognitive Psychology, 25*, 119–130. doi:10.1080/20445911.2012.75307

Wolfe, J. M. (2012). The binding problem lives on: comment on Di Lollo. *Trends in Cognitive Sciences, 16*, 307–308. doi:10.1016/j.tics.2012.04.013

Yakup, M., Abliz, W., Sereno, J. y Perea, M. (2015). Extending models of visual-word recognition to semicursive scripts: Evidence from masked priming in Uyghur. *Journal of Experimental Psychology: Human Perception and Performance, 41*, 1553–1562. doi:10.1037/xhp0000143

Ziegler, J. C., Hannagan, T., Dufau, S., Montant, M., Fagot, J. y Grainger, J. (2013). Transposed-letter effects reveal orthographic processing in baboons. *Psychological Science, 24*, 1609–1611. doi:10.1177/0956797612474322