TESIS DOCTORAL

# Procesos implícitos de aprendizaje y su papel en la adquisición del lenguaje escrito

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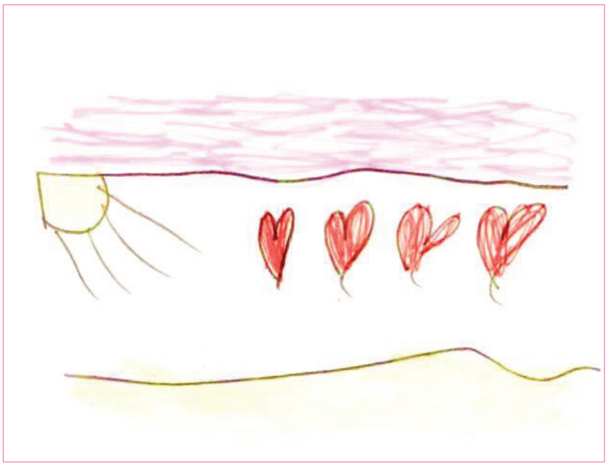

## Dedicatoria

A mi mamá Rosa y mi papá Vicente

A mis abuelas Adela y Vicenta y mis abuelos Domingo y José

Por los esfuerzos que hicieron por su familia, por todo el amor que me bridaron y los valores que me enseñaron.

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*Questa tesi dottorale è anche frutto del vostro sforzo!*

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# Publicaciones de la Tesis

Nigro, L., Jiménez-Fernández, G., Simpson, I. C., & Defior, S. (2015). Implicit learning of written regularities and its relationship to literacy acquisition in a shallow orthography. *Journal of Psycholinguistic Research*, *44*(5), 571-585. doi:10.1007/s10936-014-9303-9

Nigro, L., Jiménez-Fernández, G., Simpson, I. C., & Defior, S. (2016). Implicit learning of non-linguistic and linguistic regularities in children with dyslexia. *Annals of Dyslexia*, *66*, 206-218. doi: 10.1007/s11881-015-0116-9

Nigro, L., Jiménez-Fernández, G., Defior, S., & Simpson, I. C. (en revisión). Implicit learning of complex orthographic regularities in children with dyslexia. *Journal of Experimental Child Psychology.*

Cada estudio de esta tesis se corresponde parcialmente con los artículos aquí listados, por lo que puede haber algún solapamiento entre las introducciones y discusiones de los mismos.

# Index

# Resumen en Español

Si bien en sociedades alfabetizadas las personas están naturalmente expuestas al lenguaje escrito, usualmente es al inicio de la educación primaria cuando comienza su instrucción formal. En etapas iniciales, la escuela se centra en la enseñanza de las reglas de conversión entre grafemas y fonemas, y así los estudiantes comienzan a leer convirtiendo las letras en sonidos. Aunque aplicar estas reglas de conversión fonológica constituye una estrategia muy efectiva en los sistemas alfabéticos, existen correspondencias ambiguas o inconsistentes en las que un fonema se asocia a más de un grafema, y vice versa. Para resolver estas inconsistencias, es necesario aplicar otras fuentes de conocimiento, tales como conocimiento semántico (significado de palabras), morfológico (unidades sub-léxicas de significado), grafotáctico (posición y combinación permisible o frecuente de letras) o léxico (conocimiento específico de la palabra), entre otros. El incremento de la práctica lectora permite la adquisición de mayor conocimiento sobre las consistencias fonológicas, así como de las inconsistencias del sistema escrito. Estas inconsistencias rara vez son azarosas, sino que a los patrones irregulares suele subyacer una estructura y es mediante la exposición repetida que los individuos pueden procesar esta estructura y almacenarla para su uso posterior (Seidenberg y McClelland, 1989). De esta manera, se considera que la adquisición de patrones ortográficos complejos requiere la contribución de procesos implícitos de aprendizaje (Steffler, 2004).

El objetivo de la presente tesis doctoral consiste en estudiar la contribución de los mecanismos implícitos de aprendizaje al desarrollo de la lectoescritura, así como su relación con diferentes perfiles lectores. Para ello, hemos investigado el aprendizaje implícito de reglas lingüísticas y no lingüísticas en estudiantes de educación primaria con desarrollo típico y con dislexia. Asimismo, hemos explorado la posible relación entre las habilidades implícitas y las habilidades de lectura y escritura en español.

**Aprendizaje implícito y el desarrollo típico de la lectura**

La definición clásica de *aprendizaje implícito* hace referencia a un proceso que acontece sin consciencia o esfuerzo, mediante el cual se adquiere información estructurada a través de la exposición repetida (Reber, 1967). Este proceso excede la mera memorización en tanto el conocimiento resultante no sólo puede ser replicado, sino también transferido a situaciones nuevas (Reber, 1993; Seidenberg, 2007; Steffler, 2001).

Varios estudios han demostrado que el aprendizaje implícito contribuye al desarrollo de la lectoescritura en diferentes idiomas. Por ejemplo, se halló que estudiantes franceses de primero a cuarto curso eran sensibles a la frecuencia de estructuras con consonantes dobles (como *mm* o *ss*), pudiendo distinguir entre estructuras más o menos frecuentes (Pacton, Perruchet, Fayol, y Cleeremans, 2001). Pacton y colegas (2005) también hallaron que estudiantes de primero a quinto curso eran sensibles a las posiciones que ocupan las consonantes dobles, en tanto podían reconocer qué estructuras eran posibles al inicio o al final de una palabra. Evidencia similar fue encontrada en inglés, dado que se halló que los errores en la escritura espontánea de estudiantes de primer curso demostraba conocimiento implícito acerca de las consonantes dobles, en tanto los niños sólo duplicaban consonantes permisibles (Treiman, 1993). En español, una ortografía más transparente, se halló que estudiantes de primaria eran sensibles a la frecuencia en que ciertos bigramas ocurren (como *bu* versus *vu*) y que este tipo de conocimiento sería aplicado para resolver casos de inconsistencia fonológica (Carrillo y Alegría, 2014).

Asimismo, algunos autores han encontrado que la habilidad implícita para aprender regularidades mediante exposición está relacionada con la habilidad lectora de niños y adultos en inglés. Los resultados de dos estudios mostraron que mayores puntuaciones en tests de lectura correlacionaban con mayores puntuaciones en tareas de aprendizaje implícito (Arciuli y Simpson, 2012; Sperling, Lu, y Manis, 2004). Esta relación, no obstante, no ha sido explorada en una ortografía transparente en la que las conversiones fonológicas constituyen una estrategia muy efectiva para leer y escribir (Defior yAlegría, 2005).

Si estrategias implícitas son aplicadas por buenos lectores, también es importante investigar si los procesos implícitos también operan en casos de dificultades lectoras como la dislexia (Gombert, 2003).

**Aprendizaje Implícito en Personas con Dislexia**

La dislexia evolutiva consiste en una dificultad específica de aprendizaje causada por factores neurológicos. Se caracteriza por persistentes dificultades para reconocer palabras escritas de manera fluida, pobres habilidades de escritura y de decodificación, a pesar de haber recibido enseñanza adecuada y de poseer habilidades intelectuales y sensoriales preservadas (Lyon, Shaywitz, y Shaywitz, 2003).

Diversas teorías se han desarrollado para explicar las dificultades que experimentan las personas con dislexia, tales como la teoría del déficit fonológico (Snowling y Stackhouse, 2006), o las teorías de déficit perceptivo de tipo auditivo (Gosmwami 2011) y visual (Lassus-Sangosse et al., 2008). Una línea reciente de investigación también contempla la posible existencia de un déficit en el aprendizaje implícito (Folia et al., 2008; Vicari, Marotta, Menghini, Molinari, y Petrosini, 2003), es decir, en la capacidad de adquirir regularidades sin esfuerzo por medio de la experiencia. Este déficit podría explicar por qué las personas con dislexia poseen dificultades para automatizar patrones ortográficos a pesar de una enseñanza adecuada y de repetida exposición al lenguaje escrito. La hipótesis del déficit en aprendizaje implícito ha sido explorada principalmente a través de dos paradigmas: el aprendizaje de secuencias y el aprendizaje de gramáticas artificiales.

En una tarea de aprendizaje de secuencias (Nissen y Bullemer, 1987), los participantes deben indicar la posición o la aparición de un determinado estímulo target lo más rápido posible. Aunque no se informa a los participantes, los estímulos aparecen en función de una secuencia predeterminada que se repite en varios bloques. A medida que se suceden los bloques y se ejecuta la tarea, los participantes adquieren mayor sensibilidad a la secuencia; esto se evidencia por el hecho de que los tiempos de reacción tienden a disminuir con la consecución de bloques, pero aumentan notablemente con la introducción de un bloque aleatorio. A través de este paradigma, varios autores hallaron que niños y adultos con dislexia tienen dificultades para aprender secuencias, dado que sus tiempos de reacción no registraron alteraciones con la introducción de secuencias aleatorias (Du y Kelly, 2013; Howard, Howard, Japikse, y Eden, 2006; Jiménez-Fernández, Vaquero, Jiménez, y Defior, 2011; Stoodley, Ray, Jack, y Stein et al., 2008; Vicari et al., 2003). No obstante, otros estudios reportaron evidencia de aprendizaje implícito preservado (Kelly et al., 2002; Menghini et al., 2010; Roodenrys y Dunn, 2008). Los resultados inconsistentes posiblemente se deban a diferencias metodológicas, así como lo ha sugerido un meta-análisis con 14 estudios (Lum, Ullman, y Conti-Ramsden, 2013). Aunque los autores hallaron una tendencia a favor del déficit de aprendizaje implícito, un moderado nivel de heterogeneidad en los resultados se debía a la edad de los participantes y a las demandas de las tareas experimentales. Por otro lado, es importante aclarar que las tareas de secuencias contienen un componente motor y por tanto es posible que evalúen no sólo el aprendizaje de las secuencias visuales, sino también aprendizaje viso-motor (Goschke, 1998).

En las tareas de gramáticas artificiales (Reber, 1967) un esquema establece reglas de consecución entre elementos, y de esta manera se generan cadenas permisibles o gramaticales. Esta tarea generalmente contiene una fase de exposición en la cual los participantes son expuestos a ejemplares gramaticales, sin saber sobre la existencia de reglas. Posteriormente, se evalúa el aprendizaje implícito en una fase de prueba en la que los participantes deben discriminar entre cadenas gramaticales y no gramaticales. Utilizando figuras geométricas, Pothos y Kirk (2004) evaluaron el aprendizaje implícito de adultos con y sin problemas lectores, y hallaron un patrón inusual de resultados: el grupo con dificultades lectoras mostró mayor índice de aprendizaje que el grupo control. No obstante, un estudio similar con niños contrarió estos resultados dado que los niños con dislexia (a diferencia de los niños con desarrollo típico) no lograron aprender las reglas de la gramática artificial (Pavlidou, Williams, y Kelly, 2009); este último resultado también fue replicado en estudios posteriores (Pavlidou, Kelly, y Williams, 2010; Pavlidou y Williams, 2014). En otro estudio reciente con personas adultas, se evaluó la adquisición implícita de reglas con cadenas de letras y, efectivamente, se halló que el grupo con dislexia no podía aprender como lo hacía el grupo control (Kahta y Schiff, 2016).

Si bien los estudios con secuencias y gramáticas artificiales señalan una tendencia a favor de la hipótesis del déficit en aprendizaje implícito, factores relacionados con la edad de los participantes y las características de las tareas parecen explicar las diferencias entre los resultados. Por otro lado, la mayor evidencia provista por estos estudios se centró en el aprendizaje implícito dentro de un contexto puramente visual, dado que se excluyó la información escrita en las tareas. No obstante, si la dislexia es causada por factores especialmente relacionados con el procesamiento de información ortográfica, es necesario explorar las habilidades implícitas en un contexto lingüístico.

## Objetivos y Diseño

La presente tesis tiene el objetivo de investigar los procesos implícitos de aprendizaje y la adquisición de regularidades ortográficas en niños y niñas españoles con desarrollo típico y con dislexia, mediantes tres estudios. Aunque estudios comportamentales han demostrado que los estudiantes de educación primaria adquieren conocimiento ortográfico sin enseñanza previa (Pacton et al., 2001; Pacton et al., 2005; Treiman, 1993; Treiman y Cassar, 1995), existe escasa literatura acerca de *cómo* se adquiere este conocimiento.

### *Estudio 1*

En el estudio 1, el objetivo inicial fue diseñar una tarea ecológica de aprendizaje implícito, capaz de inducir y medir la adquisición incidental de reglas ortográficas en niños españoles con desarrollo típico. Para ello, diseñamos una tarea en la que se introdujeron reglas grafotácticas de posición en estímulos con estructura $C_1VC_2V$ (consonante1-vocalconsonante2-vocal), dado que esta estructura es muy frecuente en palabras del español. Las reglas de posición establecían que sólo tres consonantes podrían emplearse en la posición $C_1$, y sólo otras tres consonantes eran permisibles en $C_2$. Tras una breve exposición a ejemplares, se introdujo una tarea de decisión forzada en la que los participantes debían distinguir entre estímulos legales (o sea, consistentes con las reglas) e ilegales. La mitad de los estímulos legales habían sido previamente vistos en la fase de exposición, mientras que la otra mitad eran estímulos nuevos. De esta manera, se evaluó la capacidad de reconocer estímulos legales ya vistos, así como la capacidad de transferir las reglas a nuevas instancias.

Asimismo, exploramos la posible relación entre las habilidades de aprendizaje implícito, las habilidades cognitivas (inteligencia, memoria y atención) y las habilidades de lectura y escritura (en palabras y pseudopalabras) en español. Si bien estudios en inglés hallaron correlaciones positivas entre habilidades de lectura y el rendimiento en tareas de aprendizaje implícito (Arciuli y Simpson, 2012; Sperling et al., 2004), no tenemos conocimiento de estudios similares en ortografías transparentes. En español, existen pocas inconsistencias en la dirección grafema-fonema, por lo que la decodificación letra por letra es una estrategia efectiva en la mayoría de los casos. En consecuencia, en el Estudio 1 no esperábamos encontrar una correlación fuerte entre las habilidades de aprendizaje implícito y la lectura. Por otro lado, el español contiene más casos de inconsistencia en la dirección fonema-grafema, en las que la aplicación de otro tipo de regularidades ortográficas (como grafotácticas y morfológicas) pueden ser relevantes para escribir correctamente. En consecuencia, esperábamos encontrar una relación entre el aprendizaje implícito de regularidades ortográficas y la escritura de palabras inconsistentes.

Los resultados indicaron que los participantes fueron capaces de reconocer tanto estímulos legales vistos como nuevos por encima del azar, lo cual sugiere que el aprendizaje implícito de las reglas tuvo lugar. Esto demuestra que procesos implícitos contribuyen a la adquisición de reglas ortográficas en español y que son lo suficientemente robustos como para suscitar aprendizaje tras una breve exposición, en consistencia con hallazgos en inglés (Samara y Caravolas, 2014). Los análisis correlacionales mostraron que las habilidades de aprendizaje implícito no estaban relacionadas con las habilidades cognitivas de inteligencia, memoria u atención, sugiriendo que se trata de procesos independientes. En tanto a las relaciones con lectura y escritura, hallamos una clara correlación entre la habilidad de reconocer ítems vistos y la escritura de palabras inconsistentes. Esta relación posiblemente pueda ser explicada mediante un proceso cognitivo común de memoria implícita, ya que ambas tareas requieren la aplicación de conocimiento acerca de ítems previamente vistos. Por tanto, la capacidad para memorizar ítems de manera holística resulta relevante. No obstante, no se observaron correlaciones entre la identificación de estímulos legales nuevos y la escritura de palabras o pseudopalabras (siquiera cuando se esperaba la aplicación de conocimiento grafotáctico o morfológico). Esto sugiere que la habilidad de adquirir y transferir reglas no jugaría un papel en la escritura de regularidades ortográficas en español, o bien podría ser que las tareas de escritura empleadas no fuesen lo suficientemente sensibles para medir el conocimiento de patrones ortográficos complejos en estudiantes de tercer curso. Tampoco se halló una relación entre las medidas de aprendizaje implícito y las de lectura. Si bien estos resultados contrarían evidencia hallada en inglés (Arciuli y Simpson, 2012; Sperling et al., 2004), la falta de correlaciones no fue sorprendente en tanto el español es un sistema transparente. Dado que la decodificación constituye una estrategia muy efectiva para leer, es posible que la adquisición implícita de reglas ortográficas no juegue un papel tan importante como en inglés, donde abundan las inconsistencias. Estas diferencias translingüísticas sugieren que la contribución del aprendizaje implícito a la lectura estaría mediada por el grado de opacidad del sistema escrito.

***Estudio 2***

En el Estudio 2, exploramos la hipótesis del déficit en aprendizaje implícito en dislexia. Para ello, comparamos la capacidad implícita de aprender reglas de posición en estudiantes con desarrollo típico y con dislexia (emparejados en función de edad, género y CI). A su vez, investigamos el impacto del componente lingüístico en el aprendizaje implícito mediante la ejecución de dos experimentos. En el Experimento 1 las reglas de posición se introdujeron en cadenas de figuras abstractas, mientras que en el Experimento 2 se emplearon cadenas de letras. Si los niños con dislexia tienen un déficit en aprendizaje implícito de índole general, se esperaría que el rendimiento en ambas tareas fuese inferior en el grupo con dislexia. Si los niños con dislexia sólo experimentan dificultades en la adquisición de regularidades ortográficas, se esperaría que su rendimiento fuese inferior al del grupo control sólo en la tarea lingüística.

Como era esperable, los análisis intra sujeto mostraron que los participantes con desarrollo típico fueron capaces de aprender las reglas de posición en ambos experimentos, dado que lograron identificar tanto estímulos legales previamente vistos como estímulos nuevos. En cambio, los participantes con dislexia sólo fueron capaces de reconocer estímulos vistos, pero no lograron trasferir las reglas a instancias nuevas en ninguno de los experimentos. Estos resultados son consistentes con los resultados reportados por un estudio de gramáticas artificiales (Pavlidou y Williams, 2014). Sin embargo, a pesar de las diferencias halladas en los análisis intra sujeto, los análisis entre sujetos no arrojaron diferencias significativas entre los grupos en ningún experimento. Dada la ambigüedad de los resultados, es possible que las tareas empleadas no hayan sido lo suficientemente sensibles y, por tanto, sería necesario introducir tareas más demandantes para descubrir un posible déficit de aprendizaje implícito en niños con dislexia.

***Estudio 3***

En el Estudio 3, se realizaron algunas modificaciones a la tarea lingüística previamente utilizada (Estudio 1 y 2), introduciendo reglas contextuales con el propósito de incrementar la dificultad de la tarea. Este tipo de reglas establece relaciones entre dos o tres letras, y se ha demostrado que su procesamiento resulta de especial dificultad para personas con dislexia (Davies, Cuetos, y González-Seijas, 2007; Serrano y Defior, 2008; Serrano y Defior, 2012). A su vez, en el Estudio 3 se exploró la influencia de la complejidad silábica en el aprendizaje implícito, comparando el rendimiento en dos experimentos. En el Experimento 1 las reglas contextuales fueron introducidas en estímulos con estructuras silábicas simples (CVCV), mientras que en el Experimento 2 se introdujeron grupos consonánticos (CCVCV) en tanto estas estructuras representan un desafío para personas con dislexia (Serrano y Defior, 2012). Hipotetizamos que los estudiantes con dislexia no podrían aprender las reglas contextuales mediante exposición tan bien como aquellos con desarrollo típico, y que la introducción de grupos consonánticos afectaría negativamente el aprendizaje en casos de dislexia.

Los resultados demostraron que los participantes con desarrollo típico pudieron adquirir las reglas contextuales al margen de la complejidad silábica de los estímulos. Los participantes con dislexia, en cambio, sólo pudieron adquirir las reglas cuando estaban insertas en estímulos CVCV, pero fueron incapaces de reconocer estímulos nuevos o incluso ya vistos cuando se introdujeron grupos consonánticos. Esto demuestra que la presencia de sílabas complejas perjudica la adquisición de reglas ortográficas en niños con dislexia. Asimismo, se hallaron diferencias significativas entre ambos grupos, lo que brinda apoyo a la hipótesis del déficit de aprendizaje implícito en dislexia (Vicari et al., 2003; Folia et al., 2008). Otro hallazgo de este estudio fue que el rendimiento de los participantes con desarrollo típico fue mayor en los estímulos vistos que en los estímulos nuevos, sugiriendo que los lectores típicos se benefician de la familiaridad de los ítems cuando realizan juicios ortográficos. Los participantes con dislexia, en cambio, no se beneficiaron de este rasgo de familiaridad. Este resultado coincide con resultados hallados en niños alemanes con disgrafia (Ise et al, 2012).

**Conclusiones**

Los resultados de esta tesis agregan evidencia acerca del rol del aprendizaje implícito en el desarrollo de la lectoescritura. En primer lugar, corroboramos que los procesos implícitos son muy potentes y que contribuyen a la adquisición de regularidades ortográficas tanto simples como complejas, incluso tras una breve exposición. Nuestros datos también demostraron que los procesos implícitos tienen un impacto en la escritura de palabras inconsistentes en español, aunque no se evidenciaron relaciones con la escritura de palabras nuevas. Es posible que este último resultado se deba al uso de medidas de escritura no suficientemente sensibles para captar el conocimiento de regularidades ortográficas complejas. Como se anticipó, tampoco se hallaron relaciones entre las habilidades de aprendizaje implícito y de lectura, a diferencia de lo que sugiere la evidencia en inglés (Arciuli y Simpson, 2012; Sperling et al., 2004). En consecuencia, sugerimos que la relación entre los procesos implícitos de aprendizaje y el rendimiento lector podrían estar mediados por el grado de opacidad del sistema escrito. Posiblemente, la adquisición y uso de regularidades complejas tenga mayor impacto en sistemas donde las conversiones fonológicas son más inconsistentes. No obstante, aún deben llevarse a cabo más estudios para dilucidar estas cuestiones empleando tareas diferentes y reuniendo muestras más numerosas, dado que es posible que existan relaciones sutiles que sólo puedan captarse con muestras de gran tamaño.

Si bien se encontró que los niños con dislexia también pudieron aprender reglas ortográficas por exposición, sus habilidades resultaron más débiles en comparación a aquellos con desarrollo típico. Por tanto, estos resultados proveen nueva evidencia a favor de la hipótesis del déficit de aprendizaje implícito en dislexia (Vicari et al., 2003; Folia et al., 2008). Dado que no se observaron diferencias en el aprendizaje de regularidades ortográficas y no ortográficas, nuestros datos sugieren que las dificultades en el grupo con dislexia no se limitan al lenguaje escrito, sino que serían parte de una dificultad más general para adquirir regularidades visuales. Por tanto, estos hallazgos concuerdan con evidencia hallada en el campo visual por otros autores (Jiménez-Fernández et al., 2011; Pavlidou et al., 2009; Stoodley et al., 2008). No obstante, la introducción de estructuras silábicas complejas tuvo un impacto negativo en el aprendizaje implícito, probablemente por las dificultades fonológicas que caracterizan a las personas con dislexia (Snowling y Stackhouse, 2006). Como sugiere el déficit de automatización (Nicolson et al., 2001; Nicolson y Fawcett, 1990), es posible que el esfuerzo para decodificar estructuras complejas haya afectado el cómputo implícito de las reglas ortográficas, resultando en una pobre adquisición de las mismas.

Dada la importancia de los procesos implícitos en el desarrollo de la lectoescritura, creemos que deben llevarse a cabo más estudios en este campo para dilucidar cómo operan estos procesos en diferentes poblaciones y situaciones.

# Introduction

The invention of writing systems is considered a great step in human evolution, as the printed word has significantly extended the limits for communication surpassing barriers such as place and time. The appearance of writing systems not only enabled individuals to keep count of their belongings or send news to distant places, but it also enabled the imprint of personal experiences and thoughts (Mark, 2011). The History began with such written records and as a result we can look back in time and learn –for instance– about the spiritual beliefs of ancient Egyptians or the bright ideas of classic Greek philosophers.

The first identified writing systems consisted of rudimentary pictures used to represent objects, which later evolved to the representation of more complex concepts and ideas. The Chinese system is an example of such logographic writing. Some systems continued their development and logograms were replaced by characters aiming to reproduce the sounds from oral language (Alegría, 1985). In the Japanese Hiragana and Katakana scripts, for instance, these symbols represent syllables. In Western societies, in contrast, individuals use alphabetic systems where letters (graphemes) represent the isolated sounds of speech (phonemes). This phonological strategy is considered highly efficient as a small number of graphemes allows the production of any possible word.

Although individuals in literate societies are naturally exposed to written language, it is mostly in primary school when formal instruction takes place. At early learning phases, the phonological conventions are taught and students start reading by converting letters to sounds. With further reading experience individuals become sensitive to more complex regularities and achieve knowledge about orthographic chunks and words (Bishop, Nation, & Patterson, 2014; Steffler, 2004). After the first two or three years of schooling, most students become fluent readers and academic knowledge mainly relies on written information. Thus, written language is considered an essential tool for learning (Chall & Jacobs, 1983) and difficulties in reading or writing tend to result in academic problems, affecting the individual's self-esteem in many cases. Therefore, the study of literacy acquisition becomes necessary to understand the factors that contribute to literacy development and design effective educational programs.

Research in literacy should not be limited to explicit teaching/learning strategies, but should also consider the contribution of implicit mechanisms in typical literacy acquisition as well as in cases of learning impairment (Gombert, 2003). Whereas implicit mechanisms appear to underpin the learning of complex regularities in typical development (Carrillo & Alegría, 2014; Pacton, Fayol, & Perruchet, 2005; Steffler, 2004), an increasing number of studies suggest that such mechanisms may be deficient in individuals with dyslexia (Jiménez-Fernández, Vaquero, Jiménez, & Defior, 2011; Pavlidou & Williams, 2014; Stoodley, Ray, Jack, & Stein, 2008).

The current doctoral thesis aims to study the contribution of implicit learning mechanisms to the acquisition of orthographic regularities in Spanish and its relationship to different reading profiles. More specifically, we will explore the ability to learn novel orthographic rules by means of mere exposure in children with typical development and in children with developmental dyslexia.

In the following section, a theoretical framework will be introduced to show the importance of implicit mechanisms in reading and spelling acquisition. We will review the most relevant reading models and link them to the concept of implicit learning, as all these models point out that reading strategies improve as a result of experience. We will also include empirical evidence showing how implicit mechanisms contribute to typical literacy development, as well as evidence suggesting that implicit mechanisms are impaired in dyslexia. After the introduction, we will explain the motivation and rationale of our research followed by the three studies which comprise this thesis. In Study 1, a novel learning task was developed to assess the occurrence of implicit orthographic learning in typically-developing children. This study also explored the relationship between such learning and reading/writing skills. In Study 2, the implicit learning of children with typical development and children with dyslexia was compared. This was done by using two implicit learning tasks where positional regularities were embedded in non-linguistic stimuli (strings of abstract shapes) and in linguistic stimuli (strings of letters). In Study 3, the implicit learning of children with and without dyslexia was further explored using linguistic tasks. In these tasks, contextual rules were embedded in letter strings with different levels of orthographic complexity. Results from the three studies will be discussed and integrated in the General Discussion. Finally, the relevance of our findings for future research and educational practices will be discussed in Final Remarks. References from all chapters are contained in a single combined reference list at the end of the thesis; the appendixes are also displayed at the end of the manuscript.

## What is Reading?

Reading is considered a complex process where written word recognition and comprehension take place. Although both processes are essential for efficient reading, comprehension can only be achieved after the correct identification of words, which is considered the *sine qua non* requisite for reading (Share, 1995). Despite its tendency to become automatic with practice, word recognition needs the contribution of multiple cognitive abilities related to attention, perception, language and memory, among others (Defior, Serrano & Gutiérrez, 2015).

Becoming a proficient reader requires the processing and integration of many sources of information. Although applying grapheme-phoneme correspondences constitutes a rather effective strategy in alphabetic languages, there are some ambiguous mappings where one phoneme is associated with several graphemes, or vice versa. The degree of ambiguous grapheme-phoneme mappings in a written system determines its opacity: in transparent languages (like Spanish) these mappings are mainly one-to-one, whereas a significant number of ambiguous mappings are present in opaque or deep languages. To resolve these grapheme-phoneme inconsistencies, the reader needs to apply new sources of knowledge such as:

- Semantics: word meaning, useful to identify words from context and differentiate homophone words (such as *votar* and *botar*).
- Morphology: sub-lexical units of meaning, such as affixes and suffixes.
- Graphotactics: permissible or frequent position and combination of letters.
- Lexical or word-specific knowledge: memorization of words as wholes.
- Prosody: suprasegmental phonological cues that refer to speech rhythm, intonation and stress.

Given the complexity of reading processes, it is not surprising that different theories have emerged to explain how reading occurs. In the following section, we will include the most relevant models of reading. Despite the theoretical differences, all these models suggest that implicit mechanisms foster reading acquisition as a result of experience.

## Models of Reading

Reading models are mainly divided into two categories: developmental and skilled reading models.

### *Developmental Reading Models*

Developmental theories aim to explain how word recognition is gradually attained in young readers. Within these theories, stage models consider that all readers go through well-defined stages till they achieve fluency. In contrast, the continuous models argue that these stages are not so clearly defined and that not all the stages are universal.

***Stage Models.*** According to stage-like models, readers go through different developmental phases until they achieve proficiency. One seminal model of reading was provided by Uta Frith in 1985. The author claimed that literacy acquisition could be explained by three stages where differential reading strategies are applied (see Figure 1). In the first stage (*logographic*), individuals attempt to recognize familiar words as if they were objects; contextual cues are important and the memorization of words occurs without paying attention to the individual letters. In the second stage (*alphabetical),* individuals are introduced to alphabetic conversions and start establishing correspondences between graphemes and phonemes (a process known as *decoding*); the order of letters becomes relevant and individuals are able to decode novel words. In the final stage (*orthographic*), words are analyzed as strings of letters. These orthographic units coincide with morphemes (suffixes, affixes, stem words, etc.) which are stored in memory as a result of reading experience. Frith indicated that individuals can fall back into a previous strategy when one strategy is not available; however, when the orthographic stage is consolidated, Frith claimed that individuals are less likely to apply previous strategies since word recognition becomes a more automatic process.

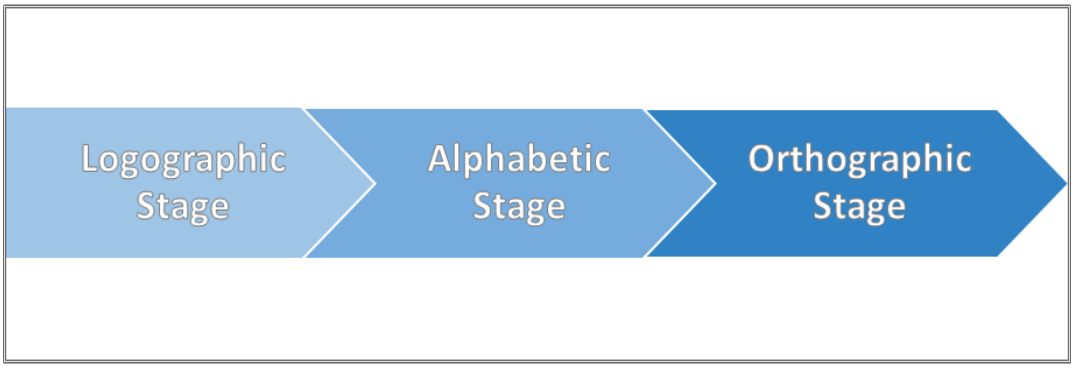



*Figure 1*. Frith's stages of word reading.

Following a similar stage approach, Ehri (1998; 2005) identified five differential reading stages ranging from a pre-alphabetic phase to an automatic alphabetic phase (see Figure 2). Whereas in a *pre-alphabetic phase* individuals can only recognize words as objects, the progressive acquisition of alphabetic knowledge allows the conversion of letters to sounds. A young learner starts by decoding a few letters (*partial alphabetic stage)* until all the letters of the alphabet are mastered *(full alphabetic phase*). In a *consolidated alphabetic phase*, reading experience fosters the storage of letter chunks in memory; this enables word recognition, enhancing decoding speed and sight reading (fast recognition of written words as wholes). Finally, proficiency is achieved as reading becomes an automatic process (*automatic phase*).

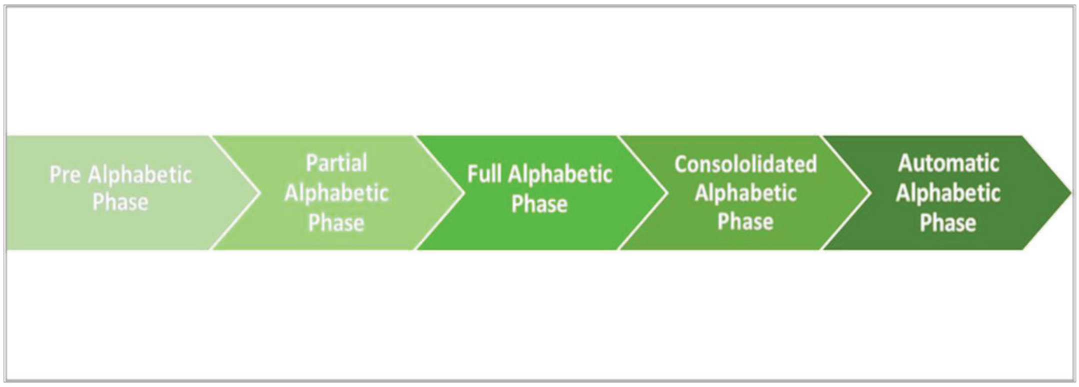



*Figure 2*. Ehri's stages of word reading.

Despite some subtle differences, both Frith's and Ehri's models suggest that the learning of explicit phonological mappings is essential to initiate reading in alphabetical systems. After mastering letter-sound conversions, individuals can move on to a further stage where orthographic knowledge is acquired not only by explicit strategies, but also in an implicit manner through experience. Repeated exposure enables the storage of letter chunks and words in the mental lexicon, which enables the rapid recognition of orthographic units.

***Models of Continuous Development.*** Although stage models have provided useful information about reading strategies, the concept of stages has been widely challenged. Some studies have failed to find signs of logographic or pre-alphabetic strategies in young learners of transparent orthographies such as German and Italian (Mann & Wimmer, 2002; Wimmer & Hummer, 1990). This evidence led some authors (e.g. Share, 2008) to claim that pre-alphabetic strategies do not necessarily constitute a developmental stage but instead transitional attempts to read when the language is opaque (like English) or when poor phonological training has been received. Moreover, much evidence has shown that reading acquisition is not linear and that novel readers also possess knowledge about orthographic regularities which stage models only attribute to more experienced readers (e.g. Pacton, et al., 2005; Treiman, 1993). Thus, models of continuous development claim that, although some strategies may be predominant according to the individual's reading level, a variety of strategies can be simultaneously applied from the beginning of reading acquisition. As exposure to print increases, more knowledge is acquired about phonology, orthography, morphology, semantics and prosody, thus enabling the application of more efficient reading strategies (Defior et al., 2015) which tend to become automatic, that is, to occur without the mediation of explicit mechanisms.

The self-teaching hypothesis (Share, 1999) also highlights the importance of practice in reading development. According to this theory, young readers apply rudimentary decoding strategies to recognize words and such encounters with print fosters orthographic knowledge that enables more fluent word recognition. As experience increases, reading performance improves gradually since more words have become familiar to the reader (Share, 2008). Fluent word recognition therefore is thought to depend on how familiar the target words are to the individuals.

### *Models of Skilled Reading*

Skilled reading theories consider how experienced individuals correctly identify and pronounce words.

***Dual-Route Models.*** Dual-route models state that experienced readers process words following two procedures: the phonological route and the lexical route (Baron, 1977; Coltheart 1980; Coltheart, 2005). The *phonological route* enables word pronunciation by converting individual graphemes into the phonemes they represent, that is, by decoding letter-by-letter. In contrast, the *lexical route* enables holistic word processing by matching the target word with an orthographic representation stored in memory, and thus instant access to the lexicon takes place. The accuracy of each route depends on the target word. For instance, regular words (which follow consistent phonological correspondences) can be processed correctly using both routes. If the word is familiar, readers tend to use the lexical route as it is faster; if the word is not familiar, the phonological route is employed. In contrast, irregular and exception words can only be correctly read aloud via the lexical route. A computational implementation of the dual-route model has been developed by Coltheart et al. (2001) and is summarized in Figure 3. In the case of Spanish (a transparent orthography), most words are regular and therefore can be accurately read following both the phonological and the lexical routes. However, expert readers mainly use the lexical route and differ from non-experts in terms of reading speed, more than reading accuracy (Serrano & Defior, 2008).

The dual-route model suggests that experience constitutes an important factor in reading performance. Experience with written words enables the storage of orthographic units and, in consequence, faster word processing is facilitated via the lexical route.

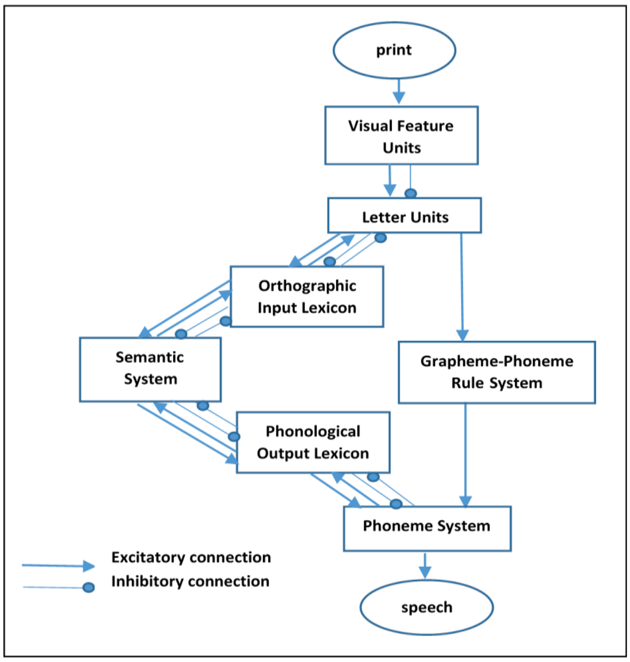



*Figure 3*. Dual-Route Cascaded Model of reading (Coltheart et al., 2001). Arrowed connections represent excitatory links whereas ball-ends show inhibitory connection.

***Connectionist Models.*** In the connectionist approach (Seidenberg & McClelland, 1989; Seidenberg, 2005) a model consists of a large network of processing elements that learn to perform tasks such as reading (see Figure 4). Different types of information are represented in the model by sets of elements or units (for instance, graphemes and phonemes) that are interconnected. The input of a printed word generates the activation of initial units, which spreads to other units generating the output of the word pronunciation. These units encode orthographic, phonological and semantic information; additional "hidden units" mediate computations between codes, enabling the processing of more complex patterns (such as irregular or exception words). According to these models, the access to semantic information in early phases follows a certain pathway of activation: orthography, phonology and finally semantics; with further practice, a shorter pathway orthography-semantics becomes more accessible.

The connectionist model learns via a series of corrections as a result of "reading experience" when the produced output (pronunciation of a word) of the model is compared with the target element (correct pronunciation). In the words of Seidenberg (2007) "learning the correspondences between spelling and sound involves picking up on the statistical structure of these mappings as instantiated in a large pool of words. The (connectionist) models pick up on this implicit structure" (p. 238). The implicit computation of complex orthographic units enables the generalization of their patterns and, as a result, regularities embedded in irregular words can be transferred to new cases without the need to memorize every item. This generalization does not occur by applying explicit rules, but by generating an implicit knowledge about orthographic patterns.

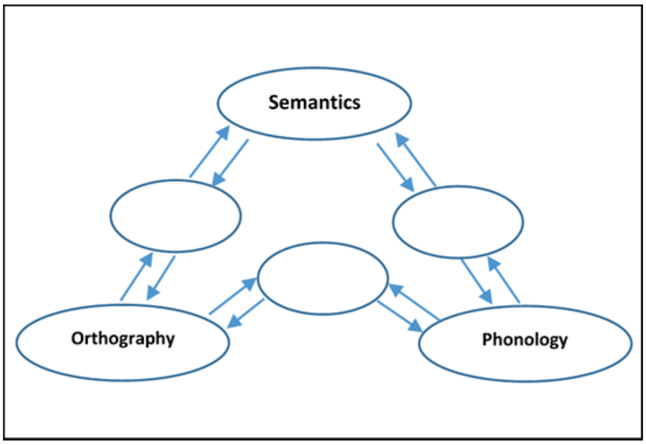



*Figure 4*. Seidenberg and McClelland's (1989) early connectionist model.

Although the aforementioned developmental and skilled reading models have different theoretical approaches to reading, they all consider the importance of experience in the improvement of word recognition processes. Experience is thought to underpin the acquisition of complex orthographic patterns by activating implicit learning mechanisms. As a result, more efficient reading strategies can be implemented. Relevant to this thesis, the connectionist model also introduces the term *statistical learning* to refer to the unconscious computations that readers make to learn the frequency with which orthographic patterns occur. Such learning is not only useful to approach known words, but can also be transferred to new instances. The concept of statistical learning is strongly related to the concept of implicit learning as both tap the ability to learn regularities by repeated exposure to exemplars. However, implicit learning also makes reference to the lack of conscious awareness during both the acquisition and the application of knowledge.

**Explicit and Implicit Strategies Involved in Reading**

As previously mentioned, reading is a complex cognitive activity where different types of information (phonological, semantic, morphological, prosodic) need to be simultaneously processed. In alphabetic systems, primary school students are taught to read by applying grapheme-phoneme mappings. These explicit conversion rules are absolutely necessary to equip children with a consistent set of tools, which remains available to monitor and control reading and spelling performance (Gombert, 2003). As reading experience increases, individuals acquire not only knowledge about phonological consistencies, but also about the inconsistencies of the language. As pointed by Seidenberg and McClelland (1989), inconsistencies are seldom random; instead, a structure underlies irregular patterns and repeated exposure enables individuals to compute such structure and store it for posterior usage. Thus, the acquisition of complex orthographic patterns is thought to rely on the aid of implicit cognitive mechanisms (Steffler, 2004).

The distinction between explicit and implicit strategies is important not only for theoretical reasons, but also for practical purposes. Learning a content through explicit mechanisms implies the effortful acquisition of information and the conscious application of such knowledge; following clear procedures or applying rules are some examples. In contrast, implicit learning is not consciously-driven and results from repetition enabling further automatization of tasks; this mechanism is more related to observation and experience, as in learning to speak a first language.

Although both explicit and implicit strategies are involved in reading and writing, most research has been focused on explicit teaching/learning methods. A relatively recent line of research, though, has also explored the contribution of implicit learning mechanisms.

## Implicit Learning and its Relation to Literacy Acquisition

A classical definition of *implicit learning* refers to an unconscious and effortless process by which structured information is acquired as a result of repeated exposure (Reber, 1967). This process exceeds mere memorization since the resulting knowledge cannot only be replicated but it can also be transferred to new situations (Reber, 1993; Seidenberg, 2007; Steffler, 2001). Some authors refer to this process as *statistical learning* (Treiman & Kessler, 2013), as they emphasize the fact that individuals compute the frequency with which regularities occur, regardless of the conscious awareness. In the current thesis, we will utilize the concept of implicit learning, which has a longer tradition and considers the fact that much knowledge about literacy is acquired without effort or instruction.

Behavioral and experimental studies have shown that implicit mechanisms are present in humans from a young age, and that they play a particular important role in oral language acquisition. For instance, it has been found that infants as young as 8-months-old are able to distinguish regularities from their language (Pelucchi, Hay, & Saffran, 2009), and that they can learn syllabic boundaries or discriminate oral units from an artificial speech after a brief exposure (Chambers, Onishi, & Fisher, 2003; Saffran, Aslin, & Newport, 1996).

Research in written language has also provided evidence that implicit learning plays a role in literacy development in different languages. Studies carried out in French showed that children from grade 1 to 4 were sensitive to the frequency with which certain clusters of double consonants occur, identifying which clusters were more frequent than others (Pacton, Perruchet, Fayol, & Cleeremans, 2001). Pacton et al. (2005) also found that children from grade 1 to 5 were sensitive to the legal positions of double consonants as they could recognize which consonant clusters were allowed at the beginning or at the end of words. Similar evidence has been found in English, where the errors in the spontaneous writing of first-graders demonstrated some implicit knowledge about permissible consonant clusters (Treiman, 1993). In Spanish, a less opaque language, it has been shown that primary school children are sensitive to the frequency with which bigrams occur (such as *bu* versus *vu*) and that this knowledge is applied to solve spelling inconsistencies (Carrillo & Alegría, 2014).

Moreover, some authors found that the ability to implicitly learn regularities was related to both children's and adults' reading skills in an opaque language (English). Results from two studies showed that subjects with higher scores on reading tests also achieved higher scores in implicit learning tasks (Arciuli & Simpson, 2012; Sperling, Lu, & Manis, 2004). This relationship, however, has not been explored in a transparent language where phonological mappings constitute a very effective strategy for reading and writing (Defior & Alegría, 2005).

The role of implicit mechanisms in reading and writing has become a topic of increasing interest during the past decade. The reviewed research shows how these mechanisms contribute to literacy development in typical populations. If implicit strategies are applied by good readers, it is also important to investigate whether implicit resources operate in cases of learning impairment such as dyslexia.

**Reading and Writing Difficulties: The Case of Dyslexia**

Developmental dyslexia is considered a specific learning disability caused by neurological factors. It is characterized by persistent difficulties with accurate and/or fluent word recognition, poor spelling skills and poor decoding skills, despite adequate instruction, normal intelligence and intact sensory abilities (Lyon, Shaywitz, & Shaywitz, 2003). Studies in alphabetic languages suggest that dyslexia affects between 3% and 8% of the population (IDA, 2002; Peterson & Pennington, 2012), a percentage that varies according to the criteria employed for the diagnosis (Miles, 2004). In Spanish, Jiménez, Guzmán, Rodríguez and Artiles (2009) found an incidence of 3.2% in primary children, whereas Alegría (2006) reported an incidence approaching 5%. The Junta de Andalucía (the Andalusian Government) contemplates the possibility of higher incidence, since the percentage reported in official documents ranges between 2% and 8%. Results from the current thesis fit within such range, since we found that 7% of primary children had signs of dyslexia when recruiting the samples for our studies.

As in other developmental disorders, research in dyslexia aims to find explanations on different levels: behavioral, cognitive and biological, which also interact with environmental factors (Frith, 2002; Frith &Morton, 1995). Although studies usually tap one specific domain, researchers need to integrate their findings with vast evidence collected in other domains (Frith, 2002).

The advance of neuroimaging methods has shed some light on the biological bases of dyslexia. Most evidence with MRI shows neurological abnormalities in the left brain hemisphere (involved in language) when performing reading-related tasks (Maisog, Einbinder, Flowers, Turkeltaub, & Eden, 2008; Richlan, Kronbichler, & Wimmer, 2011). More specifically, poor activation was found in the temporoparietal region (associated with phonological processing) and in the occipitotemporal region (associated with holistic word recognition) (Demonet, Taylor, & Chaix, 2004; Im, Raschle, Smith, Grant, & Gaab, 2015; Martin, Kronbichler, & Richlan, 2016; Shaywitz & Shaywitz, 2005). Abnormal activation has also been reported in the left frontal gyrus and the occipital gyrus (Boros, Anton, Pech-Georgel, Grainger, Szwed, & Ziegler, 2016). Studies with diffusion tensor imaging have found that brain areas of poor activation in individuals with dyslexia coincide with less brain tissue (i.e. white and grey matter) (Niogi & McCandliss, 2006; Richlan, Kronbichler, & Wimmer, 2013; Silani, Frith, Demonet, et al., 2005; Stoodley, 2016). Furthermore, these studies found positive correlations between white matter density and reading measures. Poor brain activation has also been reported in the right cerebellar hemisphere (Nicolson, Fawcett, & Dean, 2001), a structure associated with procedural learning. Given the findings provided by neuroimaging techniques, some authors consider dyslexia as a *neural connectivity impairment* (Richards & Berninger, 2008), by which several brain paths seem to be blocked or interrupted. Moreover, evidence from family risk studies found that decrease concentration of grey matter occurs even before the onset of school instruction, suggesting that less brain tissue is the consequence of a genetic alteration and not the result of reading failure (Raschle, Chang, & Gaab, 2011). Accordingly, genetic studies have identified three genes that may be associated with dyslexia and which are related to white matter in the left brain cortex (Darki, Peyrard-Janvid, Matsson, Kere, & Klingberg, 2012). This evidence supports the claim that developmental dyslexia is familial and moderately hereditable (Pennington & Olson, 2005). In addition to biological predisposition, environmental factors are also thought to have an impact on dyslexia. A comparison of neuroimaging studies across languages has shown that while underactivation of the occipitotemporal cortex can be considered universal, some neural abnormalities are orthography-specific and, in consequence, different compensatory mechanisms are thought to emerge depending on the transparency of the language (Martin, Kronbichler, & Richlan, 2016).

At the behavioural level, a great number of studies have shown that individuals with dyslexia have difficulties identifying and manipulating speech sounds. This has led many authors to support the cognitive theory of a *phonological deficit* as the core problem in dyslexia (Hulme & Snowling, 2011; Peterson & Pennington, 2012; Snowling & Stackhouse, 2006). Such deficit manifests in most cases as poor phonological awareness, which constitutes the ability to reflect on phonemes (Ramus & Szenkovits, 2008). Moreover, individuals with dyslexia have been reported to be impaired in other phonological tasks such as auditory processing of speech (Chiappe, Chiappe, & Siegel, 2001; Goswami, 2011), verbal short-term memory (Griffiths & Snowling, 2002) and naming speed (Hulme & Snowling, 2011), which is the ability to rapidly match a visual target (object, digit, color, etc.) with its name. Individuals with dyslexia perform more slowly than typical readers in naming tasks which has been mainly attributed to poor storage of phonological representations (Hulme & Snowling, 2011). However, a different theory suggests that a rapid naming deficit is not caused by phonological problems but by poor retrieval abilities (Wolf & Bowers, 1999; Wolf, Bowers, & Biddle, 2000). This controversy could find some resolution in a recent reformulation of the phonological deficit hypothesis. After evaluating the performance of individuals with dyslexia in a broad number of phonological tasks, Ramus and Szenkovits (2008) pointed out that phonological problems are only present when the task demands tap short-term memory, conscious awareness and speed. The authors then concluded that individuals with dyslexia do not have a general phonological deficit but a deficit in the access to phonological representations.

Although the phonological deficit has been the most widely accepted theory of cognitive impairment in dyslexia, other possible causes have been explored. The existence of more general deficits has been considered such as poor sensory perception of the auditory or the visual field, as well as inefficient learning processes.

Theories of *auditory deficit* suggest that detrimental perception of speech affects the development of phonological skills necessary for reading and writing. The first theories of auditory impairment claimed that individuals with dyslexia have difficulties processing rapid sound changes (Tallal, 2004). Studies with event-related potentials corroborated impaired brain activation in individuals with dyslexia when performing tasks of frequency discrimination (Baldeweg, Richardson, Watkins, Foale, & Gruzelier, 1999; Kujala, Lovio, Lepistö, Laasonen, & Näätänen, 2006; Lorna, Halliday, & Bishop, 2006; Stoodley, Hill, Stein, & Bishop, 2006). Some authors also consider that instead of frequency, the main problem resides in the perception of sound amplitude. The *amplitude modulation deficit* hypothesis (Goswami, 2011; 2016) claims that auditory problems affect the perception of the amplitude modulation of sounds (rise times), which are crucial indicators for phonological segmentation. The inability to identify rise times is thought to affect speech perception and interfere with the development of phonological skills necessary to establish grapheme-phoneme correspondences. Impaired discrimination of rise times has been reported for dyslexic individuals in several languages as well as a positive relationship between rise time sensitivity and phonological awareness (Goswami et al., 2011; Poelmans et al., 2011). Poor rise time sensitivity is thought to cause the rhythmic impairments reported for non-linguistic tasks (Thomson & Goswami, 2008; Goswami, Huss, Mead, Fosker, & Verney, 2013) and for speech (Goswami et al., 2013; Kitzen, 2001). Studies with neuroimaging have provided evidence that individuals with dyslexia have less neurological sensitivity to modulation patterns in speech and non-speech signals (Hämäläinen, Rupp, Soltesz, Szucs, & Goswami, 2012; Power, Mead, Barnes, & Goswami, 2013) and that atypical brain synchronization affects both syllabic and phonemic modulation perception (Lizarazu et al., 2015). Consistent with previous literature, impaired neural oscillations have been found in the right auditory cortex and the left inferior frontal gyrus of individuals with dyslexia when listening to sentences (Molinaro, Lizarazu, Lallier, Bourguignon, & Carreiras, 2016).

Concerning the *visual perceptual deficit*, some authors claim that individuals with dyslexia have problems with the allocation of attention within the visual field. For instance, some studies reported an impaired visual attention span, since the perception of simultaneous elements is poorer in dyslexia (Bosse, Tainturier, & Valdois, 2007; Lassus-Sangosse, N´guyen-Morel, & Valdois, 2008). Moreover, a study by Facoetti and Molteni (2001) suggested that these individuals have an asymmetric distribution of visual attentional resources as they needed more time to process stimuli in the left visual field than in the right field. Problems disengaging or shifting the attention from one element to another have also been reported (Ruffino et al., 2010), as well as poor discrimination of motion (Hari & Renvall, 2001; Schulte-Körne, Bartling, Deimel, & Remschmidt, 2004). Recent studies with neuroimaging suggest that poor processing of words in dyslexia may be due to an impairment of visuospatial processing caused by poor neural activation in the occipital lobe (Boros et al., 2016). These visual impairments are thought to affect the processing of lexical units and impoverish the ability to capture information about orthographic patterns (Vidyasagar & Pammer, 2010).

Another theory aiming to explain learning problems in dyslexia is known as the *cerebellar deficit* (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001). Given the role of the cerebellum in procedural memory, a dysfunction in this brain structure is thought to be responsible for impaired automatization of procedures. According to this theory, a cerebellar deficit may not only explain why individuals with dyslexia perform poorly in motor skills, but it could also explain why these individuals fail to efficiently master the writing system despite repeated practice. Nicolson and Fawcett (1990) found that although children with dyslexia could perform single motor tasks (such as balancing) as well as age-matched controls, they were impaired when secondary tasks were introduced (such as counting). The authors suggested that a general difficulty to fully automatize or learn procedures would force subjects to make effortful compensations, and thus a secondary task would draw their attention from the main task. In other words, given the poor contribution of automatic mechanisms, a secondary task would affect their performance since conscious-driven processes would be overloaded. The development of neuroimaging technology allowed researchers to provide some support for this hypothesis. In a study by Nicolson, Fawcett, and Dean (2001) participants with and without dyslexia performed a learning task where a sequence of key presses was introduced. Results showed that activation in the right cerebellar hemisphere was slower in subjects with dyslexia than in typical readers. The authors concluded that reading problems in dyslexia could be explained by detrimental implicit learning processes caused by abnormal cerebellar activity.

Nowadays, the assumption of a single deficit in dyslexia has been strongly challenged. The mounting evidence of deficits in different domains have led the scientific community to consider that, although a phonological deficit is always present, it may not be sufficient to cause such reading disorder (Peterson & Pennington, 2012). Thus, a multiple deficit hypothesis seems more accurate to explain developmental dyslexia, and therefore a wide variety of manifestations need to be explored.

Theories of learning impairments in dyslexia have recently spread much beyond procedural learning. For instance, Bishop et al. (2014) suggest that language impairments in dyslexia are the result of poor ability to abstract knowledge about the underlying regularities of structured material. This could explain why individuals with dyslexia need more time to learn, generalize and automatize skills, despite extensive training and practice (Bishop, Adams, & Rosen, 2006). As we will show below, this question has been explored by the *implicit learning deficit* hypothesis, which constitutes a central theory in the current thesis.

**Implicit Learning in Individuals with Dyslexia**

The implicit learning deficit hypothesis suggests that individuals with dyslexia struggle to acquire regularities by means of exposure as a consequence of detrimental implicit learning mechanisms (Vicari, Marotta, Menghini, Molinari, & Petrosini, 2003). This hypothesis has mainly been tested through two paradigms: the sequence learning task and the artificial grammar learning task.

***Research with sequence learning tasks***

A sequence learning task consists of a serial reaction time task (SRTT; Nissen & Bullemer, 1987) where participants are asked to indicate as fast as possible the position or occurrence of a certain target. Unknown to participants, stimuli are displayed following a sequence that is repeated throughout the task (see Figure 5 for examples). As participants view more blocks of stimuli and perform the task, they become progressively sensitive to the embedded sequence. This is evidenced by the fact that reaction times tend to decrease with successive blocks, but they increase sharply when a randomly ordered block is introduced. Through this paradigm some authors have found that children with dyslexia were impaired in learning sequences since their reaction times did not significantly increase with the introduction of inconsistent sequences (Jiménez-Fernández et al., 2011; Stoodley et al., 2008; Vicari et al., 2003). Similar results have been reported for adults with dyslexia (Du & Kelly, 2013; Howard, Howard, Japikse, & Eden, 2006; Stoodley, Harrison, & Stein, 2006), thus supporting the hypothesis of an implicit learning deficit as a persistent feature of dyslexia. These results, however, are contentious as other studies have found evidence of preserved implicit learning in both children and adults with dyslexia (Kelly et al., 2002; Menghini et al., 2010; Roodenrys & Dunn, 2008; Rüsseler, Gerth, & Münte, 2006).

Inconsistent results within the sequence learning paradigm may be explained by differences in the methodological approaches. This explanation is supported by Lum, Ullman, and Conti-Ramsden (2013) who conducted a meta-analysis of 14 SRTT studies. These authors found a moderate level of heterogeneity in the results that was related to differences in the age of participants and the demands of the learning tasks. Thus, a very important issue concerns the age of participants: while some studies included child participants, others included adolescents and adults who (due to a much longer exposure to print) may have developed compensatory strategies to process visual stimuli. Additionally, a broad range of task features seems to account for different findings, such as the length of the exposure phase, the length of the sequences, the introduction of first-order versus second-order conditional sequences (i.e. when the location of a target can be predicted by the location of just one previous stimulus or when multiple previous stimuli are necessary), and the response requirements for the task (e.g., some participants were asked to press a button when viewing a specific target and others were required to press different buttons indicating the position of every element). Finally, it is also important to note that a sequence learning task generally contains a motor component for the response which has led some authors to argue that it may not only tap the learning of visual sequences, but also visual-motor procedural learning (Goschke, 1998).

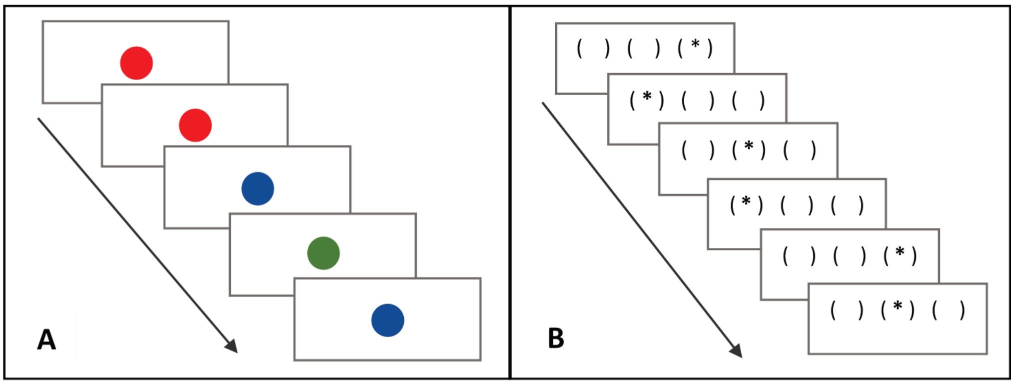



*Figure 5.* Diagram A represents a sequence learning task used by Vicari et al. (2003) where a sequence was embedded in the color of the circles and participants were asked to press a key when the green circle appeared. Diagram B represents a task used by Jiménez et al. (2011) where a sequence was embedded in the position of the target (*) and participants were asked to press a key corresponding to the target shifting position (1, 2 or 3).

### ***Research with artificial grammar learning tasks***

An artificial grammar learning (AGL) task (Reber, 1967) has no motor component and is thus believed to assess implicit learning purely in the visual domain. In the AGL paradigm, stimuli are created by using a small artificial grammar that determines which letters can legally succeed others. Hence, a letter string is considered *grammatical* when all the contained letters adhere to the succession rules (see Figure 6 for an example). This task typically consists of an exposure phase where grammatical exemplars are displayed, although the participants are unaware of the existence of rules. Utilizing a later test phase, the occurrence of implicit learning is assessed by displaying previously unseen grammatical and ungrammatical stimuli, and asking participants to classify them based on their grammaticality. Although there is no clear consensus on what content is actually learned in an AGL task (exemplars, chunks or rules), some authors suggest that it explores the ability to abstract complex rules and transfer them to novel circumstances (Pothos, 2007).

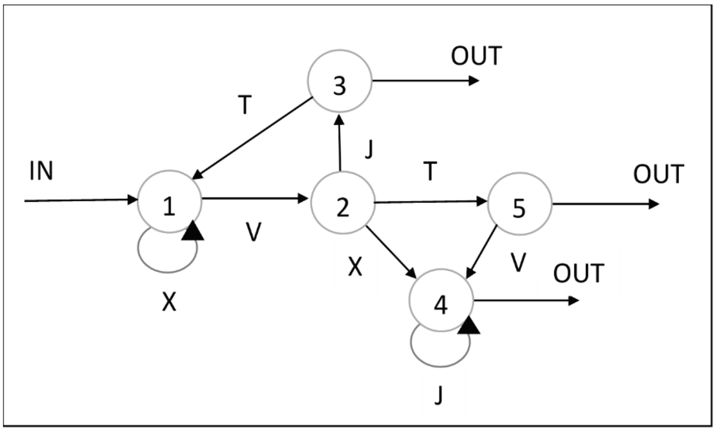



*Figure 6*. Artificial grammar designed by Knowlton and Squire (1996). IN indicates the start of the grammar and OUT the exit. Arrows indicate permissible paths for letter combinations.

Through an AGL task, Pothos and Kirk (2004) investigated implicit learning in adults with dyslexia and found an unusual pattern: not only could participants with dyslexia learn the regularities of the grammar, but they also outperformed participants from the control group. The authors used an AGL task designed by Knowlton and Squire (1996), replacing the letter stimuli with geometric shapes (see Figure 7). However, a subsequent AGL study carried out with children found a very different pattern of results despite utilizing the same task (Pavlidou, Williams, & Kelly, 2009). Pavlidou et al. found that control participants were able to learn the regularities, while participants from the group with dyslexia exhibited no evidence of implicit learning even when explicit instructions to memorise the stimuli were introduced. These results suggested that children with dyslexia have an implicit learning deficit and this pattern was corroborated by follow-up studies (Pavlidou, Kelly, & Williams, 2010; Pavlidou & Williams, 2014).

Such contrasting results between the aforementioned studies could be explained by important differences between the samples, such as the age and the inclusion criteria established for participants with dyslexia. Firstly, differences in the age may be very important especially when considering that the adult participants recruited by Pothos and Kirk were university students (and therefore had experienced more exposure to print). Secondly, it can be argued that Pothos and Kirk established a non-strict inclusion criterion for the dyslexic group, as they did not assess participants' IQ (thus not controlling for intellectual disabilities), and included participants for whom English was not the native language (which provides an alternative explanation for their reading difficulties).

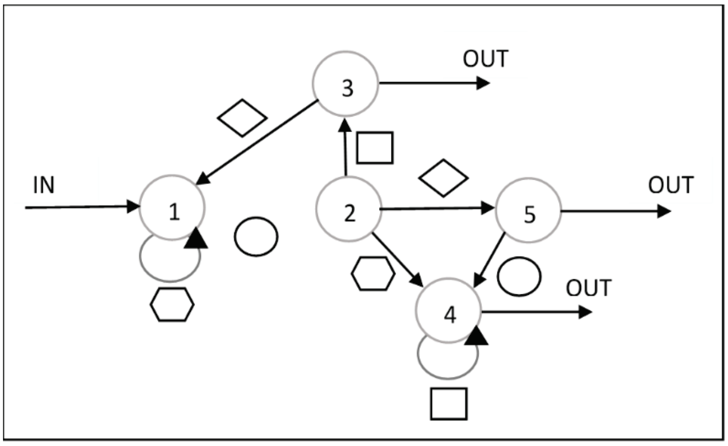



*Figure 7.* Example of the artificial grammar used by Pothos & Kirk (2004) and Pavlidou et al. (2009). IN indicates the start of the grammar and OUT the exit. Arrows indicate permissible paths for shape combinations.

As shown by this review, results from a significant number of studies are not conclusive about a possible implicit learning deficit in dyslexia. Factors related to the age of the participants and the characteristics of the learning tasks seem to account for different results, which suggests that implicit learning mechanisms do not operate in an absolute fashion (*completely present* versus *completely absent*). Instead, the effectiveness of implicit mechanisms may improve with age (as found in typical populations by Arciuli & Simpson, 2012), and may be dependent upon the features of the learning environment.

Of importance, the SRTT and AGL studies investigated implicit abilities of individuals with dyslexia in the visual domain, deliberately excluding written information. However, if dyslexia is caused by a factor specifically related to the processing of orthographic information, then studies with non-linguistic material might not be able to reveal the broad complexity of implicit orthographic acquisition. Thus, more research should be carried out in order to explore the ability to implicitly learn orthographic patterns in individuals with dyslexia.

# Motivation and Research Overview

The present thesis aims at investigating implicit learning processes and the acquisition of orthographic regularities in Spanish children with typical development and in children with developmental dyslexia.

As reviewed in the introduction, results from behavioral studies indicate that young children are able to apply knowledge about orthographic conventions (beyond phonological mappings) even prior to receiving formal instruction. For instance, in the study of Pacton et al. (2001), French children were able to identify frequent consonant clusters embedded in pseudowords, although such frequency patterns are not taught at school. Thus, this study provides evidence that some orthographic knowledge is acquired by implicit means. However, there is not much literature exploring the conditions under which this learning takes places.

Implicit learning mechanisms have been studied through different paradigms, being the sequence learning task and the AGL tasks the most popular paradigms. However, both tasks introduce limitations that distant the experimental results from real language acquisition. On one hand, sequence learning tasks study the acquisition of sequential (not simultaneous) regularities embedded in non-linguistic stimuli. Moreover, most sequential tasks introduce a motor component, thus tapping not only visual learning but also motor-procedural learning. On the other hand, artificial grammars are useful to study the acquisition of complex succession patterns embedded in linguistic stimuli; however, they have been mainly used to generate unpronounceable letter strings (such as *VVXKLN*) or strings of shapes that do not resemble real language conventions.

In order to study children's implicit learning abilities and relate these abilities to the natural acquisition of orthographic patterns, Study 1 aimed to develop a learning task able to elicit implicit learning in primary students. Moreover, we explored the possible relationship between implicit learning abilities and reading and writing skills. After generating a suitable implicit learning task, Study 2 explored the implicit learning abilities of children with developmental dyslexia in comparison with typically-developing children. Two experiments were conducted in order to assess whether the learning of positional regularities differed when they were embedded in linguistic and non-linguistic stimuli. The implicit ability to learn orthographic regularities was further explored in Study 3. In this last study, we aimed to challenge the implicit resources of children with dyslexia by including complex contextual patterns where co-occurence relationships were established among letters. Furthermore, we explored whether the presence of consonant clusters affected the learning of children with dyslexia, since such clusters are considered challenging for these students (Serrano & Defior, 2012).

**Overview Study 1**

In Study1, the aim was to develop an *ecological* implicit learning task able to measure the implicit acquisition of graphotactic regularities in Spanish children with typical development. Research in oral language has provided evidence that infants are able to learn positional constraints embedded in one-syllable pseudowords (i.e. CVC, consonant vowel consonant) after a brief exposure (Chambers et al., 2003). In Study 1, similar positional rules were embedded in two-syllable pseudowords in order to generate stimuli with a frequent Spanish word structure: CVCV (as in *casa*, house). Moreover, the relationship between implicit learning and reading and writing skills was explored. Studies in English have found positive correlations between reading/writing performance and performance in implicit learning tasks. This suggests that good literacy skills are related to better implicit learning of visual regularities in a deep orthography (Arciuli & Simpson, 2012; Sperling et al., 2004; Steffler, 2004). However, to our knowledge, no similar study has been conducted in a shallow orthography like Spanish. In relation to reading, Spanish is very transparent as it contains just a few cases of inconsistencies, and therefore phonological mappings should be enough to produce accurate reading in most cases. Accordingly, no strong relationship would be expected between implicit learning abilities and reading in Spanish. In contrast, the writing system contains more cases of phonological inconsistencies and therefore more attention to graphotactic cues is necessary. A relationship between the implicit learning of graphotactic patterns and the spelling of inconsistent words should be expected if these variables were closely related.

The development of a valid task to elicit and measure implicit learning in Spanish children provided us with a baseline to plan further studies and explore implicit learning in children with reading impairment.

**Overview Study 2**

In Study 2, the implicit learning deficit hypothesis was explored by comparing the performance of children with typical development and children with dyslexia (matched by age, gender and IQ) in implicit learning tasks where positional rules were introduced. Furthermore, the impact of linguistic information on the implicit learning was also explored by undertaking two experiments. In Experiment 1, positional rules were embedded in strings of abstract shapes, whereas in Experiment 2, the positional rules were embedded in letter strings. If children with dyslexia have a general implicit learning impairment, performance in both experiments would be expected to be poorer in the group with dyslexia. If children with dyslexia are only impaired in the acquisition of orthographic regularities, their performance would only be expected to be poor when performing the linguistic task.

The results obtained in both experiments were ambiguous. Whereas between-subject analyses yielded no significant differences between the two groups in any of the experiments, within-subject analyses showed that participants with dyslexia failed at transferring the orthographic knowledge to new strings. Given such ambiguous results, the implicit learning deficit was further explored in Study 3 with new experimental tasks. As the trend in Study 2 showed a difficulty to generalize the positional knowledge, we hypothesised that more challenging tasks might be necessary to fully uncover an implicit learning impairment in children with dyslexia.

**Overview Study 3**

In Study 3, some changes were performed in the orthographic learning task in order to challenge the implicit learning resources of children with dyslexia. Since positional rules might not have been demanding enough to uncover an implicit learning impairment, contextual rules were embedded in the new stimuli. Contextual regularities establish relationships between two or more letters and it has been proven that children with dyslexia persistently struggle with them (Davies, Cuetos, & González-Seijas, 2007; Serrano & Defior, 2008; Serrano & Defior, 2012).

Additionally, Study 3 explored the influence of syllabic complexity on the learning of contextual regularities by comparing the performance on two experiments. In Experiment 1, contextual rules were embedded in stimuli with simple syllabic structures: CVCV, as CV is considered easy for children with and without dyslexia. In Experiment 2, the contextual regularities were embedded in stimuli with one complex syllabic structure: CCVCV, as consonant clusters (CC) are considered challenging for children with dyslexia (Serrano & Defior, 2012). We hypothesized that children with dyslexia could not learn the contextual regularities by exposure as well as their controls and that consonant clusters would negatively affect their learning performance.

# Experimental Series

# STUDY 1

## Implicit Learning of Written Regularities and its Relation to a Shallow Orthography

As some studies have suggested, implicit learning processes appear very early in development to help capture the regularities of oral language. For instance, Saffran, Aslin, and Newport (1996) found that 8-month-old infants were able to isolate oral units from an artificial speech stream based solely on the statistical relationships between neighboring sounds. Infants were exposed to a continuous speech stream which consisted of four three-syllable nonwords, repeated in a random order for two minutes. The infants were then presented with legal and illegal nonwords (where the order of syllables was altered) and results showed that the infants listened longer to illegal items, which were not familiar as they contained novel patterns. The authors suggested that infants may possess experience-dependent mechanisms powerful enough to acquire language regularities. Similarly, Chambers, Onishi, and Fisher (2003) investigated whether 16-month-old infants were able to learn novel phonotactic regularities after a brief exposure. Children heard pseudowords with a CVC structure where certain phonotactic rules were embedded (for instance, /b/ sound was always presented as onset and never as coda, as in /bæp/). In the test phase, the infants heard novel pseudowords which either followed the phonotactic rules (legal items such as /bæp/) or violated them (illegal items such as /pæb/). Differences in the infants' listening times suggested that they were able to differentiate legal from illegal items.

Writing systems, as they represent the oral language, are also governed by a wide range of regularities. In alphabetical systems, specifically, phonemes are represented by graphemes and correspondences ideally activate 1-to-1 mappings (as mainly occurs in shallow orthographies). These phonological correspondences are explicitly taught through formal instruction. However, all systems contain some level of inconsistencies where phoneme-grapheme correspondences activate 1-to-2 or 1-to-many mappings. Due to these inconsistencies and other spelling exceptions, phonological knowledge is not enough to achieve literacy proficiency. Therefore, it becomes necessary to apply other sources of knowledge regarding semantics, morphology and orthography aside from phonological mappings, such as lexical (or word-specific) knowledge, and graphotactic regularities which refer to legal letter combinations. The implicit acquisition of graphotactic regularities will be the main focus of this study.

While some written regularities are acquired through explicit instruction, others can be learned by exposure through implicit mechanisms. As mentioned, Pacton et al. (2001) provided evidence that orthographic knowledge about graphotactic regularities can be implicitly acquired and used very early in school. These authors found that French children from grades 1 to 4 were sensitive to the frequency of double consonants. Participants were presented with pairs of pseudowords which differed only in the double consonant (e.g. *assyla* vs *avvyla*) and were asked to choose the pseudoword which looked like a real French word. Results showed that children tended to choose pseudowords which contained more frequent doublets, although both spelling patterns (*ss* or *vv*) were possible. In addition, they found that children from grade 1 to 5 were also sensitive to the legal positions of the double consonants, successfully identifying which doublets were allowed at the beginning or at the end of words. Similarly, Treiman (1993) found evidence that English speaking children had some implicit knowledge about graphotactic patterns as early as first grade. This author analyzed the spontaneous writing of 43 children and found that their spelling errors reflected some knowledge about where double consonants could be placed and which consonants could not be doubled.

In addition to graphotactic patterns, morphological information can also be implicitly learned and used to resolve spelling inconsistencies. For instance, in French the sound /et/ can be either spelled -aite, -ète, -ête or -ette. However, when this sound refers to a diminutive suffix, it can only be spelled -ette. Pacton, Fayol and Perruchet (2005) found evidence of the use of this derivational morphology when they analyzed the spelling productions of second graders. Participants heard sentences which contained pseudowords, such as "a small /sorive/ is a /sorivet/", and they were asked to write the sentences down. Results showed that pseudowords like /sorivet/ were generally spelled with –ette (*sorivette*), suggesting that children used their morphological knowledge of a diminutive suffix.

These studies provide empirical evidence that young children not only learn phoneme-grapheme correspondences which are explicitly taught at school, but they also learn graphotactic and morphological regularities by implicit mechanisms. There is, however, little research focused on how these regularities are actually acquired and what the relationship may be between implicit learning abilities and literacy skills in typical populations.

Sperling, Lu, and Manis (2004) studied the aforementioned relationship in adult English speakers and found that their performance on a categorical implicit learning task was related to their reading profile. Participants who were faster to learn a categorization rule were better in a reading aloud task. This positive relationship between implicit learning and reading was also found by Arciuli and Simpson (2012) in a child population (5 to 12 year-olds). In their task, participants were shown a stream of non-linguistic stimuli, where –unknown to the participants– items were always grouped into triplets. Results showed that children were able to identify these triplets and better performance on this task was a predictor of better performance on a reading aloud task.

Besides reading, the ability to implicitly learn visual regularities was also explored in relation to writing skills. Steffler (2004) studied whether performance on two artificial grammar learning (AGL) tasks was related to fifth-graders' ability to read and write. Literacy skills were estimated with the spelling task of test WRAT-3 (Wilkinson, 1993) and with the reading and writing of ambiguous words ending in -ed (such as *planned* and *planed*). In one of the AGL tasks participants were presented with pseudowords (e.g. *dafk*), while in the other task they saw non-pronounceable letter strings (e.g *lxpy*). The test phases included three types of legal stimuli in order to test children's ability to generalize the underlying rules: the *maintenance* items (previously encountered in the exposure phase), the *near generalization* items (not encountered previously) and the *far generalization* items (constructed with the same underlying rules but with new letters). Each test item (grammatical and non-grammatical) was displayed at the time and children were asked to judge their grammaticality. Results showed that performance on the maintenance items of both AGL tasks together (which were not significantly different) correlated with the spelling of words ending in -ed, but not with reading. When taking into account only correct identification of grammatical items, significant correlations arose between the WRAT-3 spelling performance and the learning task scores, not only for maintenance items but also for near generalization items. The author concluded that the ability to generalize visual patterns to novel instances (attested by performance on the near generalization items) seemed to be related to spelling skills.

As suggested by this review, the ability to implicitly learn visual regularities seems to be related to reading and writing skills in English, which is considered a deep orthography due to its many spelling inconsistencies and exceptions. However, to our knowledge, there is no empirical evidence showing a link between implicit learning and proficiency with reading and writing in a shallow orthography, such as Spanish.

The Spanish reading system is quite shallow as correspondences between graphemes and phonemes are mainly 1-to-1. There are just a few cases of 1-to-2 mappings –for example, the letter G can either represent phoneme /g/ or /x/ depending on the following letter. In contrast to reading, the Spanish writing system contains several inconsistencies where phoneme-to-grapheme mappings are not always sufficient to produce correct spellings. For example, the phoneme /b/ can either be represented by letter B or V; however, when the sound /b/ is followed by /r/, it can only be represented by B as in *abrir* (to open). Besides graphotactic information, morphological knowledge is also necessary to correctly write specific phonological patterns. For example, the final /aba/ sound of a word, when referring to the past tense of a verb, is always spelled with B as in *cantaba* (sang). These rules may be utilized to solve inconsistencies and spell words which are not very familiar to the individual. However, with familiar words lexical knowledge (that is, word-specific knowledge) is enough to produce correct spellings as words can be spelled from memory alone (and thus no rule-based knowledge needs to be applied). As these examples suggest, writing proficiency in Spanish requires the integration of different sources of information such as graphotactic, morphological and lexical knowledge in addition to phoneme-grapheme correspondences. This information is not always explicitly taught but it can be acquired by means of experience, suggesting that implicit learning processes may play an important role in literacy acquisition.

**The Current Study**

The present study explores in 8 year-old children the relationship between implicit learning, cognitive skills and proficiency with reading and writing in Spanish (which is a shallow orthography). We were interested in this age as the automatization of reading skills is expected to increase rapidly after two years of schooling. However, writing skills are not expected to be so advanced, as the Spanish system presents several cases of inconsistencies which demand the application of other sources besides phonological knowledge. Therefore, more exposure to the writing system may be necessary to acquire a high level of spelling skills. To test implicit learning in a child Spanish population, we designed an implicit learning task where certain letters were embedded in a CVCV structure (very frequent in Spanish) in order to create graphotactic regularities which do not exist in the real language, but which could mimic existing patterns. If successful, this task could be considered an ecologically valid method to test the implicit acquisition of orthographic regularities.

If implicit learning of visual regularities is related to reading and writing skills, a positive correlation between the implicit learning task and the reading and spelling tasks would be expected. Correlations between implicit learning and literacy proficiency were previously found in a deep orthography, where advanced lexical and orthographic knowledge (besides grapheme-phoneme correspondences) are necessary to read and write correctly. In contrast, in a shallow orthography, the sole application of grapheme-phoneme rules could guarantee accurate reading of both words and pseudowords. Thus, we predict that the implicit learning of graphotactic regularities may not play such an important role when reading in a shallow orthography, and –if this is accurate– no relationships are expected to arise.

## Implicit learning and its relation to reading and writing skills (Test LEE)

### Method

**Participants.** Fifty-five third-graders participated in this study. All participants were native Spanish speakers attending the grade corresponding to their chronological age (8-9 years), came from a middle social background and had never been diagnosed with any learning disabilities.

**Materials and Apparatus.** Participants'cognitive abilities, reading and writing skills, and implicit learning abilities were estimated.

***Intelligence.*** Participants' intellectual capacity was estimated according to the Raven's Colored Progressive Matrices (Raven, 1996).

***Memory.*** Memory span and working memory were assessed using the digit span task from the Revised Weschler Intelligence Scale for Children (WISC, Weschler, 1974).

***Attention.*** Visual attention ability was estimated with Test Faces, Perception of Differences (Thurstone & Yela, 1979).

***Word reading.*** Using the Test LEE (Defior et al., 2006), participants were asked to read a list of 42 words of medium frequency which vary in length and orthographic complexity. A maximum of 2 points can be awarded for each item with 1 point awarded for correct decoding and a further point for reading fluency (i.e. absence of repetitions or syllabic reading). Participants' reading speed (i.e. the time spent to read all items) was also measured.

***Pseudoword reading.*** Participants were asked to read the 42 pseudowords of Test LEE, which were made up by combining syllables extracted from the word reading task. Reading speed was also measured and scoring criteria was identical to the word reading task.

***Word Writing.*** The word writing task of the Test LEE consists of 44 words, from which 42 items were also included in the reading task. Participants heard every item twice and were asked to write it down. For each correct item, one point is awarded.

***Pseudoword Writing.*** The pseudoword writing task of Test LEE contains 32 pseudowords, from which 23 were also included in the reading task. Administration and scoring criteria was identical to the word writing task.

***Implicit learning.*** Stimuli for the implicit learning task were pseudowords in the form $C_1VC_2V$ and were formed from a set of 10 letters: six consonants (F, L, M, N, S, T) and four vowels (A, E, I, O). The six consonants adhered to a set of artificial graphotactic rules, not present in the Spanish language, which restricted the position in which they could appear. In the first consonant position ($C_1$) only three letters (L, M, T) could be utilized, whereas in the second consonant position ($C_2$) only three different letters (F, N, S) could appear. No restrictions were placed on the vowels. Thus, there were 144 possible combinations (3 x 4 x 3 x 4) and these were termed *legal* as they adhered to the graphotactic rules (e.g. MIFO). Only 36 legal items were selected for inclusion in the exposure phase. These were selected such that all combinations of $C_1$, $C_1V$ and $C_1VC_2$ appeared the same number of times in the 36 legal stimuli (12 times, 3 times and once, respectively). It was not possible to ensure that each $VC_2V$ combination appeared the same number of times without including real Spanish words. Because of this, 26 of the $VC_2V$ combinations were used once and five combinations were used twice in the 36 stimuli. Twelve of the 36 training items were selected (to ensure that each consonant and vowel appeared the same number of times) and were used in a later test phase as *legal seen* stimuli (see Procedure). Another 12 legal items, not used in the exposure phase, were selected from the remaining 108 possible legal combinations to be used as *legal unseen* stimuli (i.e. not seen in the exposure phase and therefore they could not be memorized prior to the test phase). None of the items were real words in Spanish.

All 24 legal stimuli (12 seen and 12 unseen) were used to generate the 24 illegal stimuli used in the test phase. This was done by exchanging the position of $C_1$ and $C_2$ in each instance (e.g. FIMO). For each participant, 16 of the possible 24 legal stimuli (eight seen and eight unseen), along with their matching illegal stimuli, were selected for inclusion in the test phase[1]. These 16 legal items were then randomly combined with the 16 illegal items to form 16 pairs. In the test phase each pair was shown twice, with the legal stimuli appearing once on the left and once on the right, to give a total of 32 test trials for each subject. All stimuli are shown in Appendix 1.

This task was implemented using the E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002) and it was administered using a laptop computer with a 13-inch screen.

***Explicit learning.*** The possibility that children gained explicit knowledge about the orthographic rules was assessed through a short questionnaire with the following two questions: “If another child came to play this game, what piece of advice would you give her/him in order to solve it?” and “Did you notice anything special about these words?”.

**Procedure.** The test battery was administered in three sessions. The first session had an approximate duration of 15 minutes and consisted of the individual administration of the intelligence test (Raven) and the word and pseudoword reading tasks from Test LEE. In the second session, the writing task and the attention task were administered in groups of 10-12 students. Finally, in the third session, each participant was engaged in the memory task and

[1] This essentially reduced the number of trials in the test phase from 48 to 32, and this was done to reduce the possibility of participant fatigue during the test phase. Items were selected such that, for each group of 3 participants, all 24 legal and 24 illegal items were used twice each.

the implicit learning task, for about 25 minutes. The learning task was introduced as a game and participants were told that they were about to see words from a foreign language.

The administration of the implicit learning experiment consisted of two phases: an *exposure phase,* where legal stimuli were displayed, and a *test phase*, where pairs of stimuli were displayed, one stimulus being legal (seen or unseen previously) and one illegal (and therefore, not seen before). Between phases, six simple mathematical additions were introduced as a distractor task.

In the exposure phase, the administrator explained to participants that they would see African words, though nothing was said about the positional constraints. Stimuli were presented in three blocks separated by brief breaks. Each block contained the 36 legal items, presented in a random order; thus, at the end of the exposure phase, participants had seen 108 items. Each trial started with a blank screen (400 ms) followed by a fixation point (400 ms), after which the stimuli was displayed (1000 ms). In order to maintain attention, 12 random stimuli (three per block) were displayed in red, as opposed to the usual black, and participants were asked to push the spacebar as soon as they saw a red word.

In the test phase, participants were asked to identify words from this foreign language among pseudowords. There were two blocks of 16 trials, each trial contained a pair of stimuli (one legal and one illegal) placed one next to the other in the center of the screen. Participants were told that only one word was African and that their task consisted of introducing their response by pressing one of two keys according to the target position. Participants had no time limit to respond and no feedback was given. The whole experiment took approximately 15 minutes, depending on the participant's response speed. The brief interview to assess explicit knowledge was introduced immediately after completing the test phase.

**Results**

None of the 55 participants reported any explicit knowledge about the artificial rules. However, five of the participants were excluded from the analysis on the basis that they displayed signs of reading impairment. This was defined as a score equal to or below the 25th percentile in both word and pseudoword reading measures from test LEE. All data summaries and data analyses report just the 50 participants retained for analysis.

The descriptive statistics of all measures are presented in Table 1.

Table 1

*Descriptive statistics: mean scores and (standard deviations), minimum and maximum scores for the cognitive measures, and the reading and writing tasks*

| Measure | Mean and (Standard Deviation) | Minimum | Maximum |
|---|---|---|---|
| **Cognitive Measures** | | | |
| IQ – Raven | 95.1(15.45) | 75 | 120 |
| Verbal Memory – WISC | 14.0 ( 2.93) | 9 | 22 |
| Attention – Faces (60) | 57.9 ( 2.14) | 52 | 60 |
| **Reading Skills** | | | |
| Word Reading Accuracy – LEE (84) | 76.1 ( 4.4) | 66 | 84 |
| Word Reading Speed – LEE (seconds) | 49.7 (13.8) | 27 | 97 |
| Pseudoword Reading Accuracy – LEE (84) | 70.1 ( 5.8) | 56 | 82 |
| Pseudoword Reading Speed – LEE (seconds) | 66.4 ( 3.8) | 42 | 135 |
| **Writing Skills** | | | |
| Word Writing LEE overall (44) | 38.1 (3.4) | 30 | 44 |
| Pseudoword Writing LEE (32) | 26.1 (3.6) | 16 | 32 |

*Note.* Numbers between parentheses in the measure column refer to the maximum possible score in the task.

In order to test whether implicit learning had occurred, single-sample *t*-tests were conducted comparing participants' performance against chance level (50%) both for the seen and unseen stimuli. We found that participants performed above chance in both cases (seen: M = 60.8 %, *SD* = 17,4 $t_{49} = 4.58$, $p < .001$, $r = .55$; unseen: M = 61.2%, *SD* = 15.2; $t_{49} = 5.19$; $p < .001$, $r = .60$), which indicates that participants could successfully identify seen stimuli as well as novel stimuli that were rule-consistent.

Correlation analyses were run in order to explore whether implicit learning was related to reading and writing skills, as well as to the cognitive measures. Results from the correlation analyses between the implicit learning task and the cognitive measures are displayed in Table 2.

Table 2

*Pearson correlation among the implicit learning task (seen and unseen items) and the cognitive measures (intelligence, memory and attention) (N= 50)*

| | IL-Unseen | IQ | Memory | Attention |
|---|---|---|---|---|
| IL-Seen | $r = .374$** $p = .006$ | $r = -.24$ $p = .089$ | $r = -.21$ $p = .135$ | $r = -.02$ $p = .867$ |
| IL-Unseen | | $r = .05$ $p = .720$ | $r = -.13$ $p = .378$ | $r = .16$ $p = .276$ |
| IQ | | | $r = -.08$ $p = .568$ | $r = .18$ $p = .223$ |
| Memory | | | | $r = .02$ $p = .918$ |

*Note.* Implicit Learning (IL).

*$p < 0.05$. **$p < 0.01$.

Correlation analyses between the implicit learning task and measures of reading and writing skills are shown in Table 3.

Table 3

*Pearson correlation among the implicit learning task (seen and unseen items), the reading tasks (accuracy and speed) and the writing tasks (word and pseudoword writing lists) (N= 50)*

| | IL-Unseen | WR Accuracy | WR Speed | PWR Accuracy | PWR Speed | WW | PWW |
|---|---|---|---|---|---|---|---|
| IL-Seen | *r* = .37**<br>*p* = .006 | *r* = .20<br>*p* = .162 | *r* = -.25<br>*p* = .078 | *r* = .03<br>*p* = .857 | *r* = -.20<br>*p* = .169 | *r* = .20<br>*p* = .168 | *r* = .15<br>*p* = .304 |
| IL-Unseen | | *r* = .07<br>*p* = .617 | *r* = -.14<br>*p* = .335 | *r* = -.11<br>*p* = .431 | *r* =-.16<br>*p* = .272 | *r* = .06<br>*p* = .689 | *r* = .15<br>*p* = .290 |
| WR Accuracy | | | *r* = -.51*<br>*p* = .000 | *r* = .51**<br>*p* = .000 | *r* =- .33*<br>*p* = .019 | *r* = .513**<br>*p* = .000 | *r* = .49**<br>*p* = .00 |
| WR Speed | | | | *r* = -.29<br>*p* = .051 | *r* = .33*<br>*p* = .021 | *r* =-.44**<br>*p* = .002 | *r* = -.29**<br>*p* = .051 |
| PWR Accuracy | | | | | *r* =-.13**<br>*p* = .373 | *r* = .40**<br>*p* = .005 | *r* = .26**<br>*p* = .078 |
| PWR Speed | | | | | | *r* =-.25<br>*p* = .095 | *r* = -.12<br>*p* = .406 |
| WW | | | | | | | *r* = .57**<br>*p* = .000 |

*Note.* Implicit Learning (IL), word reading (WR), word writing (WW), pseudoword reading (PWR), pseudoword writing (PWW).

*$p < 0.05$. **$p < 0.01$.

Performance on seen or unseen items did not correlate with reading accuracy or reading speed. No significant correlations were found either between implicit learning and writing skills.

**Discussion**

The current results show that our novel experimental task was able to induce the implicit learning of orthographic regularities in Spanish children. Thus, we achieved our objective to develop an ecologically valid implicit learning task, able to assess the acquisition of linguistic regularities (similar to those of natural language) by means of mere exposure.

When exploring the relationship between implicit learning abilities and reading skills, we failed to find any significant correlations. The lack of correlations is not surprising given that the Spanish reading system is very transparent, and therefore decoding skills are sufficient to correctly read in most cases. Therefore, the current data suggests that implicit learning abilities are not related to reading in Spanish as they are in English. Of note, studies in English found significant correlations after assessing 38 children (Arciuli & Simpson, 2012) and 44 adults (Sperling et al., 2004), which constitute smaller samples than the current one. Thus, this difference in the results suggests that the relationship between implicit learning and reading is likely moderated by the opacity of the orthography.

Contrary to our expectations, no correlations were found between implicit learning abilities and writing skills in Spanish –a result that also contradicts findings in English (Sperling et al, 2004; Steffler, 2004). Thus, these results either suggest that implicit learning abilities are not so relevant for spelling in a transparent orthography, or that some methodological issues account for the current results. Although the word and pseudoword writing tasks of Test LEE contain some items with inconsistent phonological patterns, most items are consistent and therefore can be accurately spelled by applying phonological conversions. If implicit learning contributes to the acquisition of complex orthographic patterns, it may be necessary to employ spelling tasks that tap into the complex patterns of Spanish in order to find a relationship between implicit learning and writing skills.

### Implicit learning and the writing of inconsistent items (Test Proesc)

To further explore the relationship between implicit learning and writing performance, we conducted a new study employing a novel standardized writing test which assessed the spelling of inconsistent patterns.

#### Method

**Participants.** In order to optimize time and effort, twenty-six children from the sample of 50 participants were assessed with the new writing task. Although the remaining twenty-four participants were also contacted, we could not assess them due to time restrictions.

**Materials.** As the participants had already been assessed with the implicit learning task, only the writing tasks were administered.

***Word writing***. The word writing task of Test Proesc (Cuetos, Ramos, & Ruano, 2002) consists of two lists of 25 items each, where inconsistent phonological patterns are embedded. List A assesses lexical spelling purely as the inconsistent patterns can only be solved with word-specific knowledge. In contrast, List B assesses rule-based spelling, as the inconsistencies can also be solved with the application of graphotactic or morphological rules. For example, the /b/ sound in cantaba (the past tense of sing) is ambiguous as it could be represented either by B or V; however, an orthographic rule mandates that all past tense verbs ending in /aba/ be spelled with B. Although inconsistencies in List B can be solved following rules, it is important to note that a lexical strategy could also be employed.

***Pseudoword writing.*** The pseudoword writing task of Test Proesc is divided in two parts, which are here referred to as *lists* for clearer understanding. List A (Coding Skills) comprises 10 items which assesses phoneme-grapheme coding skills. List B (Rule-based Spelling) comprises 15 items, which, in addition to coding skills, assess the ability to transfer morphological and graphotactic Spanish patterns to pseudowords. For example, there is a rule which mandates that all words beginning with the diphthong /ue/ must be spelled with an initial H (hue); accordingly, if this rule is also applied to pseudowords, the item /uefo/ should be spelled with *huefo*.

## Results

The descriptive statistics of the writing measures are presented in Table 4.

Table 4

*Descriptive statistics: mean scores and (standard deviations), minimum and maximum scores of the IQ and the writing tasks (N = 26).*

| Measure | Mean and (Standard Deviation) | Minimum | Maximum |
|---|---|---|---|
| Word Writing Proesc List A- Lexical (25) | 20.42 (2.83) | 15 | 25 |
| Word Writing Proesc List B- Rule-based (25) | 21.46 (2.23) | 16 | 25 |
| Pseudoword Writing Proesc overall (25) | 18.19 (2.08) | 14 | 21 |
| Pseudoword Writing Proesc List A- Coding (10) | 7.77 (1.03) | 5 | 9 |
| Pseudoword Writing Proesc List B- Rule-based (15) | 10.42 (2.04) | 6 | 13 |

Performance in the implicit learning task for this portion of participants followed the same pattern as for the original sample of 50 participants (seen items: M = 61%, $SD = 15.5$, $t_{25} = 3.14$; $p = .004$, $r = .53$; unseen items: M = 62%, $SD = 12.5$, $t_{25} = 5.01$; $p < .001$, $r = .71$). Of important note, 26 participants constitute a small sample size and therefore only correlations of large effect size ($r \geq .5$) could be detected (Faul, Erdfelder, Lang, & Buchner, 2007).

Results from the correlation analyses are displayed in Table 5.

Table 5

*Pearson correlation among the implicit learning task (overall, seen items and unseen items), the reading tasks (accuracy and speed) and the writing tasks (word and pseudoword writing lists) (N= 26)*

| | IL-Unseen | WW- All Items | WW- List A Lexical | WW- List B Rule-based | PWW- All items | PWW-List A Coding | PWW-List B Rule-based |
|---|---|---|---|---|---|---|---|
| IL-Seen | *r* = .29 *p* = .155 | *r* = .57** *p* = .003 | *r* = .54** *p* = .004 | *r* = .41* *p* = .037 | *r* = .03 *p* = .885 | *r* =-.01 *p* = .967 | *r = .03* *p = .867* |
| IL-Unseen | | *r* = .06 *p* = .579 | *r* = .25 *p* = .220 | *r* = -.15 *p* = .473 | *r* = .11 *p* = .586 | *r* = .31 *p* = .126 | *r = -.04* *p = .840* |
| WW-All Items | | | *r* = .84** *p* = .000 | *r* = .84** *p* = .000 | *r* = .39 *p* = .050 | *r* = .16 *p* = .446 | *r = .32* *p = .116* |
| WW-List A Lexical | | | | *r* = .42* *p* = .035 | *r* = .32 *p* = .112 | *r* = .23 *p* = .259 | *r = .21* *p = .306* |
| WW- List B Rule-based | | | | | *r* = .33 *p* = .096 | *r* = .03 *p* = .881 | *r = .32* *p = .106* |
| PWW-All items | | | | | | *r* = .28 *p* = .162 | *r = .87*** *p = .000* |
| PWW-List A Coding | | | | | | | *r = -.22* *p = .286* |

*Note.* Implicit Learning (IL), word reading (WR), word writing (WW), pseudoword reading (PWR), pseudoword writing (PWW).

*$p < 0.05$. **$p < 0.01$.

We found that the ability to recognize legal seen items was significantly related to performance on word writing overall, and to List A (lexical spelling) ($r$ = .54; $p$ = .004) and List B (Rule-based Spelling) ($r$ =.41; $p$ = .037) separately, but not to pseudoword writing. The ability to recognize legal unseen items was also not related to word or pseudoword writing in any case; the correlation between unseen items and pseudoword writing List B (ruled-based spelling) was particularly far from significance.

**Discussion**

A strong correlation was found between the performance on seen items and the word writing task (both lexical and rule-based spelling). These results replicate the findings of an artificial grammar learning task conducted with English-speaking children, where the ability to identify legal seen stimuli correlated with writing skills (Steffler, 2004). Performance on seen items reflects instance-based knowledge and is an indicator of exemplar recognition, whereas the spelling of inconsistent words reflects knowledge about lexical units. Therefore, the relationship between seen items and inconsistent word writing may be explained by a common memory process. Both seen items and words have been previously encountered by the subject and thus they might have become familiar. According to Pérez, Majerus, and Poncelet (2012), this familiarity is the effect of repeated exposure, as it enables the storage of specified items in memory. The stronger relationship between seen items and List A (lexical spelling) over List B (ruled-based spelling) provides some support for this hypothesis, since to correctly spell the words from List A one must rely exclusively on stored information about lexical units.

No significant correlations were found between implicit learning and the pseudoword writing task. Again, it is not surprising that the acquisition of complex orthographic patterns was not strongly related to pseudoword spelling where just phonological conversions were sufficient (List A). In contrast, if (as theoretically proposed) List B measures the ability to transfer complex orthographic rules to new instances (pseudowords), we would have expected a relationship with performance on unseen items, as these items measure the ability to transfer rules to novel items. Contrary to expectations, this relationship was very far from significance.

**General Discussion**

In the present study we assessed whether the ability to implicitly learn graphotactic regularities was related to reading and writing skills in Spanish, a shallow alphabetic language which contains virtually no inconsistencies in the reading system but which contains several inconsistencies in the writing system.

Participants showed significant implicit learning of the graphotactic patterns, as they were not only able to identify legal seen items, but also to transfer the rules to new items (previously unseen). It is important to highlight that no relationship was found between the implicit learning task and the cognitive measures (intelligence, verbal memory or visual attention). These results support the implicit learning phenomenon, as they show that this learning ability is strong enough to learn new visual/linguistic regularities, in absence of effortful or conscious strategies.

No significant correlations arose between implicit learning of graphotactic regularities and reading skills. These results differ from findings in English, where the ability to implicitly learn visual regularities was related to reading skills (Arciuli & Simpson, 2012; Sperling et al., 2004). Nevertheless, the current results are not surprising given that Spanish is a transparent orthography. As grapheme-to-phoneme mappings are mainly 1-to-1, applying decoding rules (which are explicitly taught in school) constitutes a very effective strategy in Spanish, and therefore the implicit ability to acquire complex orthographic patterns may not be as relevant in Spanish as it is in English. The contrasting results between the two orthographies suggest that the relationship between implicit learning abilities and reading performance is moderated by the opacity of the orthography.

As Steffler's (2004) study suggests, the implicit learning of visual regularities seems to be related to writing skills in English. The Spanish writing system as –opposed to the reading system– has several inconsistencies which cannot be resolved with the sole application of phoneme-grapheme correspondences. As some authors have shown (e.g. Pacton et al., 2001; Treiman, 1993), other orthographic regularities can be implicitly acquired and used to produce correct spellings when dealing with inconsistent words. Thus, the ability to implicitly learn graphotactic regularities was expected to be related to proficiency with writing in Spanish, particularly when spelling inconsistent patterns. Correlation analyses conducted with the Test LEE showed no significant relationship between implicit learning and writing skills, probably because most writing items could be accurately spelled by applying phonological conversions. In contrast, a significant relationship was found between implicit learning and the word writing task of Test Proesc, where all items contain an inconsistent spelling pattern. This relationship, however, was only found with regards to the seen items of the implicit learning task but not for the unseen items. Discrimination between seen and unseen items is therefore relevant: while performance on unseen items shows the generalization of rules to novel stimuli, performance on seen items reflects instance-based knowledge. This clear relationship between inconsistent word writing and seen items shows that there is a common retrieval mechanism, as both have been previously encountered by the subject and thus they are familiar. In both cases, repetitions of instances may activate implicit learning processes, which generate sensitivity to the items and their subsequent recognition. The stronger relationship between seen items and List A (lexical spelling) over List B (ruled-based spelling) supports this hypothesis, since word spelling in List A relies exclusively on retrieval processes.

When it came to pseudoword writing of items which only assessed phoneme-grapheme mappings (in both Test LEE and Proesc), no relationships were found with the implicit learning task. These results are in line with our previous findings regarding reading, suggesting once again that phonological knowledge in a shallow orthography is not related to the implicit learning of graphotactic patterns. However, contrary to expectations, no relationships were either found between the implicit learning abilities and the spelling of pseudowords where graphotactic and morphological knowledge was expected to be applied (List B of Test Proesc). This does not necessarily mean that the implicit learning of graphotactic regularities does not play any role in writing new words; as Pacton et al. (2001) showed, graphotactic knowledge is implicitly learned and used quite early in development. The lack of correlations may rather be explained by other reasons, such as the small sample size that completed the Test Procesc or the features of this pseudoword writing task itself. Descriptive statistics showed that at this age (8 years-old), children's mean accuracy rate in List B (rule-based spelling) was 67%. This result may suggest two possibilities. First, it may indicate that 8 year-olds have not yet acquired certain graphotactic regularities. Secondly, it may be the case that the pseudoword task is not sensitive enough to capture children's graphotactic knowledge. In contrast to Pacton et al.'s (2005) task (where children had to identify frequent graphotactic patterns embedded in pseudowords), in the Test Proesc children were asked to spell pseudowords to dictation (which implies a stronger effort to produce the spelling). In addition, asking children to write "made up" words may encourage them to use phoneme-grapheme rules exclusively. As these words do not exist and a context is not provided to imagine a meaning, children might have just focused on spelling the phonemes without paying attention to the graphotactic or morphological regularities existing in the real language.

To summarize, results from this study suggest that implicit learning may not be related to reading skills in a shallow orthography as they are in an opaque orthography, since explicit phonological rules might be enough to read accurately in most cases. Implicit learning of seen items proved to be related to the spelling of inconsistent words, suggesting that the ability to learn whole items from exposure plays a clear role in the writing of inconsistent words. In contrast, no relationship was found between the identification of novel items and word or pseudoword spelling (not even when graphotactic and morphological knowledge was expected to be applied). These results either suggest that there is no relationship between the ability to transfer orthographic patterns and spelling skills in a transparent orthography, or that the methodological approach was not accurate enough to capture this relationship.

**Limitations of the Current Study**

It is important to consider that –as previously mentioned– the present study contains some limitations. The first limitation may be due to the sample sizes employed. Whereas a sample size of 50 participants may be enough to detect moderate ($r \geq .3$) correlations, a sample of 26 participants only enables the detection of correlations exhibiting a large effect size ($r \geq .5$). In both cases, the sample sizes may not be enough to find a significant correlation if its effect size is small ($r \leq .3$). Therefore, we consider that a follow-up study should increase the sample size to explore weather implicit learning abilities are related to reading or writing in Spanish in a subtle manner. The second limitation of the current study is related to the spelling measures employed (i.e., Test LEE and Test Proesc) which might have failed at capturing participants' knowledge of frequent morphological or graphotactic patterns. In order to overcome these limitations, further research needs to be conducted. New studies could include larger samples and also older participants. Literacy tasks should include judgment tasks with pairs of pseudowords (where graphotactic knowledge can be assessed), pseudoword spelling embedded in a sentence context (where morphological knowledge can be assessed) and/or spelling of homophones (which need different sources of knowledge to resolve their ambiguous spellings).

# STUDY 2

Implicit Learning of Non-linguistic and Linguistic Regularities in Children Typical Development and in Children with Dyslexia

Studies carried out with typical populations suggest that implicit learning indeed plays an important role in literacy acquisition as it enables subjects to acquire orthographic regularities which are not explicitly taught through formal education (Pacton et al., 2005; Pacton et al., 2001). In fact, the Study 1 of the current thesis was able to show that typically-developing children can learn positional regularities after a brief exposure to exemplars. Moreover, some studies in English found that the ability to implicitly learn regularities is related to both children's and adults' reading skills (Arciuli & Simpson, 2012; Sperling et al., 2004). We also found in Study 1 that implicit learning plays a role in the acquisition of inconsistent words in Spanish.

Considering the importance of implicit mechanisms in reading and spelling acquisition, authors such as Gombert (2003) have highlighted the relevance of studying implicit learning processes in individuals with dyslexia. Despite adequate instruction, intelligence and intact sensory abilities, individuals with developmental dyslexia struggle to master orthographic patterns. This has led some authors to propose the existence of an implicit learning deficit partially responsible for the poor acquisition of orthographic regularities (Nicolson, Fawcett, Brookes, & Needle, 2010; Sperling, Lu, & Manis, 2004). The hypothesis of an implicit learning deficit in dyslexia has been mainly explored employing sequence learning tasks and artificial grammar learning (AGL) tasks.

Using the sequence learning paradigm, some authors have found evidence of implicit learning impairments in children (Jiménez-Fernández et al., 2011; Stoodley et al., 2008; Vicari et al., 2003) and adults with dyslexia (Du & Kelly, 2013; Howard et al., 2006; Stoodley et al., 2006). However, other studies reported preserved implicit learning abilities in children and adult populations (Kelly et al., 2002; Menghini et al., 2010; Roodenrys & Dunn, 2008;

Rüsseler et al., 2006). Such inconsistent results may be explained by differences in the methodological approaches. As found in a meta-analysis study with SRT tasks, large variability in the results seems to be explained by the age of the participants and the relative difficulty of each task (Lum et al., 2013).

Ambiguous results have also been reported using AGL tasks. For instance, Pavlidou et al. (2009) investigated the abilities of children with dyslexia to implicitly learn regularities that were embedded in shape strings. Results showed that control participants were able to acquire the regularities, whereas participants from the group with dyslexia exhibited no evidence of learning. In contrast, Pothos and Kirk (2004) reported a very different pattern of results in adults with reading difficulties. Although they employed the same tasks as Pavlidou et al., they found that participants with reading difficulties were able to learn the regularities of the grammar and –more surprisingly– they outperformed participants from the control group. Such contrasting results between these two studies could be explained by key differences between the samples –for example, differences in the age of the participants and the fact that Pothos and Kirk used a far less stringent inclusion criterion for the group with dyslexia.

While the previously described studies investigated the implicit learning of non-linguistic patterns, another AGL study explored the acquisition of linguistic regularities in children with poor spelling skills (Ise, Arnoldi, Bartling, & Schulte-Körne, 2012). In this study, letter strings were generated by two artificial grammars: one containing pronounceable strings (CVCVC) and the other containing non-pronounceable strings (CCCCC). Results showed that although poor spellers were above chance at identifying high frequency patterns in both conditions, they nevertheless performed significantly worse than control participants.

In addition, the analysis of training item recognition revealed that good spellers benefited from the linguistic component, whereas poor spellers did not. However, the results of this study cannot be generalized to individuals with dyslexia as children who showed difficulties in sentence reading (a potential indication of dyslexia) were excluded from the study. Nevertheless, the fact that poor spellers were impaired in the acquisition of linguistic regularities suggests that assessing the implicit learning ability of dyslexic individuals using linguistic and non-linguistic material may be revealing.

To summarize, there is much heterogeneity in the results of studies which have explored the possible link between dyslexia and implicit learning. This heterogeneity may suggest that implicit learning mechanisms do not operate in an all-or-none fashion, and instead may depend upon the features of the sample and the complexity of the learning task. Hence, in order to explore whether an implicit learning deficit is a contributing factor to dyslexia, the focus should be placed on exploring which regularities individuals with dyslexia can and cannot acquire through implicit mechanisms.

One important point to note is that previous research has largely focused on the implicit learning of visual regularities in a general domain. To our knowledge, when Study 2 was conducted, no study had yet investigated the implicit acquisition of orthographic patterns in children with dyslexia; nor had any study compared this ability to the learning of non-linguistic regularities.

**The Current Study**

The current study explored whether children with dyslexia were impaired in the implicit acquisition of positional patterns and whether the introduction of linguistic information affected this acquisition. We selected for possible inclusion in the study children who were in third-grade (8 and 9 year-olds) since it is in this grade when difficulties in reading fluency tend to manifest in Spanish. As previously noted, most researchers have explored the implicit learning abilities of individuals with dyslexia using visual tasks that excluded orthographic cues. Thus, it is not clear whether dyslexics' spelling difficulties are due to difficulties in the acquisition of rules in a visual domain or whether their performance is affected by the introduction of linguistic information. In order to explore this question, we designed two learning tasks where identical positional regularities were embedded within non-linguistic and linguistic strings.

In Experiment 1, abstract shapes were introduced in order to produce four-element-stimuli which lacked visual familiarity and possessed no phonological cues, thus preventing verbalization. In Experiment 2, we explored children's implicit learning of linguistic regularities embedded in a CVCV structure, a very common word structure in Spanish.

The non-linguistic task was tested in a pilot study of 17 typically-developing children aged 8-9 years, with the mean level of correct responses being 59.7% (*SD* = 16.4, range 43.7 – 96.9). The linguistic task was tested previously with 50 typically-developing children of the same age (Study 1), and participants obtained a mean level of correct responses overall of 61.4% (*SD* = 12.1, range 40.6 – 84.4). Importantly, there was no significant difference in performance between these two groups ($t_{41} = 3.86$, $p = .701$), thus suggesting that these tasks elicit a similar level of implicit learning in typically-developing children.

If children with dyslexia have a language-specific implicit learning impairment, they would be expected to show lower levels of implicit learning compared to typically-developing participants in Experiment 2, but not in Experiment 1. In contrast, if children with dyslexia have a general visual implicit learning deficit (not specifically related to the learning of linguistic material), they would be expected to show lower levels of implicit learning than control participants in both experiments. Finally, if children with dyslexia were not impaired in the implicit learning of positional rules, they would be expected to show similar levels of learning to those of control participants in both experiments.

## Experiment 1: Implicit Learning Task without Linguistic Content

### Method

**Participants.** Seventy third-grade students were selected by their teachers as candidates for the group with developmental dyslexia (DD) as they showed persistent reading difficulties in absence of behavioral indicators of comorbid disorders (such as attention deficit or language impairment) or major social problems (such as frequent school absences). None of the participants had received any clinical treatment for their reading difficulties. From this candidate group, a final sample of 21 children (16 boys and five girls) was selected such that all participants had average to high non-verbal IQ (equal to or above 85 in Raven's test), along with poor reading skills. Poor reading was defined as a score equal to or below the 25th percentile in reading accuracy of words and pseudowords from test LEE (see Materials and Apparatus). Since Spanish is a transparent orthography, inaccurate reading is a clear indicator of reading problems. Reading speed was also measured and although most of these children were below the 25th percentile on this measure, a small number had a reading speed above this percentile. However, the high error rate for these children along with information provided by teachers leaves no doubt about the diagnosis of DD.

The 21 participants with DD were matched by age, gender and IQ with 21 typically-developing (TD) children. These participants were selected to have good reading skills, defined as a score equal to or above the 50th percentile in both reading accuracy and reading speed of words and pseudowords (Test LEE).

All participants were native Spanish speakers, came from a similar middle-class background, lived in the same district and attended the school grade that corresponded to their chronological age. A summary of the two groups' non-verbal IQ and reading abilities is presented in Table 6.

Table 6

*Mean scores and (standard deviations) of non-verbal IQ, word reading accuracy and reading speed, and pseudoword reading accuracy and reading speed broken down by group: developmental dyslexia (DD) and typically-developing(TD).*

| Group | IQ | Word Reading Percentile | | Pseudoword Reading Percentile | |
|---|---|---|---|---|---|
| | | Accuracy | Speed | Accuracy | Speed |
| DD | 96.3 (8.7) | 12.1 (5.4) | 24.8 (19.3) | 12.1 (4.3) | 36.2 (24.1) |
| TD | 98.1 (10.4) | 75.8 (14.9) | 83.7 (9.4) | 68.9 (12.6) | 76.8 (19.4) |

**Materials and Apparatus.**

***Word and Pseudoword Reading.*** Participants' reading skills were measured using the word and pseudoword reading tasks from the standardized Test LEE (Defior et al., 2006). The word reading task consists of a list of 42 words of medium frequency which vary in length and orthographic complexity. A maximum of 2 points can be awarded for each item with 1 point awarded for correct decoding and a further point for normal fluency (i.e. absence of repetitions or syllabic reading). Reading speed (i.e. the time spent to read all items) was also assessed.

The pseudoword reading task also includes 42 items, made up by combining syllables extracted from the word reading task. Reading speed was also assessed and scoring criteria was identical to the word reading task.

***Intelligence.*** Intellectual capacity was estimated using the Raven's Colored Progressive Matrices (Raven, Court, & Raven, 1996) which provides a measure of non-verbal IQ.

***Implicit Learning of Non-Linguistic Regularities.*** Stimuli for the implicit learning task consisted of four-shape strings ($S_1S_2S_3S_4$) formed from a set of 10 abstract shapes based on Fiser and Aslin (2001) (see Appendix 2). Three specific shapes could be embedded in $S_1$ and three different shapes in $S_3$. The remaining four shapes could appear in both $S_2$ and $S_4$, thus giving a total of 144 possible legal combinations. Thirty-six strings were selected for inclusion in the exposure phase. Eight of these were also selected for inclusion in a later test phase as *legal seen* stimuli (see Procedure). Another set of eight legal items, not used in the exposure phase, was selected from the remaining 108 possible legal combinations to be used as *legal unseen* stimuli (i.e. not seen in the exposure phase and therefore they could not be memorised prior to the test phase). The sixteen legal stimuli were used to generate the 16 illegal stimuli introduced in the test phase. This was done by exchanging the position of $S_1$ and $S_3$ in each instance (i.e., $S_3S_2S_1S_4$). The legal items were randomly combined with the illegal items to form 16 pairs. In the test phase each pair was shown twice to give a total of 32 test trials for each subject with the positon of the legal items counterbalanced (left vs right).

***Explicit learning.*** The possibility that children gained explicit knowledge about the orthographic rules was assessed through a short questionnaire with the following two questions: "If another child came to play this game, what piece of advice would you give her/him in order to solve it?" and "Did you notice anything special about these words?".

**Procedure.** The test battery was individually administered in two sessions. The non-verbal intelligence test and the reading test were administered in the first session, while the implicit learning task was administered between two and eight weeks later in the second session. This task was presented utilizing the E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002).

In order to create an engaging environment, the experiment was introduced as a game and the evaluator explained that participants who won the game would receive stickers (stickers were given to all participants regardless of their performance).

The experiment was administered in two phases: an *exposure phase,* where legal stimuli were displayed, and a *test phase*, where pairs of stimuli were displayed, one stimulus being legal (previously seen or unseen) and one illegal (and therefore not seen before). Between phases, a distractor task was introduced consisting of six one-digit additions.

In the exposure phase, participants were told that they would see words from a new language, though nothing was said about the positional constraints. Stimuli were presented in three blocks separated by short breaks. Each block contained the 36 legal items presented in a random order and, thus, at the end of the exposure phase participants had seen 108 items. Each trial started after a blank screen (400ms) and a fixation point (400ms), and it consisted of displaying one figure in position 1 and adding subsequent figures in positions 2, 3 and 4 at intervals of 150ms[2]. Once the whole stimulus was completed (that is, all four components were visible), it remained on screen for a further 150ms. In order to maintain attention, 12 randomly selected stimuli (three per block) were displayed in red as opposed to the usual black and participants were asked to push the spacebar as soon as they saw a red "word".

Immediately after the distractor task, the test phase was introduced and participants were asked to identify "words" from the new language. There were two blocks of 16 trials, each containing a pair of stimuli (one legal and one illegal) placed one next to the other in the centre of the screen. The administrator explained that only one item in each pair was a "word" and that participants should decide which one by pressing one of two keys that corresponded to the position of the stimuli on the screen. There was no time limit to respond and no feedback was given. The experiment was administered in one session of approximately 15 minutes, depending on how quickly each participant responded during the test phase.

The questionnaire exploring explicit knowledge was administered immediately after the experiment.

[2] Shapes were sequentially added as a previous pilot study with a sample of typically-developing third-graders showed that participants could only learn the visual regularities when each shape was added to the display one-at-a-time (instead of presenting all four shapes at once).

**Results**

All participants were retained for analyses as none showed evidence of explicit knowledge about the positional rules when answering the explicit learning questionnaire. Independent sample *t*-tests confirmed no differences between the two groups in terms of IQ ($t_{40} = .61$, $p = .544$, $r = .10$) but significant differences in terms of word reading accuracy ($t_{40} = 37.73$, $p < .001$, $r = .99$), word reading speed ($t_{40} = 12.05$, $p < .001$, $r = .88$), pseudoword reading accuracy ($t_{40} = 9.45$, $p < .001$, $r = .83$) and pseudoword reading speed ($t_{40} = 5.84$, $p < .001$, $r = .68$).

No significant differences were found between the performance of participants across blocks 1 or 2 ($p > .05$) for either group; thus, results were collapsed across blocks in all subsequent analyses. Figure 8 summarizes the correct response rate in the test phase for seen stimuli (16) and unseen stimuli (16) separately for the DD and TD group.

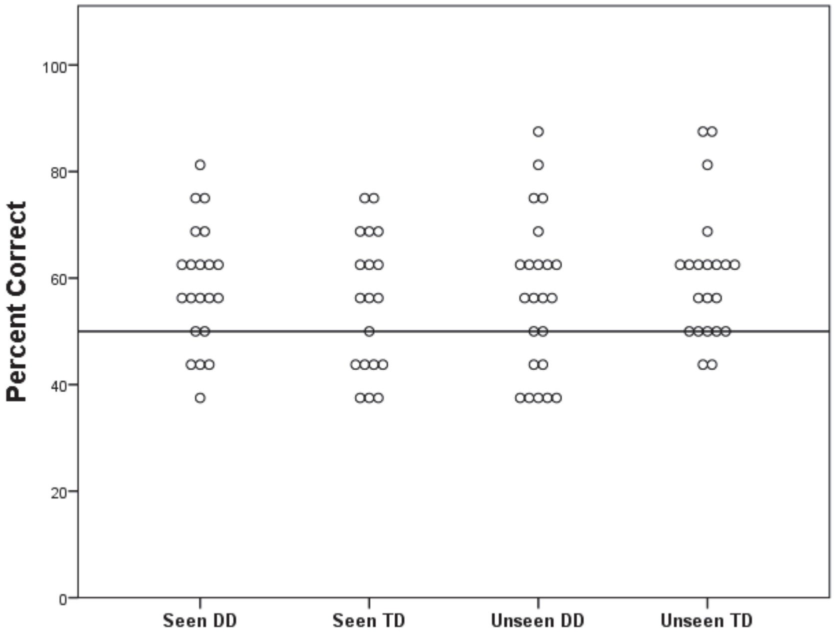



*Figure 8*. Percent correct performance on seen and unseen items for participants with developmental dyslexia (DD) and with typical development (TD).

Results from one sample *t*-tests showed that participants from the TD group performed above chance level in both cases (seen items: M = 57.1, *SD* = 14.15, $t_{20}$ = 2.31, *p* = .032, *r* = .46; unseen items: M = 60.4, *SD* = 12.55, $t_{20}$ = 3.80; *p* = .001, *r* = .65). In contrast, participants with DD performed above chance level only in the seen condition (M = 58.6; *SD* = 11.4, $t_{20}$ = 3.46, *p* = .002, *r* = .61), whereas performance on unseen items did not reach significance (M = 54.8; *SD* = 13.7, $t_{20}$ = 1.59; *p* = .126, *r* = .33) thus suggesting some difficulty in transferring the underlying rules to novel instances.

In order to explore the possibility of an implicit learning deficit within the DD group, a mixed ANOVA was run with one within-subject factor corresponding to type of legal stimuli (seen and unseen) and one between-subject factor corresponding to group (DD and TD). Results revealed no significant main effect of group ($F$ [1, 40] = .45, $p$ = .505, $r$ = .10) or type of legal stimuli ($F$ [1, 40] = .01, $p$ = .908, $r$ = .02). The interaction between group and type of stimulus was also not significant ($F$ [1, 40] = 1.96, $p$ = .169, $r$ = .22).

**Discussion**

Experiment 1 explored implicit learning processes in children with DD when presented with non-linguistic visual material. If children with DD have a general deficit related to the implicit learning of positional rules, they would be expected to show lower levels of learning when compared to their age-matched controls. However, no differences in the performance of the two groups were found, thus suggesting that the implicit learning was similar in both groups.

Nevertheless, although children with DD performed above chance level in the seen condition, they were at chance level in the unseen condition. This latter result might suggest that transferring the underlying positional rules to new instances was somewhat challenging for participants with DD. However, the non-significant interaction in the ANOVA does not support the idea that unseen items were more difficult for the DD group compared to the TD group. Additionally, the effect size of the interaction was small ($r$ = .22) and a power calculation tool (Faul, Erdfelder, Lang, & Buchner, 2007) revealed that more than 80 children would be needed in each group to find a significant difference for this magnitude of effect. Thus, rather than being a lack of power, we believe that this result represents a genuine lack of difference between the two groups for the stimuli used in this experiment.

As noted in the introduction, the question about an implicit learning deficit in individuals with DD should not be considered in an all-or-none fashion, but in relation to the characteristics of the learning task. Previous literature in this area has mainly focused on non-linguistic visual regularities and thus the hypothesis of an implicit learning deficit was explored in a general domain. In contrast, by introducing letters within the stimuli, Experiment 2 allowed us to investigate the possible existence of a linguistic-specific problem with respect to the acquisition of positional regularities.

## Experiment 2: Implicit Learning Task with Linguistic Content

### Method

**Participants.** A new sample of 66 poor readers was preselected by teachers and tested as candidates for the DD group. A final sample of 21 participants with DD (12 boys and 9 girls) was selected and matched with 21control subjects, applying the same criteria as in Experiment 1. A summary of the two groups' non-verbal IQ and reading abilities is presented in Table 7.

Table 7

*Mean scores and (standard deviations) of non-verbal IQ, word reading accuracy and reading speed, and pseudoword reading accuracy and reading speed broken down by group: developmental dyslexia (DD) and typically-developing (TD).*

| Group | IQ | Word Reading Percentile | | Pseudoword Reading Percentile | |
|---|---|---|---|---|---|
| | | Accuracy | Speed | Accuracy | Speed |
| DD | 100.0 (8.9) | 10.9 (3.4) | 15.9 (13.4) | 12.1 (4.6) | 27.1 (21.1) |
| TD | 100.5 (9.2) | 82.6 (8.0) | 84.2 (10.8) | 79.0 (7.3) | 85.5 (5.7) |

**Materials and Apparatus.**

***Word and Pseudoword Reading and Intelligence.*** The same tasks as in Experiment 1 were used to assess reading skills and non-verbal IQ.

***Implicit Learning of Orthographic Regularities.*** The experimental design of this task was the same as in the Experiment 1 of the current study, since identical positional constraints were embedded in the stimuli; however, the abstract shapes of Experiment 1 were replaced by letters (as it is shown in Appendix 2). Stimuli of this task were $C_1V_1C_2V_2$ pseudowords and were formed from a set of 10 letters: six consonants (F, L, M, N, S, T) and four vowels (A, E, I, O). In the first consonant position ($C_1$) only three letters (L, M, T) could be embedded, whereas in the second consonant position ($C_2$) three different letters (F, N, S) could appear. No restrictions were placed on either vowel position (please, see Study 1 for further details).

***Explicit Knowledge.*** The acquisition of conscious knowledge about the positional rules was assessed using the same questionnaire as in Experiment 1.

## Results

All participants were retained for analyses as none showed evidence of explicit knowledge about the orthographic rules when answering the explicit learning questionnaire. Independent sample *t*-tests confirmed no significant differences between the two groups in terms of non-verbal IQ ($t_{40} = 1.70$, $p = .866$, $r = .26$). In contrast, significant differences were found for word reading accuracy ($t_{40} = 37.73$, $p < .001$, $r = .98$), word reading speed ($t_{40} = 18.25$, $p < .001$, $r = .94$), pseudoword reading accuracy ($t_{40} = 35.91$, $p < .001$, $r = .98$) and pseudoword reading speed ($t_{40} = 12.21$, $p < .001$, $r = .89$).

No significant differences were found between the performance of participants across blocks 1 or 2 ($p > .05$) and therefore results were collapsed across blocks in all subsequent analyses. Figure 9 summarizes the correct response rate in the test phase for seen stimuli (16) and unseen stimuli (16) separately for the DD and TD group.

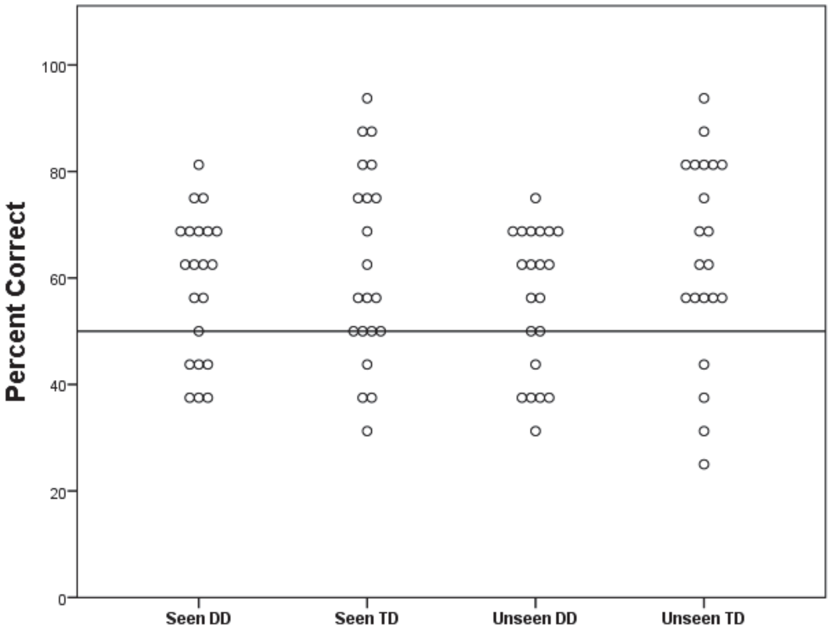



*Figure 9.* Percent correct performance on seen and unseen items for participants with developmental dyslexia (DD) and with typical development (TD).

Results from single sample *t*-tests showed that participants from the TD group again performed above chance level in both (seen items: M = 62.2, *SD* = 18.3, $t_{20}$ = 3.04, *p* = .006, *r* = .56; unseen items: *64.0*, *SD* = 18.8, $t_{20}$ = 3.40, *p* = .003, *r* = .60). Participants with DD also performed above chance level on seen items (M = 58.6, *SD* = 13.6, $t_{20}$ = 2.90, *p* = .009, *r* = .54), while performance on the unseen items just failed to reach significance (M = 55.9, *SD* = 13.6, $t_{20}$ = 2.00, *p* = .059, *r* = .41).

To assess whether differences between the DD and the TD group were significant, a mixed ANOVA was run. There was no main effect of group (*F* [1, 40] = 2.10, *p* = .155, *r* =

.22) nor type of legal stimulus (*F* [1, 40] = .02, *p* = .884, *r* = .02). The interaction between group and type of legal stimulus was also not significant (*F* [1, 40] = .53, *p* = .468, *r* = .11). This indicates that, despite TD children showing higher scores in the experiment, the differences between the two groups were not significant. The small effect sizes again suggest that the null results are not due to a lack of statistical power and instead represent a true lack of difference between the two groups in this task.

**Discussion**

Experiment 2 explored the ability of children with DD to implicitly learn linguistic regularities embedded in pseudowords with a frequent word structure (CVCV). As subjects with DD show persistent difficulties mastering orthographic patterns, we predicted that they would show an implicit learning impairment compared to TD children. However, despite including linguistic information, the pattern of results for Experiment 2 was the same as for Experiment 1. We found that participants with DD could identify items previously encountered at a significant level and that recognition of novel items approached significance.

The analysis of the variance (ANOVA) yielded no significant differences between the DD and the TD group. Taken together, the results of the *t*-test and the ANOVA suggest that children with DD are able to implicitly learn simple orthographic patterns after a brief exposure in a similar manner to TD children.

## Combining Experiment 1 and Experiment 2

Although the regularities introduced in both experiments were identical in terms of position within the string and frequency of occurrence, they differed in terms of content (non-linguistic or linguistic). In order to determine if the presence of linguistic material moderated the learning effect, results from Experiment 1 and Experiment 2 were combined into a single dataset.

### Results

Firstly, independent-sample *t*-tests were conducted to ensure that there were no differences in the non-verbal IQ and reading performance of the two DD groups and the two TD groups across Experiment 1 and 2. No significant differences were found between the two DD groups (IQ: $t_{40} = 1.35$, $p = .186$, $r = .21$; word reading accuracy: $t_{40} = .86$, $p = .396$, $r = .13$; word reading speed: $t_{40} = 1.72$; $p = .094$, $r = .26$; pseudoword reading accuracy: $t_{40} = .00$, $p = 1.00$, $r = .00$; pseudoword reading speed: $t_{40} = 1.29$, $p = .203$, $r = .20$). When comparing the two TD groups, no significant differences were found regarding IQ ($t_{40} = .77$, $p = .445$, $r = .12$) or reading speed (word reading speed: $t_{40} = .51$, $p = .614$, $r = .08$; pseudoword reading speed: $t_{23.62} = 1.91$, $p = .069$, $r = .29$), although significant differences were found in accuracy reading scores (word reading accuracy: $t_{29.88} = 2.31$, $p = .026$, $r = .39$; pseudoword reading accuracy: $t_{40} = 3.26$, $p = .002$, $r = .46$) indicating that participants in the TD group of Experiment 2 were better decoders than TD participants of Experiment 1. Despite these differences, participants of Experiment 1 were equally useful for comparison with the DD group as they all fulfilled the criteria to be classified as good readers (see Participants).

In order to compare the performance of the DD and the TD groups across both experiments, a three-way mixed ANOVA was performed. Two of the factors were between-subjects: experiment (non-linguistic or linguistic) and group (DD or TD). The remaining factor was within-subjects and corresponded to type of legal stimulus (seen or unseen). Unsurprisingly, given the results from the first two experiments, neither the main effect of group ($F$ [1, 80] = 2.43, $p$ = .123, $r$ = .17) nor the main effect of type of legal stimulus ($F$ [1, 80] = .03, $p$ = .852, $r$ = .02) were significant. Importantly, there was no main effect of type of experiment ($F$ [1, 80] = .94, $p$ = .335, $r$ = .11), showing that the performance of all children as a single group was not different when learning non-linguistic or linguistic positional rules. The interaction between experiment and group ($F$ [1, 80] = .54, $p$ = .464, $r$ = .08) was not significant, confirming that both DD and TD children performed equally well when presented with non-linguistic and linguistic material. Given these results, it is unsurprising that none of the other interactions reached significance: type of legal stimulus and type of experiment ($F$ [1, 80] = .00, $p$ = .970, $r$ = .00); type of legal stimulus and group ($F$ [1, 80] = 2.13, $p$ = .148, $r$ = .16); the three-way interaction between type of stimulus, group and experiment ($F$ [1, 80] = .11, $p$ = .737, $r$ = .04).

## General Discussion

Implicit learning mechanisms seem important to develop a set of literacy skills that can only emerge after extended periods of exposure to print (Grabe, 2010). As subjects with dyslexia have persistent difficulties mastering written regularities, an increasing number of authors have suggested the existence of an underlying implicit learning deficit (in addition to a core phonological deficit). However, although a trend suggests the existence of an implicit learning deficit, differences in the results of a vast number of studies could be explained by methodological differences among studies (Lum, et al., 2013). Thus, the literature suggests that implicit learning abilities should not be considered in an all-or-none fashion, but in relation to the complexities of the learning task and the characteristics of the participants.

In the present study, to our knowledge, we explored for the first time the ability of children with DD to implicitly acquire both non-linguistic and linguistic regularities after a brief exposure. In Experiment 1 positional regularities were embedded in abstract shape strings, while in Experiment 2 the same regularities were embedded in letter strings.

Despite using different visual materials, results from both experiments showed a very similar pattern. Participants with DD could significantly identify previously seen items; however, unlike TD children, the identification of novel legal items did not reach a significant level, suggesting that the application or transfer of this knowledge was somewhat challenging for children with DD. Nevertheless, the analysis of the variance (ANOVA) yielded no significant differences between the DD and the TD group in any of the experiments. Thus, these results indicate (i) that Spanish children with DD are able to learn positional regularities after a brief exposure similarly to non-dyslexic children, and (ii) that the linguistic component does not influence *per se* the implicit learning of DD or TD children. The latter finding partially agrees with the work of Ise et al. (2012), who showed that the performance of German children with poor spelling skills did not differ between readable or non-readable stimuli. However, unlike Ise et al., the present study did not find a linguistic material advantage in the TD group. These contrasting results may be explained by the fact that the AGL task used by Ise et al. contained more complex regularities than the tasks of the current study.

Findings from the current study also disagree with previous research carried out with AGL tasks in populations with dyslexia. Whereas the current study shows that both DD and

TD children are able to implicitly acquire positional regularities, Pothos and Kirk (2004) reported that dyslexic adults outperformed non-dyslexic individuals who failed to learn the rules of an AGL task. In order to understand these differences, the characteristics of each study should be taken into account. The dyslexic participants recruited by Pothos and Kirk were adults and as such these participants may have developed compensatory strategies throughout their lives to process visual information. Furthermore, Pothos and Kirk did not apply strict criteria of dyslexia, since neither mother tongue nor intelligence was controlled. Also of note, Pothos and Kirk explained the superior performance of their dyslexic participants by suggesting that the method of presentation (namely, strings of geometric shapes presented side-by-side) caused their control subjects to exert conscious efforts to process each element of the stimuli, and that this might have interfered with their ability to implicitly learn the relationships between the elements. However, the items in the present study (both in Experiment 1 and 2) were presented in the same manner and yet TD children demonstrated significant implicit learning. Thus, the current results not only disagree with the anomalous result reported by Pothos and Kirk (superior performance by DD participants), but they also provide some evidence which weighs against the explanation provided by the authors.

Our findings also do not corroborate the existence of an implicit learning impairment in children with DD, as found by Pavlidou et al. (2009; 2010) who evaluated English speaking children using the same AGL task as Pothos and Kirk (2004). Once again, differences in the methodology could explain the different results. Whereas AGL tasks assess the learning of complex succession patterns, the present study assessed the learning of simple positional regularities which could have been somewhat easier for DD children to acquire. Such contrasting results suggest that IL mechanisms do not operate in an all-or-none fashion, but instead are sensitive to the nature of the learning material and, in particular, the complexity of the relationships.

In the present study, both experiments included positional rules where the identification of just position 1 or just position 3 was enough to successfully complete the task. Results from the ANOVA showed that children with DD were not impaired in the acquisition of these simple rules, regardless of the content (non-linguistic or linguistic). However, results from the *t*-tests suggested a trend by which children with DD could find it slightly harder to transfer these rules to new instances. Thus, this disagreement in the results suggest a main limitation in the current study: the low complexity of the material used in the implicit learning tasks may not have been sensitive enough to uncover a learning impairment in the group with DD. To overcome this limitation, it would be necessary to increase the demands of the experimental tasks. Accordingly, a follow-up study should include stimuli with more complex regularities to encourage higher levels of item processing. For instance, contextual regularities could be embedded in the strings in order to study dyslexics' ability to process whole-stimulus and establish connections among its parts. Specifying which regularities individuals can or cannot acquire through implicit mechanisms is important given that such mechanisms do not operate in an absolute manner.

Although the current study was conducted in Spanish (a transparent writing system), we believe that these findings could be generalized to other languages. Results suggest that the implicit acquisition of positional patterns is a relatively simple task for third-graders and it is not affected by the linguistic content of the items. Thus, based on the present results, we would not expect dyslexic children who spoke a more opaque language (such as English) to demonstrate learning difficulties with this task.

To summarize, the present study explored for the first time the ability of children with DD to implicitly learn positional rules embedded in non-linguistic and linguistic strings. Both the DD group and the TD group were able to acquire the positional rules regardless of the nature of the material, with no differences found between the two groups. Nevertheless, within-group analyses showed that the DD group found it somewhat difficult to generalize the rules to novel stimuli. Thus, although no implicit learning impairment was found in the DD group, it may be the case that more complex regularities would prove more difficult to acquire through implicit mechanisms. Thus, our findings encourage further investigation regarding the possibility that an underlying implicit learning deficit may play a role in dyslexia.

# STUDY 3

Implicit Learning of Complex Orthographic Regularities in Children with Typical Development and in Children with Dyslexia

As it was previously mentioned, a vast number of studies conducted with sequence learning tasks and artificial grammar learning (AGL) tasks suggest that individuals with dyslexia are impaired in the implicit acquisition of visual regularities (Du & Kelly, 2013; Howard et al, 2006; Jiménez-Fernández et al., 2011; Pavlidou & Williams, 2014; Stoodley et al., 2008; Vicari et al., 2003). However, other studies have found no detrimental implicit learning abilities in individuals with dyslexia (Kelly et al., 2002; Menghini et al., 2010; Pothos & Kirk, 2004; Roodenrys & Dunn, 2008; Rüsseler et al., 2006). Such contrasting results suggest that implicit learning impairments in dyslexia are not all-or-nothing, but instead they may (or may not) manifest according to the characteristics of the learning tasks and the individuals. As found in a meta-analysis study carried out with SRT tasks (Lum et al., 2013), some heterogeneity in the results seemed to be explained by differences in the age of the participants (since older participants may display higher levels of performance) and the complexity of the learning tasks. For instance, Du and Kelly (2013) showed that adults with dyslexia were not impaired in the learning of first-order sequences (when only one previous stimulus is necessary to accurately predict the position of the target stimulus), but they were impaired when higher-order sequences were introduced in the task (multiple previous stimuli need to be processed). Additionally, Hedenius et al. (2013) pointed out the importance of the amount of practice. These authors evaluated the performance of children with and without dyslexia on a sequence learning task in which they were required to indicate the position of a target stimulus by pressing one of four keys. Whereas no difference was found between the groups after two testing sessions, a significant difference arose when a third testing session was introduced. This suggests that individuals with dyslexia may benefit significantly less from extended practice than typical readers.

Furthermore, although individuals with dyslexia have specific problems acquiring orthographic regularities, most studies exploring their implicit learning abilities have avoided the use of linguistic stimuli. To our knowledge, only a small number of studies have explored the implicit acquisition of orthographic regularities in individuals with writing impairment (Ise et al., 2012) and with dyslexia (Kahta & Schiff, 2016; Nigro, Jiménez-Fernández, Simpson, & Defior, 2016). Kahta and Schiff used an AGL task where succession rules were embedded in consonant strings five to seven letters in length (such as XXVTV and VJTVXJ). Results showed that although both adults with and without dyslexia could learn the succession constraints of the consonants, significantly poorer implicit learning was displayed by the group with dyslexia. Of note, the letter strings used in this study were unpronounceable and therefore unlike real words. In contrast, in the Study 2 of the current thesis (i.e. Nigro et al., 2016) we investigated the ability of Spanish children with dyslexia to implicitly learn positional regularities embedded in pronounceable pseudowords with a CVCV structure. Results showed no significant differences between the performance of the groups in terms of the amount of implicit learning observed. However, within-group analysis showed some level of difficulty in the group with dyslexia: whereas these participants were able to identify previously encountered stimuli above chance level, they failed at identifying novel legal stimuli. Thus, the results found in Study 2 were ambiguous. If implicit learning impairments in dyslexia manifest only with demanding tasks, we argued the tasks employed in Study 2 might not have been sensitive to uncover an actual deficit. Accordingly, we suggested that further research should be carried out employing experimental tasks with more complex stimuli.

## The Current Study

The aim of the present study was to explore the implicit learning abilities of children with and without dyslexia when exposed to complex linguistic regularities. The participants were presented with linguistic stimuli similar to those used in Study 2, although positional rules were replaced by contextual rules. This was done to increase the task demands as it has been shown that contextual rules are more difficult to acquire than positional rules (Defior, Jiménez-Fernández, & Serrano, 2009; Samara & Caravolas, 2104).

In natural languages contextual regularities establish a relationship between two or more letters and can be relevant to resolve spelling inconsistencies. For example, in Spanish the phoneme /b/ is ambiguous since it can be represented by either the letter B or V; however, when /b/ is followed by /r/ (as in *abrir*) only the letter B is permissible. Research has shown that typical Spanish readers start applying contextual knowledge by the end of second grade (Defior et al., 2009), and the same has been reported in deeper orthographies such as French (Alegría & Mousty, 1996) and English (Hayes, Treiman, & Kessler, 2006). In contrast, evidence has shown that children with dyslexia have persistent difficulties mastering such complex patterns in Spanish (Serrano & Defior, 2012), French (Alegría & Mousty, 1996) and German (Landerl & Wimmer, 2000).

In addition to studying the implicit acquisition of orthographic contextual rules, the current study explored the influence of syllabic complexity on such learning– that is, whether the acquisition of these contextual rules might be affected by the complexity of the syllables included in the stimuli. In Experiment 1, contextual regularities were embedded in pseudowords with a simple structure (CVCV), given that CV is considered an easy syllable in Spanish (Davies et al., 2007; Defior & Serrano, 2005). In Experiment 2, contextual regularities were embedded in stimuli with a more complex structure (CCVCV), as they contained consonants clusters (CC). Studies in Spanish and English have found that decoding and spelling consonant clusters is challenging for children with dyslexia who tend to modify the sequential order of the consonants or eliminate one of them (Bruck & Treiman, 1990; Cassar, Treiman, Moats, Pollo, & Kessler, 2005; Serrano & Defior, 2012).

If participants benefit from the orthographic familiarity of the stimuli, they would be expected to identify previously seen items better than unseen items. If children with dyslexia have an implicit learning deficit responsible for poor automatization of orthographic patterns, they would be expected to perform significantly worse than controls in both experiments, especially in the unseen condition (as this condition assesses the application of the orthographic knowledge in novel situations). Furthermore, if the complexity of the syllabic structure mediates the implicit learning of children with dyslexia, these participants would be expected to show lower performance, or no learning at all, in Experiment 2 (CCVCV).

## Experiment 1: Implicit learning of contextual rules in CVCV stimuli

### Method

**Participants.** Forty-six fourth graders participated in the experiment (22 girls and 24 boys). Twenty-three participants were included in the group with developmental dyslexia (DD) and 23 in the group with typical development (TD). Participants for the DD group were selected from a wider sample of 62 poor readers preselected by their teachers for showing persistent reading difficulties in absence of evident social problems, oral language impairments, neurological or attentional disorders. The final sample of 23 children with DD was determined such that all participants had average to high IQ (equal or above 85 in a non-verbal intelligence test) along with poor reading skills, defined as a score equal to or below the 25th percentile in reading accuracy of words and pseudowords in a standardized reading test (see Materials). Participants of the DD group were matched by school grade, gender and non-verbal IQ with 23 good readers, who were selected from a wider sample of 80 students preselected by their teachers. Good readers were defined as individuals who scored equal to or above the 50th percentile in standardized measures of word and pseudoword reading accuracy and speed. All participants were native Spanish speakers, came from a similar middle-class background and attended the school grade corresponding to their chronological age (9-10 years old).

**Materials and Apparatus.**

***Word and Pseudoword Reading.*** Participants' reading skills were measured using the word and pseudoword reading tasks from the standardized Test LEE (Defior et al., 2006), which assesses reading accuracy and speed.

***Intelligence.*** Non-verbal intelligence was estimated using the Raven's Standard Progressive Matrices (Raven, Court, & Raven, 1996).

***Implicit learning.*** The stimuli consisted of pseudowords with a $C_1V_1C_2V_2$ structure where only four consonants could be embedded in $C_1$ (D, L, P, T), four consonants in $C_2$ (F, M, N, S) and any of four vowels in $V_1$ and $V_2$ (A, E, I, O). The contextual rules specified that each $C_1$ consonant could be paired with just one $C_2$ consonant as follows: T with F (e.g. TIFA), D with N (e.g. DENO), P with M (e.g. POME), and L with S (e.g. LASI). For each contextual combination sixteen exemplars could be generated (1x4x1x4), thus giving a total of 64 possible items. Thirty-two stimuli (eight from each contextual combination) were selected to appear in the exposure phase and were displayed four times each, giving a total of 128 training items. Eight of these 32 stimuli (two of each contextual combination) were selected to be included in the subsequent test phase as legal *seen* stimuli. Eight exemplars not included in the exposure phase were also included in the test phase as legal *unseen* stimuli (see Procedure). A total of 16 legal stimuli (eight seen and eight unseen) were paired with 16 illegal stimuli, which were constructed by splitting the syllables from the 16 legal stimuli and combining a first syllable ($C_1V_1$) with a second syllable ($C_2V_2$) with no regards to the artificial rules. The 16 pairs of pseudowords were shown twice during the test phase to give a total of 32 test trials. The appearance of vowels was counterbalanced in the exposure phase and no real Spanish words were included in the task. All stimuli are shown in Appendix 3.

**Procedure.** The entire test battery was individually administered across two sessions: the intelligence and the reading tests in the first session and the implicit learning task in the second. Approximately two months separated the sessions.

The implicit learning experimental task was introduced as a game in which participants would imagine traveling to a "far-away country" where a different language was spoken (see Study 1 for further details). As in a typical implicit learning task, the current task consisted of an exposure phase where regularities were introduced through repeated presentation of exemplars, followed by a test phase where the acquisition of knowledge was assessed. Stimulus presentation was controlled using E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002).

During the exposure phase, the 32 legal exemplars were randomly displayed once each in four blocks, thus giving a total of 128 instances. Each trial was displayed for 1000ms and was preceded by a blank screen (400ms) and a fixation point (400ms). As is common in implicit learning experiments, a cover task was introduced in the exposure phase to ensure that the participants paid attention to the stimuli (Arciuli & Simpson, 2012b; Arciuli, Torkildsen, Stevens & Simpson, 2014; Brady & Oliva, 2008; Turk-Browne, Jungé, & Scholl, 2005). Eight of the 32 exemplars were displayed in red as opposed to the usual black (two from each contextual combination) and participants were asked to press the space bar whenever a red "word" appeared on screen. A short break was given after the presentation of each block to prevent participant fatigue. After completing the exposure phase, a short distractor task consisting of six single-digit additions was administered.

During the test phase, participants viewed 32 pairs of stimuli (one legal and one illegal) placed either side of the centre of the screen. Half of the legal stimuli had been *seen* in the exposure phase, whereas the other half were new (*unseen*) stimuli. Participants were asked to choose "the word that belonged to this new language" by pressing one of two keys. The 32 trials were presented in two blocks (16 trials each) separated by a short break; trials were identical in both blocks although left and right positions of the stimuli were counterbalanced.

**Results**

In order to verify that participants paid attention to the stimuli during the exposure phase, the percentage of items successfully identified in the cover task was analyzed. Accuracy was above 85% in all cases and therefore all participants were retained for analysis. Table 8 presents a summary of the two groups' non-verbal IQ and reading abilities. Independent sample *t*-tests confirmed that there were no differences between the two groups in terms of IQ ($t_{44} = 0.18$, $p = .861$, $r = .03$), whereas significant differences were found in terms of word reading accuracy ($t_{32.31} = 12.55$, $p < .001$, $r = .91$), word reading speed ($t_{44} =$

9.78, $p < .001$, $r = .83$), pseudoword reading accuracy ($t_{22.55} = 14.34$, $p < .001$, $r = .95$) and pseudoword reading speed ($t_{44} = 7.33$; $p < .001$, $r = .74$).

Table 8

*Mean score and (standard deviation) for IQ, reading accuracy and reading speed for words and pseudowords broken down by group*: *developmental dyslexia (DD) and typical development (TD).*

| Group | IQ | Word Reading Percentile | | Pseudoword Reading Percentile | |
|---|---|---|---|---|---|
| | | Accuracy | Speed | Accuracy | Speed |
| DD | 94.2 (7.6) | 12.8 ( 8.9) | 24.8 (19.2) | 10.4 ( 2.1) | 31.1 (22.6) |
| TD | 94.6 (7.5) | 65.0 (17.8) | 73.9 (14.6) | 62.2 (17.2) | 72.2 (14.6) |

As no significant differences were found between the performance of participants across blocks 1 and 2 of the implicit learning task ($p > .05$), results were collapsed across blocks in all subsequent analyses. Figure 10 summarizes the correct response rate in the test phase for seen stimuli (16) and unseen stimuli (16) separately for the DD and TD group.

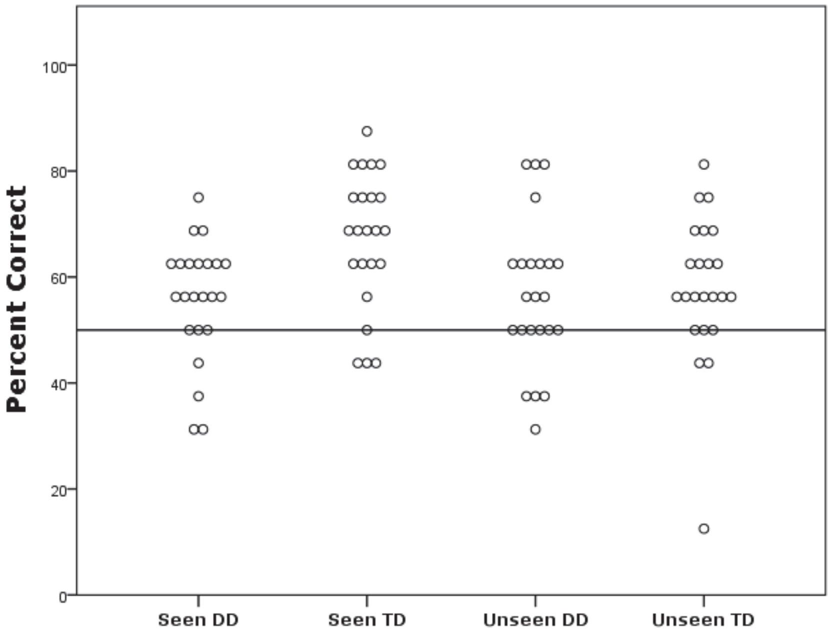



*Figure 10*. Percent correct performance on seen and unseen items for participants with developmental dyslexia (DD) and with typical development (TD).

In the following analyses, *p*-values from traditional analyses are reported so that readers can assess significance. Bayes factors (*B)* are also reported to assess the strength of evidence for each theory. A *B* of 3 or above indicates substantial evidence in favor of the alternative hypothesis, while a *B* of 1/3 or below indicates substantial evidence for the null hypothesis. A *B* between 3 and 1/3 indicates data insensitivity for distinguishing the alternative and null hypotheses. Appendix 5 contains more information on how the Bayes factors for the present study were calculated.

To explore whether implicit learning took place, single sample *t*-tests were run for both the DD and the TD group independently comparing participants' performance against chance level (50%). Performance was tested separately for type of legal stimulus: seen and unseen. Participants in the TD group performed above chance level in both conditions (seen stimuli: M = 67.1, *SD* = 12.8, $t_{22} = 6.41$, $p < .000$, $r = .81$, $B_{H(0,8)} \approx 10^7$; unseen stimuli: M = 57.9, *SD* = 13.9, $t_{22} = 2.72$, $p = .012$, $r = .50$, $B_{H(0,8)} = 14.02$). Participants in the DD group also performed above chance level in both conditions (seen stimuli: M = 55.7, *SD* = 11.3, $t_{22} = 2.42$, $p = .024$, $r = .46$, $B_{H(0,8)} = 6.87$; unseen stimuli: M = 56.8, *SD* = 14.1, $t_{22} = 2.31$, $p = .031$, $r = .43$, $B_{H(0,8)} = 6.02$), although scores for this group were lower than those for the TD group.

Results of a mixed ANOVA comparing the performance of the two groups showed a significant group effect ($F$ [1, 44] = 4.64, $p = .037$, $r = .31$), confirming that participants with DD performed worse than TD participants. Although no main effect of type of legal stimulus was found ($F$ [1, 44] = 2.58, $p = .115$, $r = .22$), a significant interaction arose between group and type of stimulus ($F$ [1, 44] = 4.15, $p = .048$, $r = .29$). Simple effects testing confirmed that the difference between seen and unseen stimuli was significant for the TD group ($F$[1, 44] = 6.64, $p = .013$, $r = .36$, $B_{H(0,8)} = 12.87$) but not for the D group ($F$[1, 44] < 1, $p = .763$, $r = .05$). The Bayes factor in this instance was $B_{H(0,8)} = 0.33$, just above the level needed to accept the null hypothesis. Nevertheless, the evidence moderately supports the null hypothesis that DD children were no better on seen trials compared to unseen trials. Simple effects testing also confirmed that the TD group outperformed the DD group on seen stimuli ($F$[1, 44] = 10.27, $p = .003$, $r = .44$, $B_{H(0,8)} = 59.04$). However, the data indicated insensitivity as to whether the TD group outperformed the DD group on unseen stimuli, but if anything supported the hypothesis of no group difference ($F$[1, 44] < 1, $p$ = .793, $r$ = .04, $B_{H(0,8)}$ = 0.56)[3].

**Discussion**

In Experiment 1, we studied the acquisition of contextual regularities embedded in pseudowords with a simple and common syllabic structure in Spanish (CVCV). Results showed that Spanish children are able to implicitly learn contextual regularities after a brief exposure, a result that agrees with evidence reported for English-speaking individuals (Samara & Caravolas, 2014). The current result also extends previous evidence in Spanish where children were found to learn positional patterns by implicit mechanisms (Nigro et al, 2016), thus showing that Spanish speakers can acquire both positional and contextual patterns after a brief exposure.

Moreover, Experiment 1 yielded some results that were not previously found in relation to positional rules (Study 2). Firstly, we found that not only did DD participants identify seen stimuli above chance, but they could also transfer the contextual rules to new stimuli. Secondly, a significant interaction between type of stimuli and group showed that TD participants recognized seen stimuli better than unseen stimuli and that they outperformed DD participants in this condition. The difference between results of Study 2 and the present results may be explained by the extension of the exposure phase. The current experiment had longer exposure to exemplars than in Study 2, which may have facilitated the consolidation of implicit learning for both DD and TD participants as well as increased

[3] NB: There is one obvious outlier in the data – a child from the TD group who scored 12.5% correct on unseen items, which represents a score more than 3 *SD*s below the mean. Removing this child and repeating all of the analyses yielded the same overall pattern of results.

the differences between the two groups in the seen condition. This suggestion is in line with the results of Hedenius et al. (2013), who found that the differences in the learning of DD and TD children only became significant after extended exposure. Together, these two results suggest that children with DD benefit from experience to a lesser extent than TD children.

The better recognition of previously encountered stimuli in the TD group also shows an effect of implicit memory. It is likely that after repeated exposure some items were stored in memory and thus became familiar. When training items were presented in the test phase, retrieval mechanisms might have enabled the recognition of such items by comparing them with the orthographic units stored. In contrast, participants with DD had a similar performance on seen and unseen stimuli, indicating that they did not benefit from orthographic familiarity. This might be due either to poor storage of the training items or to poor access to the items stored in memory (this will be discussed further in the General Discussion).

In summary, Experiment 1 showed that both TD and DD participants were able to learn contextual orthographic regularities after a brief exposure. However, whereas item-specific familiarity was an advantage for the TD group, participants with DD did not benefit from this trait and performed more poorly than the controls.

As noted previously, CV syllables are considered easy to decode in Spanish and it has been shown that children with DD do not struggle with them (Defior & Serrano, 2005). In contrast, syllables with consonant clusters (CC) can be highly challenging for individuals with reading problems (Alegría & Mousty, 1996; Landerl & Wimmer, 2000; Serrano & Defior, 2012), resulting in either inaccurate or slow decoding. In order to explore the impact of syllabic complexity in the implicit learning of contextual rules, Experiment 2 introduced stimuli with a CCVCV structure.

### Experiment 2: Implicit learning of contextual rules in CCVCV stimuli

#### Method

**Participants.** A new sample of participants was recruited for Experiment 2 in order to maintain the same level of participant naivety as in Experiment 1. The new sample consisted of 43 children: 20 fourth graders (12 girls and 8 boys) and 26 fifth graders (14 girls and 12 boys); 23 children participated in the DD group and were matched by age and gender with 23 TD children (selection criteria for both groups was the same as in Experiment 1). Participants of the DD group and the TD group were selected from wider samples of 76 poor readers and 121 good readers preselected by their teachers. All participants were native Spanish speakers, came from a similar middle-class background and attended the school grade corresponding to their chronological age (4th grade: 9-10 years old; 5th grade: 10-11 years old).

**Materials and Apparatus.**

***Word and Pseudoword Reading and Intelligence.*** The same tests were used as in Experiment 1 to estimate reading skills and non-verbal intelligence.

***Implicit learning.*** This task was similar to the task used in Experiment 1, but consonant clusters were introduced in the first syllable of the stimuli. Artificial constraints were embedded in pseudowords with a $C_1C_2V_1C_3V_2$ structure where only four consonant clusters could be used in $C_1C_2$ (CL, FR, GR, and PL), only four consonants in $C_3$ (D, M, S and T), and any of four vowels in $V_1$ and $V_2$ (A, E, I or O). The contextual rules determined that each $C_1C_2$ could just be paired with one $C_3$, in such a way that CL was paired with T (e.g. CLATE), FR with M (e.g. FREMI), GR with S (e.g. GRISO) and PL with D (e.g. PLODA). Legal and illegal stimuli were constructed following the same procedure as in Experiment 1. All stimuli are shown in Appendix 4.

**Procedure.** The procedure of Experiment 2 was identical to the procedure used in Experiment 1, except for the time each stimulus was displayed. Since the stimuli in this experiment contained 1 extra letter compared to the stimuli in Experiment 1, the presentation time was increased to 1250ms to ensure that the average display time per letter was consistent across experiments (250ms per letter).

**Results**

As per Experiment 1, accuracy in the cover task for all participants was above 85% and thus all participants were retained for analysis. A summary of the two groups' non-verbal IQ and reading abilities is presented in Table 9. Independent sample *t*-tests confirmed no significant differences between the DD and the TD group in terms of non-verbal IQ ($t_{44}$ = .96; $p$ = .343; $r$ = .15). In contrast, significant differences were found for word reading accuracy ($t_{31.83}$ = 14.52; $p < .001$; $r$ = .56), word reading speed ($t_{44}$ = 9.13; $p < .001$; $r$ = .46), pseudoword reading accuracy ($t_{22.48}$ = 11.29; $p < .001$; $r$ = .58) and pseudoword reading speed ($t_{44}$ = 7.19; $p < .001$; $r$ = .37).

Table 9

*Mean score and (standard deviation) for IQ, reading accuracy and reading speed for words and pseudowords broken down by group: developmental dyslexia (DD) and typical development (TD).*

| Group | IQ | Word Reading Percentile | | Pseudoword Reading Percentile | |
|---|---|---|---|---|---|
| | | Accuracy | Speed | Accuracy | Speed |
| DD | 93.6 (8.6) | 12.8 ( 7.8) | 22.0 (18.7) | 10.4 ( 2.1) | 28.0 (25.2) |
| TD | 96.0 (8.3) | 67.0 (16.1) | 76.1 (21.4) | 57.6 (19.9) | 76.7 (20.6) |

As no significant differences were found between the performance of participants across blocks 1 and 2 ($p$ > .05), results were collapsed across blocks in all subsequent analyses. Figure 11 summarizes the correct response rate in the test phase for seen stimuli (16) and unseen stimuli (16) separately for the DD and TD group.

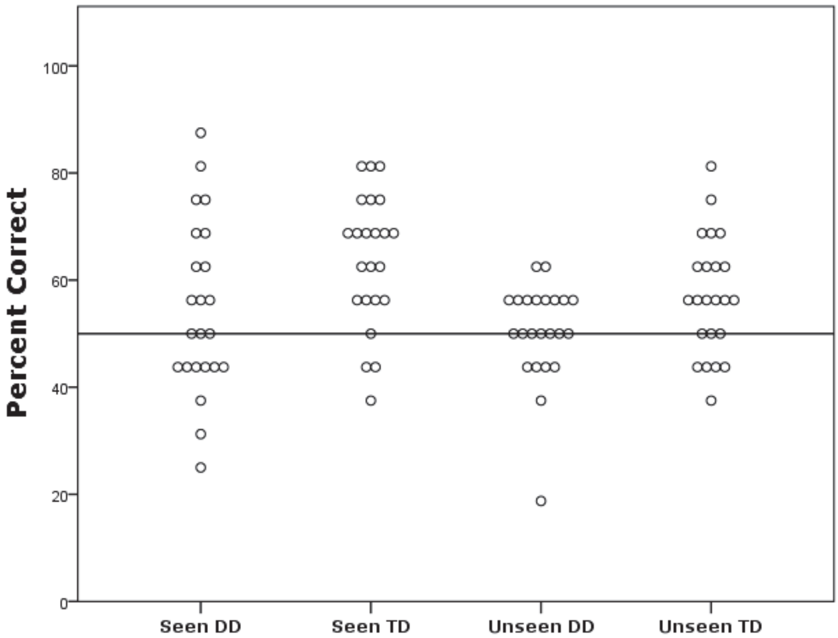



*Figure 11*. Percent correct performance on seen and unseen items for participants with developmental dyslexia (DD) and with typical development (TD).

In order to assess whether implicit learning had taken place, single sample *t*-tests were run for both the TD and the DD group independently, comparing participants' performance to chance. Performance was tested separately for seen and unseen stimuli. Participants from the TD group performed above chance level in both conditions (seen stimuli: $M = 63.9$, $SD = 12.3$, $t_{22} = 5.38$, $p < .001$, $r = .75$, $B_{H(0,8)} \approx 10^5$; unseen stimuli: $M = 57.1$, $SD = 11.0$, $t_{22} = 3.07$, $p = .006$, $r = .55$, $B_{H(0,8)} = 30.88$). In contrast, data indicated insensitivity as to whether the performance of DD participants exceeded chance in the seen condition ($M = 54.6$, $SD = 16.0$, $t_{22} = 1.38$, $p = .180$, $r = .29$, $B_{H(0,8)} = 1.49$). However, in the unseen condition performance of DD participants was clearly at chance level ($M = 50.3$, $SD = 9.3$, $t_{22} = .14$, $p$

= .890, $r = .03$, $B_{H(0,8)} = 0.27$). Thus, while very weak implicit learning may have taken place with the seen stimuli, no implicit learning took place in the DD group for unseen stimuli.

As expected, a mixed ANOVA revealed a significant main effect of group ($F$ [1, 44] = 9.99, $p = .003$, $r = .43$) as well as a main effect of type of stimulus ($F$ [1, 44] = 4.43, $p = .041$, $r = .30$). No interaction was found between these two variables ($F$ [1, 44] = .214, $p = .646$, $r = .07$)[4]. Bayes factors confirmed that the TD group outperformed the DD group in both seen and unseen stimuli (seen $B_{H(0,8)} = 5.94$; unseen $B_{H(0,8)} = 6.41$). However, the main effect of type of stimulus may have been largely driven by the TD group; although Bayes factors confirmed an advantage for seen over unseen stimuli for TD participants ($B_{H(0,8)} = 3.11$), the data were insensitive for DD participants ($B_{H(0,8)} = 1.26$).

**Discussion**

In Experiment 2, we explored children's implicit learning of contextual regularities embedded in CCVCV pseudowords. Once again, results from the *t*-tests showed that TD children were able to learn the contextual regularities despite the presence of consonant clusters, as they could identify both seen and novel stimuli above chance level. In contrast, participants with DD were not able to learn the orthographic rules; not only did they fail to transfer the rules to new instances (as it was previously found in Study 2), but they also failed to recognize previously encountered stimuli. This result suggests that contextual regularities become very challenging for children with DD when they are embedded in letter strings with

[4] NB: There is one obvious outlier in the data – a child from the DD group who scored 18.75% correct on unseen items, which represents a score more than 3 *SD*s below the mean. Removing this child and repeating all of the analyses yielded the same overall pattern of results.

complex syllabic structures. As expected, a significant main effect of group corroborated the differences in the learning of the two groups. Additionally, the main effect of type of stimulus indicated that identifying familiar stimuli with complex syllables was easier than transferring the rules to novel items.

In summary, results from Experiment 2 indicate that children with DD cannot learn contextual orthographic rules after a brief exposure as well as TD children, and suggest that increased syllabic complexity can hinder the implicit learning in children with DD.

## Comparisons across experiments

To further support the claim that the stimuli in Experiment 2 proved harder for DD participants, Bayes factors were calculated comparing each type of stimuli between experiments.

### Results

For TD participants, although the data indicated insensitivity, there was slightly more support for the null hypothesis – that is, that the two experiments were of equal difficulty (seen $B_{H(0,8)} = 0.90$; unseen $B_{H(0,8)} = 0.49$). For DD participants, there was slight evidence suggesting that the seen stimuli were equally difficult between experiments ($B_{H(0,8)} = 0.54$). In contrast, there was clear support for the suggestion that TD children found the unseen stimuli more difficult in Experiment 2 compared to Experiment 1 ($B_{H(0,8)} = 3.03$).

## General Discussion

In the current study we explored the capacity of children with and without dyslexia to implicitly learn contextual orthographic rules. Additionally, we tested the impact that syllabic complexity has on such learning by manipulating this factor: in Experiment 1 the orthographic rules were embedded in pseudowords with simple syllabic structures (CVCV), whereas in Experiment 2 the rules were embedded in pseudowords that contained one complex syllabic structure (CCVCV). As we will further discuss, the combined results suggest that implicit mechanisms are strong enough to acquire complex orthographic regularities by means of exposure, and that such mechanisms are weaker in individuals with dyslexia.

With regards to typically-developing participants, significant learning was observed in the seen and unseen conditions of both experiments, indicating that Spanish children are able to learn orthographic contextual rules after a brief exposure regardless of the syllabic complexity of the stimuli. Therefore, this study provides experimental evidence that implicit mechanisms play an important role in the typical acquisition of orthographic regularities as it was previously suggested by behavioral studies (Cassar & Treiman, 1997; Pacton et al, 2005; Pacton et al., 2001; Steffler, 2004; Treiman, 1993).

Participants with dyslexia were also able to acquire the contextual rules when they were embedded in pseudowords with simple syllabic structures (CVCV), but they failed to learn the rules in the presence of consonant clusters (CCVCV). Of note, not only did these participants fail to transfer the contextual rules, but they demonstrated a weak ability (at best) to recognize previously encountered items, suggesting that the stimuli were too complex. Therefore, although the contextual rules presented in Experiment 1 and Experiment 2 were very similar, the introduction of consonant clusters hindered the learning of participants with dyslexia who (as previously noted) struggle to decode CCV syllables. Possibly, cognitive resources applied to decoding processes may have interfered with the acquisition of the underlying orthographic rules or the memorization of the items. This suggestion is supported by Binamé and Poncelet (2016) who found that the phonological ability to match letters and sounds moderates the acquisition of orthographic regularities and the storage of orthographic units in memory.

The distinction between seen and unseen stimuli across experiments is interesting as it provides information about different implicit mechanisms, namely, item memorization versus rule generalization. It was found across experiments that typically-developing children could better recognize previously encountered stimuli compared to new stimuli. Higher performance on seen stimuli suggests the contribution of implicit memory mechanisms and highlights the importance of lexical familiarity in literacy performance. Such familiarity emerges as the result of experience when implicit processes enable the effortless storage and retrieval of the orthographic units. On the other hand, making judgements about novel items requires more complex cognitive processes, such as the generalization of the underlying rules (according to Reber, 1967) or the computation of the statistical frequency with which the patterns occur (according to the statistical learning perspective; e.g. Kessler, 2009).

In contrast, it was found in both experiments that participants with dyslexia performed similarly in the seen and unseen condition and that they recognized seen stimuli more poorly than control participants. This indicates that children with reading impairment do not benefit from lexical familiarity as much as typically-developing children do –a result that was previously found in German children with writing impairment (Ise et al., 2012). This could be explained either by poor storage or by poor retrieval of linguistic information in dyslexia.

For instance, Hulme and Snowling (2011) claimed that poor phonological skills are responsible for the storage of imprecise phonological units, whereas Ramus and Szenkovits (2008) suggested that individuals with dyslexia can save accurate phonological representations but have poor access to them.

Taken together, the results of experiments 1 and 2 support the existence of an implicit learning impairment in children with dyslexia when acquiring complex orthographic information. This is in line with previous studies exploring dyslexics' implicit learning of non-linguistic regularities with sequence learning tasks (Du & Kelly, 2013; Howard et al., 2006; Jiménez-Fernández et al., 2011; Stoodley et al., 2006; Stoodley et al., 2008; Vicari et al., 2003) and with AGL tasks (Pavlidou et al., 2009; Pavlidou & Williams, 2014). Moreover, the current results agree with AGL studies testing the acquisition of linguistic regularities in children with dysgraphia (Ise et al., 2012) and in adults with dyslexia (Kahta & Schiff, 2016). These studies found that participants with learning disabilities were able to implicitly learn the regularities embedded in letter strings (as we found in Experiment 1), but performed more poorly than control participants (as we found in both experiments). These results suggest that implicit learning mechanisms underpin the acquisition of orthographic knowledge also in cases of learning disabilities, but to a lesser extent. Moreover, these results suggest that implicit learning impairments underlie both reading and writing disorders, and that they persist through adulthood.

Finally, it is important to note that the present methodology overcame the limitation found in a similar study carried out with positional regularities (Study 2), where no clear group differences were observed between participants with and without dyslexia. Firstly, the extension of the exposure phase in the current study may have facilitated the consolidation of implicit learning for both groups as well as increased the group differences. Secondly, while positional rules might have not been challenging enough for children with dyslexia, the introduction of contextual rules uncovered an implicit learning deficit. Learning contextual rules requires holistic processing of the exemplars in order to grasp the relations between letters. As found in the current study, individuals with reading impairment cannot grasp such complex connections as typical readers do.

To summarize, evidence from the present study suggests that (1) typically-developing Spanish children can implicitly acquire contextual orthographic rules embedded in syllables with simple and complex structures after a brief exposure; (2) children with dyslexia are impaired in the implicit acquisition of contextual orthographic rules as they show poorer transfer of rules to novel items compared to controls; (3) the syllabic complexity of the stimuli seems to hinder the implicit learning of orthographic rules in children with dyslexia; (4) children with dyslexia benefit to a lesser extent from orthographic familiarity as they cannot recognize previously encountered letter strings as well as typically-developing children.

# General Discussion

The aim of the current thesis was to explore the contribution of implicit learning abilities to literacy development and its relationship with different reading profiles in Spanish. For this purpose, three studies were conducted investigating the implicit acquisition of linguistic and non-linguistic regularities by means of exposure in children with typical development and in children with dyslexia. We believe that our findings add to knowledge about the role of implicit learning in typical and atypical literacy development, and show that poor acquisition of orthographic patterns may be explained by deficient implicit resources.

The first achievement of this thesis was the design of an ecologically valid task able to induce and measure implicit learning of linguistic regularities in Spanish children. In contrast to most commonly used methodologies (such as the sequence learning and the artificial grammar learning paradigms), regularities in our experiments were embedded in linguistic stimuli that resembled real words of natural language. Furthermore, we distinguished between the ability to identify previously seen items and the ability to transfer rules to new instances. Whereas the first ability is more related to memory processes, the second reflects actual sensitivity to the regularities.

Results from this thesis show that implicit mechanisms indeed play a role in the acquisition of orthographic regularities in Spanish. We also found that the implicit learning abilities of children with dyslexia differ from the abilities of typical readers. Therefore, findings from this thesis will be discussed in two sections that distinguish between children with typical development and children with dyslexia.

## The Role of Implicit Learning in Typical Literacy Development

We found that typically-developing children were able to acquire simple and complex written regularities after a few minutes of exposure, consistent with previous evidence in English (Samara & Caravolas, 2014). This corroborates that implicit learning is a rapid and robust mechanism (Aslin & Newport, 2012), and that it underpins the acquisition of regularities of written language similarly as it occurs in oral language (Chambers et al., 2002; Pelucchi et al, 2009; Saffran, et al., 1996). Participants in our studies were able to identify both seen and novel legal items above chance level, suggesting that not only did they memorize stimuli but they could also transfer the linguistic rules to previously unseen stimuli. However, the number of items correctly classified as legal was greater for previsouly seen stimuli than for novel stimuli, a result also reported by Ise et al. (2012). This is not surprising since recalling items is thought to be a more basic process than the generalization of rules (Steffler, 2001). Nonetheless, this result is important as it shows that typical readers benefit from familiarity when performing orthographic judgements. Such familiarity emerges as a result of repeated exposure, which is thought to transform unfamiliar letter strings into fully-specified representations stored in long-term memory (Pérez, Majerus, & Poncelet, 2012).

Consistent with evidence in oral and written language (Onishi et al., 2002; Samara & Caravolas, 2014), we found that children were able to acquire both positional and contextual regularities by implicit mechanisms. Learning positional patterns requires sustained attention to individual elements within a string; in contrast, contextual patterns require holistic processing of strings in order to establish co-dependent relationships among letters, and therefore these regularities are considered complex (Kessler, 2009). The fact that children could acquire both types of regularities by mere exposure shows that implicit mechanisms are effective also in cases of complex patterns, as it has been suggested by behavioral studies (Carillo & Alegría, 2014). Thus, our data confirms that children are powerful learners who observe and compute the frequency with which letters occur and co-occur (Pollo, Treiman, & Kessler, 2007). Additionally, we found that the amount of implicit learning displayed by typically-developing children was not mediated by the syllabic complexity of the stimuli, since the learning of contextual rules did not differ when these rules were embedded in CVCV or CCVCV stimuli. This suggests that typical readers can process orthographic information independently of the phonological features of the letter strings.

In order to compare the possible mediation of linguistic content in the implicit acquisition of knowledge, we conducted two experiments. In these experiments, the same positional constraints were embedded in four-element strings, but one experiment employed strings of abstract shapes whereas the other employed strings of letters. Unsurprisingly, we found that children were also able to acquire non-linguistic regularities by means of exposure, as was reported in previous studies (Arciuli & Simpson, 2012; Fiser & Aslin, 2002; Pavlidou et al., 2010). The comparison across experiments yielded no differences in the amount of learning displayed, suggesting that the implicit acquisition of orthographic knowledge is part of a more general implicit learning ability that operates across different types of visual stimuli.

Given the importance of implicit learning in literacy development (Cassar & Treiman, 1997; Pacton et al., 2005; Pacton et al., 2001; Treiman, 1993), we explored whether implicit learning abilities were directly related to reading and writing performance in Spanish. Such relationships were found in English-speaking children and adults (Arciuli & Simpson, 2012; Sperling et al., 2004; Steffler, 2004), suggesting that implicit mechanisms contribute to better reading and writing skills in a deep orthography. In the case of Spanish, we found that the recognition of familiar items was related to the spelling of inconsistent words. We argue that this relationship could be explained by a common underlying mechanism, namely implicit memory, a retrieval process that involves unintentional recollection of episodes and which can affect spelling choices (Steffler, 2001). In both the implicit learning task and the word writing tasks, children were required to use information about previously encountered items, and therefore the ability to store orthographic representations was relevant. Thus, our data shows that implicit memory abilities are related to word writing, a finding that agrees with the developmental models of reading (Ehri, 1998; Frith, 1985) and the dual-route models of reading (Coltheart 1980; Coltheart, 2005) and spelling (Houghton & Zorzi, 2003). According to these models, the exposure to print enables the storage of words in memory and when these words are encountered or need to be spelled, a fast orthographic strategy can be applied.

Whereas we found that the recognition of seen items in the implicit learning task was related to word spelling, no relationship was found between the ability to identify novel items in the implicit learning task and word or pseudoword spelling (not even when graphotactic knowledge was expected to be applied). This result was somewhat surprising given that Spanish contains a few grapheme-phoneme inconsistencies where the application of graphotactic or morphological knowledge may be required. We argued that either the ability to implicitly acquire and transfer regularities is not strongly related to the writing of orthographic conventions in Spanish, or that methodological limitations could account for the results. It is likely that the writing tasks employed were not sensitive enough to measure graphotactic or morphological knowledge in young students (8-year-olds), and that bigger sample sizes may be necessary to find subtle relationships. In any case, more research needs to be carried out in order to clarify this question.

As we hypothesized, no relationships were found between implicit learning abilities and reading skills in Spanish. These results differ from evidence found in English, where the acquisition of visual information correlated with the reading skills of children and adults (Arciuli & Simpson, 2012; Sperling et al., 2004). The differences between the two languages suggest that the contribution of implicit mechanisms to reading performance is moderated by the opacity of the orthography. Since English is an opaque orthography, the ability to track co-occurrence patterns may be necessary to solve a great number of phonological inconsistencies. In contrast, Spanish is very transparent in the grapheme-phoneme direction, and therefore decoding letter-by-letter is a very efficient strategy for reading in most cases. Thus, although implicit learning contributes to the acquisition of orthographic regularities in Spanish, our data suggests that individual differences do not account for variance in reading. Nonetheless, it could also be the case that subtle relationships exist between implicit learning and reading in Spanish; if so, bigger samples need to be employed to uncover such relationships.

**Implicit Learning Abilities in Individuals with Dyslexia**

Although individuals with dyslexia are exposed to written language similarly to typical readers, they persistently struggle to master the regularities of the orthographic code. Considering these difficulties, some authors have proposed the hypothesis of an implicit learning deficit as a possible cause of dyslexia (e.g. Vicari et al., 2003). Although the overall data of this thesis supports the existence of an implicit learning deficit, some ambiguous results indicate that impairments are not *completely present* or *completely absent,* but instead depend upon the features of the learning material.

We found that children with dyslexia performed similarly in two tasks where positional rules were embedded in both linguistic and non-linguistic stimuli (Study 2). Although the participants could recognize familiar items in both tasks, they could not transfer the positional regularities to new instances like typical readers did. The same pattern of results was found by an artificial grammar learning study (Pavlidou et al., 2014), thus showing that children with dyslexia have difficulties in the implicit acquisition of rules. The fact that equal results were found in the linguistic and the non-linguistic tasks suggests that dyslexics' difficulties to acquire orthographic knowledge is part of a more general implicit learning problem. Thus, our results extend evidence of poor implicit learning in the visual domain (Jiménez-Fernández et al., 2011; Pavlidou et al., 2009; Stoodley et al., 2008; Vicari et al., 2003). Nonetheless, despite the difficulties found in the group with dyslexia, our data yielded no significant differences between this group and the typically-developing group. We argued that the experimental task should be more challenging in order to uncover an implicit learning impairment in dyslexia.

When the demands of the experimental tasks were increased and the learning of contextual rules was assessed (Study 3), we found clearer results. Children with dyslexia could recognize both seen and unseen items when the contextual rules were embedded in CVCV stimuli, thus showing that implicit learning took place. The fact that the rules were transferred to novel items may be explained by the extension of the exposure phase (as longer extension may have enhanced the learning) and the increased age of the participants. In this experiment, participants were one year older than those who took part in Study 2 and, as found in a study with typical readers (Arciuli & Simpson, 2012), older individuals can better acquire regularities by implicit mechanisms. Nonetheless, the learning performance of children with dyslexia was significantly poorer than the performance of typically-developing children. Thus, when the complexity of the learning material was increased, the difference in performance observed between the two groups also increased. These results agree with the findings of a meta-analysis conducted with sequence learning tasks (Lum et al., 2013); although most evidence supported the existence of an implicit learning deficit in dyslexia, the age of the participants and the characteristics of the tasks accounted for variation in the results. Of important note, although development seems to strengthen the implicit learning abilities of the individuals, much evidence shows that difficulties in individuals with dyslexia still persist through adulthood (Du & Kelly, 2013; Howard et al., 2006; Kahta & Shiff, 2016; Stoodley et al., 2006), suggesting that an implicit learning deficit is a stable characteristic of dyslexia.

When the contextual regularities were embedded in letter strings with consonant clusters, we found that children with dyslexia failed to transfer the rules or even recognize previously encountered stimuli. Clearly, the introduction of complex syllabic structures interfered with the acquisition of the orthographic rules – a result that was not found in typical readers. This may be partially explained by the phonological deficit attributed to individuals with dyslexia (Snowling & Stackhouse, 2006). As children with dyslexia struggle when reading or spelling consonant clusters (Bruck & Treiman, 1990; Cassar et al., 2005; Serrano & Defior, 2012), decoding problems may have affected the processing of the letter strings and, consequently, the establishment of contextual relationships among the letters. This suggestion is also consistent with the hypothesis of a procedural learning deficit (Nicolson et al., 2001; Nicolson & Fawcett, 1990), by which the automatization of procedures is thought to be impaired. According to this theory, individuals with dyslexia cannot perform two demanding tasks at the same time since one demanding task may require the aid of explicit mechanisms, leaving no available resources to automatize the other task. In this case, the processing of the consonant clusters may have required strong decoding efforts, thus hindering the implicit computation of the underlying rules.

These explanations seem likely, as it was found that decoding abilities moderate the acquisition of orthographic regularities and the storage of orthographic representations in memory (Binamé & Poncelet, 2016). Accordingly, we found that children with dyslexia did not benefit from orthographic familiarity as much as typical readers when performing recognition tasks; that is, unlike typically-developing children, they did not identify familiar items better than new items. This result was also found in German children with dysgraphia (Ise et al., 2012). The poor advantage of orthographic or lexical knowledge in cases of reading/writing impairment may be explained by the storage of inaccurate phonological representations (Hulmes & Snowling, 2011) or by poor retrieval of phonological units (Ramus & Szenkovits, 2008). One way or the other, poor phonological skills seem to explain the poor acquisition of orthographic units.

Another possible explanation for the difficulties encountered by the participants with dyslexia could be provided by the theory of a visual perceptual deficit (Bosse et al., 2007; Lassus-Sangosse et al., 2008; Vidyasagar & Pammer, 2010). This theory states that dyslexics' poor processing of words is the consequence of a more general visuoattentional deficit that affects the scanning of simultaneous elements. Accordingly, visuoperceptual difficulties may have interfered with the processing of the stimuli during the exposure phase and, therefore, with the processing of the underlying regularities. Results from this thesis may provide some support for this theory since participants with dyslexia performed equally poor in tasks where positional rules were embedded in linguistic and non-linguistic material. However, these participants were able to recognize previously seen stimuli and only struggled to transfer the rules to new instances. These results suggest that children with dyslexia were able to visually process the stimuli (at least in a shallow manner), but they failed to implicitly learn the underlying orthographic rules.

Altogether, our results support the existence of an implicit learning deficit in individuals with dyslexia and suggest that other difficulties may also interfere with the acquisition of orthographic regularities, consistent with the hypothesis of a multiple deficit. If dyslexia constitutes a connectivity problem where many neural paths are interrupted (Richards & Berninger, 2008), different behavioral manifestations are expected to be found. Clearly, more studies need to be carried out at the behavioral, neurobiological and environmental level to further understand the features of dyslexia.

# Final Remarks

## Future Research

We have corroborated in this thesis that implicit mechanisms contribute to the acquisition of written regularities by means of mere exposure. How these mechanisms work is a question that needs to be further explored in relation to the characteristics of the learning material, the circumstances under which the learning takes place and the features of the individuals.

Specifically, we have found that a brief exposure to rule-governed material may be sufficient for typical readers to then identify familiar items as well as novel items that are rule-consistent. In contrast, individuals with dyslexia struggled to automatize certain rules and displayed lower learning effects compared to control participants. However, it could be the case that individuals with dyslexia only needed more time to acquire the rules. For instance, we observed in Study 2 that positional patterns were not automatized by third graders with dyslexia, whereas in Study 3 fourth-graders with dyslexia were able to acquire complex contextual patterns in a task that contained more training blocks. It is not clear, though, whether the increased age of participants or the longer exposure to exemplars accounted for the different results. Therefore, more studies need to be conducted exploring the mere impact of extended exposure in the implicit learning of individuals with and without dyslexia.

Furthermore, if implicit learning mechanisms are strong enough to enable the identification of rule-consistent items after a brief exposure, it could be interesting to explore if they also enable the generation of rule-consist items. And if so, can individuals with reading or writing impairment perform as well as typical individuals? To answer these questions, follow-up studies with different populations could be carried out administering generation tasks after the exposure to exemplars.

More research could also explore the relationship between implicit learning abilities and language-specific characteristics. In the current thesis, we found that implicit learning abilities were not related to reading performance in Spanish; in contrast, studies in English did find a positive relationship between these two variables. These contrasting results suggest that implicit learning plays a different role according to the opacity of the language. Moreover, the relationship between implicit learning and writing skills in Spanish is not clear yet. Therefore, more research is necessary to clarify the relationship between implicit learning abilities and reading/writing skills across different orthographies.

In addition to behavioral manifestations, neurological factors need to be explored to gain a more thorough understanding of the implicit learning phenomenon. Neuroimaging techniques enable researchers to monitor neural activity in typical and atypical populations while performing different tasks. The identification of brain structures involved in implicit learning will help us understand the cognitive processes that enable the acquisition of knowledge by means of exposure. How do individuals compute patterns from a set of exemplars? Does the implicit acquisition of linguistic rules differ from the acquisition of other visual rules? What causes the poor automatization of orthographic regularities in dyslexia? Is it the combination of weak procedural mechanisms, poor phonological skills, impaired visual perception, or does the implicit learning deficit constitute an independent impairment? As proposed by the theory of impaired connectivity, it is important to understand which neural pathways are interrupted in dyslexia and how these individuals compensate for their difficulties.

While the question about teaching methods is of great importance for reading and writing development, to date only a few studies have been conducted to directly compare the effects of implicit versus explicit learning approaches. Using sequence learning tasks, artificial grammars and embedded chunks, some contradictory results were found as whether the provision of explicit instructions enhance the learning (Arciuli et al., 2014; Jiménez-Fernández et al., 2011; Kahta & Schiff, 2016; Pavlidou et al., 2009). However, most studies suggest that explicit instructions are beneficial when the rules are simple and when specific information is provided about the nature of the rules. In the specific case of orthographic rules, the introduction of explicit instruction seems to be beneficial (Clements-Stephens et al., 2012). Nonetheless, it is necessary to carry further studies under well-controlled environments. These studies could generate evidence of most effective teaching approaches and provide educators with valuable strategies to foster the learning of students with and without disabilities.

## Psychoeducational Implications

Findings from the current thesis show that implicit mechanisms contribute to the acquisition of orthographic knowledge since young ages. These mechanisms are strong enough to acquire simple and complex regularities after a brief exposure and seem to become more robust with development. Whereas some regularities may result too complex to acquire by means of exposure at a certain age, they may become more apprehensible with time. A clear implication of this thesis is that repeated exposure to print plays a very important role in the acquisition of orthographic regularities, and that complex regularities need more time to be mastered. Thus, the school curriculum should include activities that foster reading practice and repeated exposure to rule-governed material in order to underpin orthographic development.

Our data also showed that children with dyslexia can acquire some orthographic regularities by means of exposure, but their implicit mechanisms are weaker in comparison to typically-developing students. Hence, when confronted to cases of spelling inconsistency individuals with dyslexia should not only rely on their implicit knowledge, but they might need to compensate with the application of clear explicit rules. As shown by experimental evidence, the introduction of explicit information can help enhance the learning processes of individuals with dyslexia (Jiménez-Fernández et al., 2011; Kahta & Schiff, 2016). Since orthographic rules are very diverse and have different levels of complexity, clear and extended periods of instruction are required. Nonetheless, this does not mean that frequent exposure to print is dispensable in individuals with dyslexia. *Au contraire!* Both explicit and implicit strategies should be encouraged by teachers and practitioners. Thus, besides receiving clear information about orthographic rules, individuals with dyslexia (as typical readers) need extensive reading practice. Since reading difficulties tend to distant individuals from the written words, the lack of practice has a negative impact on the performance. In order to avoid this vicious circle, the motivation of the students' needs to be taken into account, so that they also read for pleasure or curiosity. Thus, children with reading impairment could also enjoy the magic of the written code, that is, that written words can take us to any real or imaginary scenario, make us fly to far-away places or even travel back in time.

# References

Alegría, J. (1985). Por un enfoque psicolingüístico del aprendizaje de la lectura y sus dificultades. *Infancia y Aprendizaje, 8*(29), 79-94.

Alegría, J. (2006). Support for a psycholinguistic approach to reading acquisition and reading difficulties: Twenty years later. *Infancia y Aprendizaje*, *29*(1), 93-111. doi:10.1174/021037006775380957

Alegría, J., & Mousty, P. (1996). The development of spelling procedures in French-speaking, normal and reading-disabled children: Effects of frequency and lexicality. *Journal of Experimental Child Psychology, 63*(2), 312-338. doi:10.1006/jecp.1996.0052

Arciuli, J., & Simpson, I. C. (2012). Statistical learning is related to reading ability in children and adults. *Cognitive Science*, *36*(2), 286-304. doi: 10.1111/j.1551-6709.2011.01200.x

Arciuli, J., & Simpson, I. C. (2012b). Statistical learning is lasting and consistent over time. *Neuroscience Letters, 517*(2), 133-135. doi: 10.1016/j.neulet.2012.04.045

Arciuli, J., Torkildsen, J. v. K., Stevens, D., & Simpson, I. C. (2014). Statistical learning under incidental versus intentional conditions. *Frontiers in Psychology, 5*. doi: 10.3389/fpsyg.2014.00747

Baldeweg, T., Richardson, A., Watkins, S., Foale, C., & Gruzelier, J. (1999). Impaired auditory frequency discrimination in dyslexia detected with mismatch evoked potentials. *Annals of neurology, 45*(4), 495-503.

Baron, J. (1977). Mechanisms for pronouncing printed words: Use and acquisition. Basic processes in reading: *Perception and comprehension*, 175-216.

Biname, F., & Poncelet, M. (2016). The development of the abilities to acquire novel detailed orthographic representations and maintain them in long-term memory. *Journal of Experimental Child Psychology,* 143, 14-33. doi: 10.1016/j.jecp.2015.10.010

Bishop, D. V., Adams, C. V., & Rosen, S. (2006). Resistance of grammatical impairment to computerized comprehension training in children with specific and non-specific language impairments. *International Journal of Language & Communication Disorders*, *41*(1), 19-40.

Bishop, D. V., Nation, K., & Patterson, K. (2014). When words fail us: insights into language processing from developmental and acquired disorders. *Philosophical Transactions of the Royal Society B: Biological Sciences, 369*(1634), 20120403. doi: 10.1098/rstb.2012.0403

Boros, M., Anton, J. L., Pech-Georgel, C., Grainger, J., Szwed, M., & Ziegler, J. C. (2016). Orthographic processing deficits in developmental dyslexia: Beyond the ventral visual stream. *NeuroImage*, *128*, 316-327. doi: 10.1016/j.neuroimage.2016.01.014

Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition*, *104*(2), 198-230. doi: 10.1016/j.cognition.2006.05.009

Brady, T. F., & Oliva, A. (2008). Statistical learning using real-world scenes: Extracting categorical regularities without conscious intent. *Psychological Science, 19*(7), 678-685. doi: 10.1111/j.1467-9280.2008.02142.x

Bruck, M., & Treiman, R. (1990). Phonological awareness and spelling in normal children and dyslexics: The case of initial consonant clusters. *Journal of Experimental Child Psychology, 50*(1), 156-178.

Carrillo, M. S., & Alegría, J. (2014). The development of children's sensitivity to bigram frequencies when spelling in Spanish, a transparent writing system. *Reading and Writing, 27*, 571–590. doi: 10.1007/s11145-013-9459-y

Cassar, M., & Treiman, R. (1997). The beginnings of orthographic knowledge: Children's knowledge of double letters in words. *Journal of Educational Psychology, 89*(4), 631-644. doi: 10.1037/0022-0663.89.4.631

Cassar, M., Treiman, R., Moats, L., Pollo, T. C., & Kessler, B. (2005). How do the spellings of children with dyslexia compare with those of nondyslexic children? *Reading and Writing, 18*(1), 27–49. doi: 10.1007/s11145-004-2345-x

Chall, J. S., & Jacobs, V. A. (1983). Writing and reading in the elementary grades: Developmental trends among low SES children. *Language Arts*, *60*(5), 617-626.

Chambers, K. E., Onishi, K., & Fisher, C. (2003). Infants learn phonotactic regularities from brief auditory experience. *Cognition, 87*, 69–77. doi: 10.1016/S0010-0277(02)00233-0

Chiappe, P., Chiappe, D. L., & Siegel, L. S. (2001). Speech perception, lexicality, and reading skill. *Journal of Experimental Child Psychology, 80*(1), 58-74. doi: 10.1006/jecp.2000.2624

Clements-Stephens, A. M., Materek, A. D., Eason, S. H., Scarborough, H. S., Pugh, K. R., Rimrodt, S., ... & Cutting, L. E. (2012). Neural circuitry associated with two different approaches to novel word learning. *Developmental cognitive neuroscience, 2*, 99-113. doi: 10.1016/j.dcn.2011.06.001

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences (2 ed.)*. Hillsdale, NJ: LEA.

Coltheart, M. (1985). In defence of dual-route models of reading. *Behavioral and Brain Sciences, 8*(04), 709-710.

Coltheart, M. (2005) Modeling Reading: The Dual-Route Approach. In Snowling, M., & Hulmes, C. (Eds.), *The Science of Reading: A Handbook* (pp. 6-23). Oxford: Blackwell Publishing Ltd. doi: 10.1002/9780470757642.ch1

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108(*1), 204-256. doi:10.1037/0033-295X.108.1.204

Cuetos Vega, F., Ramos Sánchez, J.L., & Ruano Hernández, E. (2004). [*PROESC: assessment of writing processes]*. Madrid: TEA.

Davies, R., Cuetos, F., & Glez-Seijas, R. M. (2007). Reading development and dyslexia in a transparent orthography: A survey of Spanish children. *Annals of Dyslexia, 57*(2), 179-98. doi: 10.1007/s11881-007-0010-1

Defior, S., & Alegría, J. (2005). Conexión entre morfosintaxis y escritura: cuando la fonología es (casi) suficiente para escribir. *Revista de Logopedia, Foniatría y Audiología, 25*(2), 51–61.

Defior Citoler, S., Fonseca, L., Gottheil, B., Aldrey, A, Jiménez Fernández, G., Pujals, M., ... Serrano Chica, F. (2006). [*LEE: Reading and writing test in Spanish]*. Buenos Aires: Paidós.

Defior, S., Jiménez-Fernández, G., & Serrano, F. (2009). Complexity and lexicality effects on the acquisition of Spanish spelling. *Learning and Instruction, 19*(1), 55-65. doi: 10.1016/j.learninstruc.2008.01.005

Defior, S., & Serrano, F. (2005). The initial development of spelling in Spanish: From global to analytical. *Reading and Writing, 18*(1), 81-98. doi: 10.1007/s11145-004-5893-1

Defior, Serrano, & Gutiérrez (2015). *Dificultades específicas de aprendizaje*. Madrid: Editorial Síntesis.

Démonet, J. F., Taylor, M. J., & Chaix, Y. (2004). Developmental dyslexia. *The Lancet*, *363*(9419), 1451-1460. doi: 10.1016/S0140-6736(04)16106-0

Dienes, Z. (2008). *Understanding psychology as a science: An introduction to scientific and statistical inference*. Basingstoke: Palgrave Macmillan.

Dienes, Z. (2014). Using Bayes to get the most out of non-significant results. *Frontiers in Psychology, 5*. doi: 10.3389/fpsyg.2014.00781

Du, W., & Kelly, S. W. (2013). Implicit sequence learning in dyslexia: A within-sequence comparison of first- and higher-order information. *Annals of Dyslexia*, *63*(2), 154-70. doi: 10.1007/s11881-012-0077-1

Ehri, L. C. (1998). Word reading by sight and by analogy in beginning readers. *Reading and spelling: Development and disorders*, *5*, 87-111.

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of reading*, *9*(2), 167-188.

Facoetti, A., & Molteni, M. (2001). The gradient of visual attention in developmental dyslexia. *Neuropsychologia, 39*(4), 352-357. doi: 10.1016/S0028-3932(00)00138-X

Fiser, J., & Aslin, R. N. (2001). Unsupervised statistical learning of higher-order spatial structures from visual scenes. *Psychological Science, 12*(6), 499-504. doi: 10.1111/1467-9280.00392

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175-191. doi: 10.3758/BF03193146

Folia, V., Uddén, J., Forkstam, C., Ingvar, M., Hagoort, P., & Petersson, K. M. (2008). Implicit learningand dyslexia. *Annals of the New York Academy of Sciences, 1145 (1)*, 132–150.

Frith, U. (1985). Beneath the surface of developmental dyslexia. *Surface dyslexia*, *32*, 301-330.

Frith, U. (2002). Resolving the paradoxes of dyslexia. In Reid, G., & Wearmouth, J. (Eds.), *Dyslexia and literacy: theory and practice* (pp. 45-68). J. Wiley & Sons.

Gabay, Y., Schiff, R., & Vakil, E. (2012). Dissociation between the procedural learning of letter names and motor sequences in developmental dyslexia. *Neuropsychologia, 50*(10), 2435-2441. doi: 10.1016/j.neuropsychologia.2012.06.014

Gombert, J. (2003). Implicit and explicit learning to read: Implication as for subtypes of dyslexia. *Current Psychology Letters, 10*(1), 25-40.

Goschke, T. (1998). Implicit learning of perceptual and motor sequences: Evidence for independent learning systems. In M. A. Stadler P. A. Frensch (Eds), *Handbook of implicit learning* (pp. 401-444). Thousand Oaks, CA, US: Sage Publications, Inc.

Goswami, U. (2011). A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Sciences, 15*(1), 3-10. doi: 10.1016/j.tics.2010.10.001

Goswami, U. (2016), Educational neuroscience: Neural structure-mapping and the promise of oscillations, *Current Opinion in Behavioural Sciences 10*, 89-96. doi: 10.1016/j.cobeha.2016.05.011

Goswami, U., Huss, M., Mead, N., Fosker, T., & Verney, J. P. (2013). Perception of patterns of musical beat distribution in phonological developmental dyslexia: significant longitudinal relations with word reading and reading comprehension. *Cortex*, *49*(5), 1363-1376. doi: 10.1016/j.cortex.2012.05.005

Grabe, W. (2010). Fluency in Reading- Thirty-five years later. *Reading in a Foreign Language, 22*(1), 71-83.

Griffiths, Y. M., & Snowling, M. J. (2002). Predictors of exception word and nonword reading in dyslexic children: The severity hypothesis. *Journal of Educational Psychology, 94*(1), 34-43. doi: 10.1037/0022-0663.94.1.34

Hämäläinen, J. A., Rupp, A., Soltész, F., Szücs, D., & Goswami, U. (2012). Reduced phase locking to slow amplitude modulation in adults with dyslexia: an MEG study. *Neuroimage*, *59*(3), 2952-2961. doi: 10.1016/j.neuroimage.2011.09.075

Hari, R., & Renvall, H. (2001). Impaired processing of rapid stimulus sequences in dyslexia. *Trends in Cognitive Sciences*, *5*(12), 525-532. doi: 10.1016/S1364-6613(00)01801-5

Hayes, H., Treiman, R., & Kessler, B. (2006). Children use vowels to help them spell consonants. *Journal of Experimental Child Psychology*, *94*(1), 27-42. doi: 10.1016/j.jecp.2005.11.001

Hedenius, M., Persson, J., Alm, P. A., Ullman, M. T., Howard Jr., J. H., Howard, D. V., & Jennische, M. (2013). Impaired implicit sequence learning in children with developmental dyslexia. *Research in Developmental Disabilities, 34*(11), 3924-3935. doi: 10.1016/j.ridd.2013.08.014

Houghton, G., & Zorzi, M. (2003). Normal and impaired spelling in a connectionist dual-route architecture. *Cognitive Neuropsychology*, *20*(2), 115-162. doi: 10.1080/02643290242000871

Howard Jr., J. H., Howard, D. V., Japikse, K. C., & Eden, G. F. (2006). Dyslexics are impaired on implicit higher-order sequence learning, but not on implicit spatial context learning. *Neuropsychologia, 44*(7), 1131-1144. doi: 10.1016/j.neuropsychologia.2005.10.015

Hulme, C., & Snowling, M. J. (2011). Children's reading comprehension difficulties nature, causes, and treatments. *Current Directions in Psychological Science*, *20*(3), 139-142. doi: 10.1177/0963721411408673

International Dyslexia Association (2002). *Definition of dyslexia,* https://dyslexiaida.org/definition-of-dyslexia/. Adopated by the IDA Board of Directors, Nov 12, 2002.

Im, K., Raschle, N. M., Smith, S. A., Grant, P. E., & Gaab, N. (2015). Atypical sulcal pattern in children with developmental dyslexia and at-risk kindergarteners. *Cerebral Cortex, 26*(3), 1138-1148. doi: 10.1093/cercor/bhu305

Ise, E., Arnoldi, C. J., Bartling, J., & Schulte-Körne, G. (2012). Implicit learning in children with spelling disability: Evidence from artificial grammar learning. *Journal of Neural Transmission, 119*(9), 999-1010. doi: http:10.1007/s00702-012-0830-y

Jiménez, J. E., Guzmán, R., Rodríguez, C., & Artiles, C. (2009). Prevalencia de las dificultades específicas de aprendizaje: la dislexia en español. *Anales de psicología*, *25*(1), 78-85.

Jiménez-Fernández, G., Vaquero, J. M. M., Jiménez, L., & Defior, S. (2011). Dyslexic children show deficits in implicit sequence learning, but not in explicit sequence learning or contextual cueing. *Annals of Dyslexia, 61*(1), 85-110. doi: 10.1007/s11881-010-0048-3

Kelly, S. W., Griffiths, S., & Frith, U. (2002). Evidence for implicit sequence learning in dyslexia. *Dyslexia, 8*(1), 43-52. doi: 10.1002/dys.208

Darki, F., Peyrard-Janvid, M., Matsson, H., Kere, J., & Klingberg, T. (2012). Three dyslexia susceptibility genes, DYX1C1, DCDC2, and KIAA0319, affect temporo-parietal white matter structure. *Biological psychiatry*, *72*(8), 671-676. doi: 10.1016/j.biopsych.2012.05.008

Kahta, S., & Schiff, R. (2016) Implicit learning deficits among adults with developmental dyslexia. *Annals of Dyslexia, 61*(1), 85-110. doi:10.1007/s11881-016-0121-7

Kessler, B. (2009). Statistical learning of conditional orthographic correspondences. *Writing Systems Research 1*, 19-34. doi: 10.1093/wsr/wsp004

Kitzen, K. R. (2001). *Prosodic sensitivity, morphological ability, and reading ability in young adults with and without childhood histories of reading difficulty.* Doctoral dissertation, ProQuest Information & Learning.

Knowlton, B. J., & Squire, L. R. (1996). Artificial grammar learning depends on implicit acquisition of both abstract and exemplar-specific information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(1), 169-181. doi:10.1037/0278-7393.22.1.169

Kujala, R., Lovio, T., Lepistö, M., Laasonen, R., & Näätänen (2006). Evaluation of multi-attribute auditory discrimination in dyslexia with the mismatch negativity. *Clinical Neurophysiology, 117*(4), 885-893. doi: 10.1016/j.clinph.2006.01.002

Landerl, K., & Wimmer, H. (2000). Deficits in phoneme segmentation are not the core problem of dyslexia: Evidence from German and English children. *Applied Psycholinguistics, 21*(2), 243-262.

Lassus-Sangosse, D., N'guyen-Morel, M., & Valdois, S. (2008). Sequential or simultaneous visual processing deficit in developmental dyslexia? *Vision Research, 48*(8), 979-988. doi:10.1016/j.visres.2008.01.025

Lizarazu, M., Lallier, M., Molinaro, N., Bourguignon, M., Paz-Alonso, P. M., Lerma-Usabiaga, G., & Carreiras, M. (2015). Developmental evaluation of atypical auditory sampling in dyslexia: Functional and structural evidence. *Human Brain Mapping*, *36*(12), 4986-5002. doi: 10.1002/hbm.22986

Halliday, L. F., & Bishop, D. V. (2006). Auditory frequency discrimination in children with dyslexia. *Journal of Research in Reading*, *29*(2), 213-228. doi: 10.1111/j.1467-9817.2006.00286.x

Lum, J. A. G., Ullman, M. T., & Conti-Ramsden, G. (2013). Procedural learning is impaired in dyslexia: Evidence from a meta-analysis of serial reaction time studies. *Research in Developmental Disabilities, 34*(10), 3460-3476. doi: 10.1016/j.ridd.2013.07.017

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia, 53*(1), 1-14. doi:10.1007/s11881-003-0001-9.

Maisog, J. M., Einbinder, E. R., Flowers, D. L., Turkeltaub, P. E., & Eden, G. F. (2008). A meta-analysis of functional neuroimaging studies of dyslexia. *Annals of the New York Academy of Sciences*, *1145*(1), 237-259. doi: 10.1196/annals.1416.024

Mann, V., & Wimmer, H. (2002). Phoneme awareness and pathways into literacy: A comparison of German and American children. *Reading and Writing*, *15*(7), 653-682. doi: 10.1023/A:1020984704781

Mark, J. (2011). Cuneiform. *Ancient History Encyclopedia*. http://www.ancient.eu /cuneiform/.

Martin, A., Kronbichler, M., & Richlan, F. (2016). Dyslexic brain activation abnormalities in deep and shallow orthographies: A meta-analysis of 28 functional neuroimaging studies. *Human Brain Mapping*. doi: 10.1002/hbm.23202

Morton, J., & Frith, U. (1995). Causal modelling: a structural approach to developmental psychopathology. *Manual of Developmental Psychopathology*, *1*, 357-390.

Menghini, D., Finzi, A., Benassi, M., Bolzani, R., Facoetti, A., Giovagnoli, S., . . . Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: A comparative study. *Neuropsychologia, 48*(4), 863-872. doi: 10.1016/j.neuropsychologia.2009.11.003

Miles, T. R. (2004). Some problems in determining the prevalence of dyslexia. *Electronic Journal of Research in Educational Psychology*, *2*(2), 5-12.

Molinaro, N., Lizarazu, M., Lallier, M., Bourguignon, M., & Carreiras, M. (2016). Out-of-synchrony speech entrainment in developmental dyslexia. *Human Brain Mapping*. doi: 10.1002/hbm.23206

Nicolson, R. I., & Fawcett, A. J. (1990). Automaticity: A new framework for dyslexia research? *Cognition, 35*(2), 159-182. doi:10.1016/0010-0277(90)90013-A

Nicolson, R. I., Fawcett, A. J., Brookes, R. L., & Needle, J. (2010). Procedural learning and dyslexia. *Dyslexia*, *16*(3), 194-212. doi: 10.1002/dys.408

Nicolson, R. I., Fawcett, A. J., & Dean, P. (2001). Developmental dyslexia: the cerebellar deficit hypothesis. *Trends in neurosciences*, *24*(9), 508-511. doi: 10.1016/S0166-2236(00)01896-8

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*(1), 1-32. doi: 10.1016/0010-0285(87)90002-8

Niogi, S. N., & McCandliss, B. D. (2006). Left lateralized white matter microstructure accounts for individual differences in reading ability and disability. *Neuropsychologia*, *44*(11), 2178-2188. doi: 10.1177/0956797614544511

Nissen, M. J., & Bullemer, P. (1987). Attentional requirements of learning: Evidence from performance measures. *Cognitive Psychology, 19*(1), 1-32. doi: 10.1016/0010-0285(87)90002-8

Pacton, S., Fayol, M., & Perruchet, P. (2005). Children's implicit learning of graphotactic and morphological regularities. *Child Development*, *76*(2), 324-339. doi: 10.1111/j.1467-8624.2005.00848_a.x

Pacton, S., Perruchet, P., Fayol, M., & Cleeremans, A. (2001). Implicit learning out of the lab: The case of orthographic regularities. *Journal of Experimental Psychology: General*, *130*(3), 401-426. doi: 10.1037/0096-3445.130.3.401

Pavlidou, E. V., Kelly, M. L., & Williams, J. M. (2010). Do children with developmental dyslexia have impairments in implicit learning? *Dyslexia, 16*(2), 143-161. doi: 10.1002/dys.400

Pavlidou, E. V., & Williams, J. M. (2014). Implicit learning and reading: Insights from typical children and children with developmental dyslexia using the artificial grammar learning (AGL) paradigm. *Research in Developmental Disabilities*, *35*(7), 1457-1472. doi: 10.1016/j.ridd.2014.03.040

Pavlidou, E. V., Williams, J. M., & Kelly, L. M. (2009). Artificial grammar learning in primary school children with and without developmental dyslexia. *Annals of Dyslexia, 59*(1), 55-77. doi: 10.1007/s11881-009-0023-z

Pelucchi, B., Hay, J. F. and Saffran, J. R. (2009), Statistical Learning in a Natural Language by 8-Month-Old *Infants. Child Development, 80*, 674-685. doi: 10.1111/j.1467-8624.2009.01290.x

Pennington, B.F., & Olson, R.K. (2005). Genetics of dyslexia. In M.J. Snowling & C. Hulme (Eds.). *The science of reading: A handbook* (453–472). Oxford: Blackwell. Petrill, S.A., De

Pérez, T. M., Majerus, S., & Poncelet, M. (2012). The contribution of short-term memory for serial order to early reading acquisition: Evidence from a longitudinal study. *Journal of Experimental Child Psychology*, *111*(4), 708-723.

Peterson, R. L., & Pennington, B. F. (2012). Developmental dyslexia. *The Lancet*, *379*(9830), 1997-2007. doi:10.1016/S0140-6736(12)60198-6

Poelmans, H., Luts, H., Vandermosten, M., Boets, B., Ghesquière, P., & Wouters, J. (2011). Reduced sensitivity to slow-rate dynamic auditory information in children with dyslexia. *Research in Developmental Disabilities*, *32*(6), 2810-2819. doi: 10.1016/j.ridd.2011.05.025

Pollo, T. C., Kessler, B., & Treiman, R. (2009). Statistical patterns in children's early writing. *Journal of Experimental Child Psychology*, *104*(4), 410-426. doi: 10.1016/j.jecp.2009.07.003

Pollo, T. C., Treiman, R., & Kessler, B. (2007). Three perspectives on spelling development. In E. J. Grigorenko & A. Naples (Eds.). *Single word reading: Cognitive, behavioral, and biological perspectives* (pp. 175-189). Mahwah, NJ: Lawrence Erlbaum.

Pothos, E. M., & Kirk, J. (2004). Investigating learning deficits associated with dyslexia. *Dyslexia, 10*(1), 61-76. doi: 10.1002/dys.266

Pothos, E. M. (2007). Theories of artificial grammar learning. *Psychological Bulletin, 133*(2), 227-244. doi:10.1037/0033-2909.133.2.227

Power, A. J., Mead, N., Barnes, L., & Goswami, U. (2013). Neural entrainment to rhythmic speech in children with developmental dyslexia. *Frontiers in Human Neuroscience*, *7* (777), 17-34

Ramus, F., & Szenkovits, G. (2008). What phonological deficit? *The Quarterly Journal of Experimental Psychology, 61*(1), 129–141. doi: 10.1016/j.neuroimage.2010.09.055

Raschle, N. M., Chang, M., & Gaab, N. (2011). Structural brain alterations associated with dyslexia predate reading onset. *Neuroimage*, *57*(3), 742-749. doi: 10.1016/j.neuroimage.2010.09.055

Raven, J., Court, J., & Raven, J. (1996). *Manual for Raven's progressive matrices.* Madrid: TEA.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6*, 855-863.

Reber, A. S. (1993). *Implicit learning and tacit knowledge: An essay on the cognitive unconscious.* New York: Oxford University Press.

Richards, T. L., & Berninger, V. W. (2008). Abnormal fMRI connectivity in children with dyslexia during a phoneme task: Before but not after treatment. *Journal of neurolinguistics*, *21*(4), 294-304. doi: 10.1016/j.jneuroling.2007.07.002

Richlan, F., Kronbichler, M., & Wimmer, H. (2011). Meta-analyzing brain dysfunctions in dyslexic children and adults. *Neuroimage*, *56*(3), 1735-1742. doi: 10.1016/j.neuroimage.2011.02.040

Richlan, F., Kronbichler, M., & Wimmer, H. (2013). Structural abnormalities in the dyslexic brain: a meta-analysis of voxel-based morphometry studies. *Human Brain Mapping*, *34*(11), 3055-3065. doi: 10.1002/hbm.22127

Roodenrys, S., & Dunn, N. (2008). Unimpaired implicit learning in children with developmental dyslexia. *Dyslexia, 14*(1), 1-15. doi: 10.1002/dys.340

Ruffino, M., Trussardi, A. N., Gori, S., Finzi, A., Giovagnoli, S., Menghini, D., . . . Vicari, S. (2010). Attentional engagement deficits in dyslexic children. *Neuropsychologia, 48*(13), 3793-3801. doi: 10.1016/j.neuropsychologia.2010.09.002

Rüsseler, J., Gerth, I., & Münte, T. F. (2006). Implicit learning is intact in adult developmental dyslexic readers: Evidence from the serial reaction time task and artificial grammar learning. *Journal of Clinical and Experimental Neuropsychology, 28*(5), 808-827. doi:10.1080/13803390591001007

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-old infants. *Science, New Series*, *274*, 1926-1928. doi: 10.1126/science.274.5294.1926

Samara, A., & Caravolas, M. (2014). Statistical learning of novel graphotactic constraints in children and adults. *Journal of Experimental Child Psychology, 121*, 137-155. doi: 10.1016/j.jecp.2013.11.009

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime 2.0 software.* Pittsburgh: Psychology Software Tools Inc.

Schulte-Körne, G., Bartling, J., Deimel, W., & Remschmidt, H. (2004). Motion-onset VEPs in dyslexia. Evidence for visual perceptual deficit. *Neuroreport*,*15*(6), 1075-1078. doi: 10.1097/01.wnr.0000123387.87650.e2

Seidenberg, M. S. (2005). Connectionist models of word reading. *Current Directions in Psychological Science, 14*(5), 238-242. doi: 10.1111/j.0963-7214.2005.00372.x

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*(4), 523. doi: 10.1037/0033-295X.96.4.523

Serrano, F., & Defior, S. (2008). Dyslexia speed problems in a transparent orthography. *Annals of Dyslexia, 58*(1), 81-95. doi:10.1007/s11881-008-0013-6

Serrano, F., & Defior, S. (2012). Spanish dyslexic spelling abilities: the case of consonant clusters. *Journal of Research in Reading, 35*(2), 169–182. doi: 10.1111/j.1467-9817.2010.01454.x

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, *55*(2), 151-218.

Share, D. L. (1999). Phonological recoding and orthographic learning: A direct test of the self-teaching hypothesis. *Journal of experimental child psychology*,*72*(2), 95-129.

Share, D. L. (2008). On the Anglocentricities of current reading research and practice: the perils of overreliance on an" outlier" orthography. *Psychological bulletin*, *134*(4), 584. doi: 10.1037/0033-2909.134.4.584

Shaywitz, S. E., & Shaywitz, B. A. (2005). Dyslexia (specific reading disability). *Biological psychiatry*, *57*(11), 1301-1309. doi: 10.1016/j.biopsych.2005.01.043

Silani, G., Frith, U., Demonet, J. F., Fazio, F., Perani, D., Price, C., ... & Paulesu, E. (2005). Brain abnormalities underlying altered activation in dyslexia: a voxel based morphometry study. *Brain*, *128*(10), 2453-2461. doi: 10.1093/brain/awh579

Snowling, M. J., & Stackhouse, J. (Eds.) (2006). *Dyslexia, speech and language: A practitioner's handbook (2nd edition).* London: Wiley.

Sperling, A. J., Lu, Z. L., & Manis, F. R. (2004). Slower implicit categorical learning in adult poor readers. *Annals of Dyslexia, 54*(2), 281-303. doi:10.1007/s11881-004-0014-z

Steffler, D. J. (2001). Implicit cognition and spelling development. *Developmental Review, 21*(2), 168-204. doi:10.1006/drev.2000.0517

Steffler, D. J. (2004). An investigation of grade 5 children's knowledge of the doubling rule in spelling. *Journal of Research in Reading*, *27*(3), 248-264. doi: 10.1111/j.1467-9817.2004.00230.x

Stoodley, C. J. (2016). The cerebellum and neurodevelopmental disorders. *The Cerebellum*, *15*(1), 34-37. doi:10.1007/s12311-015-0715-3

Stoodley, C. J., Harrison, E. P. D., & Stein, J. F. (2006). Implicit motor learning deficits in dyslexic adults. *Neuropsychologia,* *44*(5), 795-798. doi: 10.1016/j.neuropsychologia.2005.07.009

Stoodley, C. J., Hill, P. R., Stein, J. F., & Bishop, D. V. (2006). Auditory event-related potentials differ in dyslexics even when auditory psychophysical performance is normal. *Brain Research*, *1121*(1), 190-199. doi: 10.1016/j.brainres.2006.08.095

Stoodley, C. J., Ray, N. J., Jack, A., & Stein, J. F. (2008). Implicit learning in control, dyslexic, and garden-variety poor readers. *Annals of the New York Academy of Sciences,* *1145*(1), 173-183. doi: 10.1196/annals.1416.003

Tallal, P. (2004). Improving language and literacy is a matter of time. *Nature Reviews Neuroscience*, *5*(9), 721-728. doi: 10.1038/nrn1499

Thomson, J. M., & Goswami, U. (2008). Rhythmic processing in children with developmental dyslexia: auditory and motor rhythms link to reading and spelling. *Journal of Physiology-Paris*, *102*(1), 120-129. doi: 10.1016/j.jphysparis.2008.03.007

Thurstone, L., & Yela, M. (1995). *Faces, Perception of Differences*. Madrid: TEA.

Treiman, R. (1993). *Beginning to spell: A study of first-grade children.* New York: Oxford University Press.

Treiman, R., & Kessler, B. (2006). Spelling as statistical learning: Using consonantal context to spell vowels. *Journal of Educational Psychology, 98*(3), 642. doi: 10.1037/0022-0663.98.3.642

Treiman, R., & Kessler, B. (2013). Learning to use an alphabetic writing system. *Language Learning and Development, 9*(4), 317-330. doi: 10.1080/15475441.2013.812016

Turk-Browne, N. B., Jungé, J. A., & Scholl, B. J. (2005). The automaticity of visual statistical learning. *Journal of Experimental Psychology: General, 134*(4), 552-564. doi: 10.1037/0096-3445.134.4.552

Vicari, S., Marotta, L., Menghini, D., Molinari, M., & Petrosini, L. (2003). Implicit learning deficit in children with developmental dyslexia. *Neuropsychologia, 41*(1), 108-114. doi:10.1016/S0028-3932(02)00082-9

Vidyasagar & Pammer, 2010Vicari, S., Marotta, L., Menghini, D., Molinari, M., & Petrosini, L. (2003). Implicit learning deficit in children with developmental dyslexia. *Neuropsychologia, 41*(1), 108-114. doi:10.1016/S0028-3932(02)00082-9

Wechsler, D. (1999). *WISC-R: Weschler Children Intelligence Scale- Revised Edition.* Madrid: TEA.

Wilkinson, G. S. (1993). *WRAT-3: Wide Range Achievement Test, Third Edition*. Wilmington, Delaware: Wide Range, Inc.

Wimmer, H., & Hummer, P. (1990). How German-speaking first graders read and spell: Doubts on the importance of the logographic stage. *Applied Psycholinguistics*, *11*(04), 349-368. doi: 10.1017/S0142716400009620

Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology*, *91*(3), 415. doi: 10.1037/0022-0663.91.3.415

Wolf, M., Bowers, P. G., & Biddle, K. (2000). Naming-speed processes, timing, and reading A conceptual review. *Journal of learning disabilities*, *33*(4), 387-407. doi: 10.1177/002221940003300409

Wolf, M., O'Rourke, A. G., Gidney, C., Lovett, M., Cirino, P., & Morris, R. (2002). The second deficit: An investigation of the independence of phonological and naming-speed deficits in developmental dyslexia. *Reading and Writing, 15*(1-2), 43-72. doi:10.1023/A:1013816320290

Ziori, E., & Dienes, Z. (2015). Facial beauty affects implicit and explicit learning of men and women differently. *Frontiers in Psychology, 6*. doi: 10.3389/fpsyg.2015.01124

# Appendixes

**Appendix 1.** Study 1

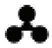
*Items from the exposure phase and items from the test phase*

| Exposure Phase | Test Phase | |
|---|---|---|
| Legal | Legal | Illegal |
| LAFE | LANO | FOTI |
| LANE | LEFO | NOLO |
| LASA | LESA | NOME |
| LEFA | LIFI | FILI |
| LENE | LONO | NATE |
| LESA | MAFO | NALO |
| LIFO | MIFA | NITE |
| LINI | MISI | SIMI |
| LISE | MONE | SATE |
| LOFA | MOSE | FAMO |
| LONO | TANA | NELO |
| LOSE | TASE | SELA |
| MAFO | TESI | FIMA |
| MANA | TINE | SOME |
| MASI | TOFI | SETI |
| MEFO | | |
| MENI | | |
| MESO | | |
| MIFA | | |
| MINO | | |
| MISO | | |
| MOFE | | |
| MONE | | |
| MOSI | | |
| TAFI | | |
| TANA | | |
| TASO | | |
| TEFE | | |
| TENI | | |
| TESI | | |
| TIFI | | |
| TINO | | |
| TISE | | |
| TOFI | | |
| TONE | | |
| TOSA | | |

*Note*. As all exemplars in the exposure phase are consistent with the graphotactic rules, they are all legal stimuli. Pairs in the test phase include one legal and one illegal item in order to create forced-choice pairs. Items from the exposure phase and pairs from the test phase are displayed in alphabetical order, although their order in the experiment was randomly assigned.

**Appendix 2.** Study 2

*Abstract shapes used in Experiment 1 and letters used in Experiment 2*

| Experiment 1 | Experiment 2 |
|---|---|
|  | A |
|  | E |
|  | I |
|  | O |
|  | D |
|  | F |
|  | L |
|  | M |
|  | N |
|  | S |
|  | T |

**Appendix 3.** Study 3: Experiment 1

*Stimuli from the exposure phase*

| | | | |
|---|---|---|---|
| DANE | LASA | PAMA | TAFE |
| DANO | LASI | PAMO | TAFI |
| DENA | LESE | PEME | TEFA |
| DENO | LESO | PEMI | TEFI |
| DINA | LISE | PIMA | TIFE |
| DINI | LISI | PIMO | TIFO |
| DONE | LOSI | POMA | TOFA |
| DONI | LOSO | POME | TOFO |

*Stimuli from the test phase*

| Legal Stimuli | | Illegal Stimuli | |
|---|---|---|---|
| Seen | Unseen | | |
| TAFE | TEFO | DOSA | PINA |
| TOFA | TIFI | PASI | LEMI |
| DONI | DINE | LIFA | TAMA |
| DENO | DANA | TISE | LOME |
| PEMO | PIME | LANI | TESO |
| POMA | PAMI | DIFO | TONE |
| LISE | LASO | PENO | DEFI |
| LOSI | LESA | DAMO | POFE |

**Appendix 4**. Study 3: Experiment 2

*Stimuli from the exposure phase*

| | | | |
|---|---|---|---|
| CLATE | GRASE | FRAMA | PLADA |
| CLATO | GRASI | FRAMI | PLADO |
| CLETE | GRESA | FREMI | PLEDA |
| CLETI | GRESO | FREMO | PLEDE |
| CLITA | GRISI | FRIMA | PLIDE |
| CLITO | GRISO | FRIME | PLIDI |
| CLOTA | GROSA | FROME | PLODI |
| CLOTI | GROSE | FROMO | PLODO |

*Stimuli from the test phase*

| Legal Stimuli | | Illegal Stimuli | |
|---|---|---|---|
| Seen | Unseen | | |
| CLETI | CLATA | GRAMI | PLASE |
| CLITO | CLETO | GRIDE | FRODE |
| FRAMI | FREMA | PLITO | PLOSI |
| FROME | FRIMO | CLEDI | CLESO |
| GRASE | GRISA | CLADO | FRETO |
| GRESO | GROSI | PLEMA | CLIMO |
| PLIDE | PLEDI | FRATA | FRISA |
| PLADO | PLODE | GROME | GRETI |

**Appendix 5.**

Bayes factors are useful for indicating a degree of support for two theories. When comparing an alternate hypothesis to the null hypothesis, the Bayes factor, *B*, indicates that the data are *B* times more likely under the alternate hypothesis compared to the null hypothesis (Dienes, 2014). *B* varies from 0 to infinity. A value $\geq 3$ for *B* represents substantial evidence for the alterative theory over the null hypothesis. In contrast, values $\leq 1/3$ represents substantial evidence for the null hypothesis over the alternative theory. For example, when testing for a group difference a $B \leq 1/3$ represents strong evidence that no group difference exists. Thus, Bayes factors allow the null hypothesis to be *accepted* – something which is not possible using traditional NHST where the correct conclusion for $p > .05$ is simply that insufficient evidence exists to reject the null hypothesis. Finally, values of *B* between 1/3 and 3 indicate data insensitivity for distinguishing the alternative and null hypotheses.

In order to calculate the Bayes factor, one must specify what the alternative theory predicts. Dienes (2014) suggested that when a clear directional hypothesis exists and the effect size can be estimated, half-normal distributions should be used for the alternative hypothesis. In the present study we believe that (1) TD children should perform as well or better than DD children; (2) Performance in the seen condition should be equal to or better than the unseen condition; and (3) Performance in Experiment 1 should be equal to or better than performance in Experiment 2. In terms of the effect size, Ziori and Dienes (2015) used a similar design to the present study – a two-alternative forced-choice task to assess the level of implicit learning. These authors used the grand mean of their data as the value of the *SD* for their half normal distribution, both for one-sample *t*-tests and group comparisons (Ziori & Dienes, 2015, p. 5). Thus, we have adopted the same methodology here. In the present study, for all participants across both experiments and both seen conditions, the average number of trials correct was 57.9% which represents a level of performance 7.9% above chance. We note that this overall effect size is very close to the effect size (8.9%) achieved in the similar study of Nigro et al. (2016). Thus, we will use a half normal distribution with a *SD* of 8 (rounded up from 7.9) and Bayes factors calculated in this manner are represented as $B_{H(0,8)}$.

All Bayes factors were calculated using the free online Bayes factor calculator associated with Dienes (2008), and as per Dienes (2014) the values for the Standard Error (*SE*) were adjusted in all cases where the degrees of freedom were less than 30.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