Games and videogames for dyslexia rehabilitation: neurocognitive and psycholinguistic foundations

Juegos y videojuegos para rehabilitación de la dislexia: fundamentación neurocognitiva y psicolingüística

https://doi.org/10.4438/1988-592X-RE-2024-405-631

Iluminada Sánchez-Doménech
https://orcid.org/0000-0002-4342-2145
Universidad internacional de La Rioja

Beatriz Martín del Campo
https://orcid.org/0000-0001-6957-6233
Universidad de Castilla

Abstract

Developmental Dyslexia (DD) is a neurodevelopmental disorder that impairs the process of learning to read and write. Its neurological etiology and associated cognitive deficits remain the subject of research. Technology has facilitated the development of platforms, games, and video games (PGVs) for DD rehabilitation. Due to the diversity of hypotheses and therapeutic approaches, it is useful to establish the state of the art, as well as to determine whether PGVs respond to this updated knowledge. With this objective, we review the neurocognitive, cognitive, and psycholinguistic hypotheses that explain DD. We conduct a review and analysis of the PGVs intended for use with DD, and which are supported by published scientific evidence and marketed in Spain. Eight were identified: Galexia, Ubinding, Glifing, Tradislexia, GraphoGame, Jellys, DytectiveU and Minecraft. These are analyzed under four levels of intervention: neurological, cognitive, psycholinguistic and performance. The PGVs are discussed in light of the research evidence in the field. Recommendations are made for further adjustment to this evidence. It is concluded that, although the direct intervention of the professional continues to be essential, the applications constitute a motivating

Received: 13/06/2023 Accepted: 05/12/2023

didactic reinforcement. However, it is advisable to have detailed theoretical-technical information to personalize the intervention based on the strengths and weaknesses of the child and considering the possible existence of DD subtypes.

Keywords: dyslexia, computer-based training, videogames, phonemic awareness, neuropsychology, psycholinguistics.

Resumen

La Dislexia del desarrollo (DD) es un trastorno del neurodesarrollo que dificultad el aprendizaje de la lectura y la escritura. Su etiología neurológica y los déficits cognitivos asociados siguen siendo objeto de investigación. La tecnología ha posibilitado el desarrollo de plataformas, juegos y videojuegos (PJV) para la rehabilitación de DD. Ante la diversidad de hipótesis y enfoques terapéuticos, es conveniente conocer el estado de la cuestión, así como comprobar si los PJV responden a este conocimiento actualizado. Con este objetivo, se revisan las hipótesis neurocognitivas, cognitivas y psicolingüísticas explicativas de la DD. Se realiza una revisión y análisis de los PJV disponibles en el mercado español con alguna evidencia científica publicada y comercializados en España y orientados a la DD. Se identifican ocho: Galexia, Ubinding, Glifing, Tradislexia, GraphoGame, Jellys, DytectiveU y Minecraft y se analizan desde cuatro niveles de intervención: neurológico, cognitivo, psicolingüístico y de desempeño. Los PJV se discuten desde el contraste con la evidencia investigadora en el campo. Se realizan recomendaciones para un mayor ajuste a esta evidencia. Se concluye que, a pesar de que la intervención directa del profesional sigue siendo imprescindible, las aplicaciones constituyen un refuerzo didáctico motivador, aunque es conveniente disponer de información teórico-técnica detallada para personalizar la intervención desde las fortalezas y debilidades del sujeto particular y considerando la posible existencia de distintos subtipos de DD.

Palabras clave: dislexia, videojuegos, intervención mediada por ordenador, conciencia fonológica, psicolingüística, neuropsicología.

Introduction

Developmental dyslexia (DD) is a neurobiological disorder that inhibits reading acquisition, despite appropriate school instruction and regardless of general intellectual capacity. Its prevalence in the population is estimated to be between 5% and 10%. The symptoms present as a letter coding deficit, low reading accuracy and/or fluency and dysorthography.

Research into the underlying neurological deficits in DD has generated different explanatory hypotheses. Currently, competing explanations for reading difficulties in DD include those that posit an underlying deficit in visual processing (Vidyasagar and Pammer, 2010), those that propose an auditory processing deficit (Goswami, 2019), a third suggesting the underlying deficits may be located in both the auditory and visual processing systems (Gori et al., 2016), and a fourth that seeks to integrate the previous postulates and hypothesizes a deficiency in the processing of short, rapid, successive stimuli (Habib, 2021).

The theories based on a single underlying cognitive factor cannot satisfactorily explain the variety of profiles and symptoms (perceptual and motor) in children with dyslexia (Willcut et al., 2019). For example, not all children with DD present only a phonological deficit (Snowling et al., 2018; Norton & Wolf, 2012), despite such a deficit being the most widely accepted hypothesis to explain DD. The double-deficit theory holds that the reading difficulties in DD arise from a deficit in phonological awareness, from a deficit in rapid automatized naming (RAN), or as a result of both (Wolf & Bowers, 2000). In addition to the diversity of cognitive profiles, the predictive utility of phonological awareness varies according to the orthographic transparency of the child's language (Pennington et al., 2012).

Technology has made significant headway in the field of rehabilitation of learning disabilities. There are four levels of technology-assisted/mediated intervention in the rehabilitation of DD: 1) the experimental level derived from hypotheses about the neurological etiology of DD; 2) interventions that aim to train the cognitive deficits underlying reading difficulties; 3) interventions focused on developing metalinguistic and linguistic skills; and 4) the level of intervention seeking to improve reading performance according to symptomatology.

Given the diversity of explanatory theories and therapeutic approaches, we consider it necessary to analyze the state of the art based on the four abovementioned levels. We propose to examine the evidence available on the causes of DD and how the technological applications developed and marketed in Spain and in Spanish address these explanatory hypotheses and scientific evidence in their interventions in DD.

Methodology

The general aim of this study is to provide an update on the explanatory hypotheses of DD and to examine the PGVs designed for the rehabilitation of DD available on the Spanish market. The specific objectives of this study are as follows: 1) to compare the PGVs with the scientific evidence on DD and its intervention; 2) to provide clinical and educational professionals with neurocognitive and psycholinguistic substantiation for making informed decisions on the use of these PGVs in rehabilitating DD; and 3) to suggest recommendations for designing intervention technology that is compatible with the findings on DD.

The research design is divided into four stages: 1) a search for applications, videogames and platforms for DD rehabilitation that are scientifically evidenced and/or commercially available in Spain; 2) an analysis of the platforms, articles, technical manuals and information supplied by the designers or distributors; 3) a classification of the activities included in the PGVs according to the level of intervention; 4) a search for scientific evidence on the neurological hypotheses, cognitive consequences and symptoms, and on the treatment of DD in each of the levels.

We used the Scopus, WOS, Dialnet and Google Scholar databases to search for PGVs with scientific evidence. No filters were used for the search period. The search was conducted in March 2023. Table I shows the keyword strings used and the results.

Following this first selection, we screened the articles, applying the following inclusion criteria: experimental studies with applications,

TABLE I. Search strings and results

Search string	**Results**	**Selected**
Intervención AND dislexia AND tecnología	WOS = 9 Scopus = 5	8
Intervención AND dislexia AND aplicaciones	WOS = 41 Scopus = 2	30
Intervención AND dislexia AND ordenador	WOS=12 Scopus = 8	3
Dificultades lectoras AND ordenador	WOS =55 Scopus=0	122
Intervención asistida por ordenador AND dislexia	Google Académico=6 WOS=3 Scopus=0	0
Dislexia-aplicación-tecnología-videojuego	Dialnet=3	0
		163

Source: Colpiled by the author.

Received: 13/06/2023 Accepted: 05/12/2023

video games and platforms for the rehabilitation of DD in children aged under 18, rehabilitation in Spanish, and referring to the application of a technological game, video game or specific platform used to assess the results. Opinion articles and theoretical or general articles on technology and rehabilitation in DD were excluded. After applying the inclusion criteria, a total of 9 relevant papers presenting empirical data on the efficacy of PGVs in Spanish remained. To find PGVs marketed in Spain, we conducted a Google search using the following words: dyslexia, intervention, reading, application, platform, game, videogame. Two books about commercially available PGVs were found (DytectiveU and Glifing). Table II shows a list of the PGVs in Spanish along with their associated publication, both research articles and books published on the PGVs in the market.

Following the analysis of the PGVs detected, we classified the activities they contain according to four levels of intervention, as described in the results section. A non-systematic bibliographic search was then performed on the theoretical and scientific foundations of each of the levels: neurological, cognitive, psycholinguistic, and performance-related or symptomological.

TABLE II. PGVs commercially available in Spain, with and without supporting scientific evidence

Program	Publication	Impact on experimental group
Transdislexia	Jiménez & Rojas (2008)	PA and pseudoword reading
Ubinding	López-Olóriz et al. (2020)	RS and reading accuracy
	Forne et al. (2022)	RS and reading accuracy
DytectiveU	Rello (2018)	Phoneme segmentation, spelling, pseudoword reading, transcription and RS
Jellys	Ostiz-Blanco et al. (2018)	No improvements in rhythm or attention
Galexia	Serrano et al. (2016)	VL, reading comprehension, reading comprehension mediated by prosodic skills
Glifing	García i Ortíz et al. (2016)	RS
Minecraft	Jiménez & Díez (2018)	VF and lexical route of reading
GraphoGame	Rosas et al. (2017)	RAN and identification of letter sounds

Note. RAN=rapid automatized naming; PA=phonological awareness; RS=reading speed; VF=verbal fluency. RF=reading fluency.
Source: Compiled by the author.

Received: 13/06/2023 Accepted: 05/12/2023

Results

Below, we analyze the four levels of intervention, examining how they are addressed in the PGVs listed in Table II, and in relation to the explanatory hypotheses and the current state of the art in interventions for DD.

First level of intervention: neurocognitive interventions

First, the phonological deficit hypothesis suggests that dyslexia stems from challenges in processing speech sounds, which affects individuals' ability to associate graphemes with their corresponding phonemes—a fundamental skill for reading in alphabetic systems (Ramus et al., 2003). This deficit may have a neurological correlate with the differences in size and morphology of the Heschl's Gyrus (HG) found in children at risk of developing dyslexia before they begin learning to read (Clark et al., 2014; Kuhl et al., 2020). This structure plays a key role in the analysis and encoding of temporal characteristics of speech. As a result, in children with DD, the neural response to the more informative parts of the speech signal is slightly out of time (Goswami, 2019). As regards this hypothesis, technology is expected to help enhance the auditory processing of speech, for example, by improving the speech envelope, which is dominated by lower frequencies (<10 Hz) that encode prosodic and syllabic features of speech (Klimovich-Gray et al., 2023), by providing training in dichotic listening (Helland et al., 2018) or auditory pacing (Van Hirtum et al., 2019; Van Herck et al., 2022). Regarding auditory rhythm training, Bonacina et al. (2015) found a positive impact on sublexical skills in both reading speed and reading accuracy and significant effects on short pseudoword reading speed (RS), long pseudoword RS, high-frequency long-word reading accuracy and text reading accuracy.

Another hypothesis for the neurological etiology of DD is a deficit in the magnocellular/dorsal system. This is grounded in differences in the morphology and location of the lateral geniculate nucleus (LGN) found in individuals with dyslexia (Giraldo-Chica and Schneider, 2018). The LGN plays a critical role in the transmission of visual stimuli to the cortex through two pathways: the ventral (occipito-temporal) and the dorsal (temporo-parietal). This structure is elemental in visual processing, motion perception (Gori et al., 2016) and the focusing of spatial and temporal attention (Ruffino et al., 2014). These pathways are home to

Received: 13/06/2023 Accepted: 05/12/2023

gyri with key functions for visual processing, such as the fusiform and lingual gyri, in which synaptic disruption or reduced streamlines have been observed (Centanni et al., 2019; Lou et al., 2019), as well as structural differences (Clark et al., 2014) in children at risk for dyslexia and who develop DD later in life. This hypothesis seeks to provide a comprehensive explanation, proposing that phonological decoding deficits in dyslexia may arise from sensory processing deficits in primary areas related to visual and auditory dynamic stimuli (Gori et al., 2016). This hypothesis thus suggests a broader deficit in spatiotemporal sensory processing (Habib, 2021) and may explain why individuals with dyslexia have difficulty remembering the relative position of letters in words, resulting in characteristic mistakes in their writing, such as substitutions, inversions, omissions and additions (Vidyasagar & Pammer, 2010). In support of this hypothesis, it has been evidenced that the inferior parietal cortex is a core region in the explicit internal representation of order, while the dorsal attentional network may intervene in a mental representation in which serial order is represented by spatial positional codes (Zhou et al., 2021). Following this hypothesis, dyslexia interventions involve exercises to improve rapid alternation between visual and auditory attention, along with attentional control through action game adaptations (Bertoni et al., 2021) and the use of specially designed video games for assessment and intervention in educational contexts, according to Tulloch and Pammer (2019).

Table III shows the PGVs that include activities oriented towards this level of intervention.

Among the PGVs analyzed in this study, Jellys (Ostiz-Blanco et al., 2018) focuses on training auditory rhythm and visual attention in children with DD. Tradislexia also incorporates activities intended to identify auditory rhythm and speech perception. In reference to movement perception, it is more than likely that video games such as Minecraft and Galexia intervene in this aspect, despite not being an explicitly stated rehabilitative goal.

Second level of intervention: cognitive skills

Sufficient evidence has been presented to support the idea that certain cognitive deficits characterize DD, namely, processing speed (PS) and working memory (WM) (Lonergan et al., 2019; Maehler et al., 2019).

TABLE III. Abilities related to the neurological etiology of DD in the PGVs

Program	MP	AU P	AC	AR	VA	DCV	DCA
Tradislexia		×		×			
Ubinding							
DytectiveU						×	×
Galexia							
Glifing							
Jellys				×	×		
Minecraft							
GraphoGame							

Note. MP=Movement perception; AU P=Auditory processing; AC=Attention control; AR=Auditory rhythm; VA=Visual attention; VDC=Visual discrimination and categorization; ADC= Auditory discrimination and categorization.
Source: Compiled by the author.

Studies using tests to dismiss comorbidity with ADHD in the composition of samples have found no deficits in sustained attention in DD, but have detected impairments in selective attention (Fernández-Andrés et al., 2019). Additionally, children with DD appear to have longer reaction times in switching attention and present auditory WM deficits (Lonergan et al., 2019). As regards other executive functions (EF), studies are contradictory, arguably due to the high rate of DD/ADHD comorbidity (Lonergan et al., 2019), the different diagnostic criteria used, the cut-off points for including participants in the samples (Doyle et al., 2018) or the types of tests administered (Sánchez-Doménech, 2022).

The PGVs analyzed include tasks that claim to improve cognitive skills. Table IV shows the skills included in each application.

Furthermore, it seems that the population with dyslexia is not entirely homogeneous in terms of WM deficits. For example, Wokuri et al. (2023) found two distinct profiles; one was associated with verbal item WM and phonological impairment, while another presented selective serial WM deficits in both the verbal and visual domains, and thus practitioners should consider the heterogeneous nature of MT impairment in DD when fashioning rehabilitation strategies.

In any event, the insufficient evidence on the efficacy of training in domain-general cognitive skills suggests that the most useful intervention strategy in cognitive deficits associated with DD is that of

Received: 13/06/2023 Accepted: 05/12/2023

TABLE IV. Training in domain-general cognitive skills

Program	PS	WM	EF	STVM	VA
Tradislexia	×	×			
Ubinding		×		×	
DytectiveU		×	×		
Galexia					
Glifing		×	×		
Jellys					×
Minecraft	×	×			
GraphoGame					

Note. PS=Processing speed; WM=Working memory; STVM=Sort-term verbal memory; EF=Executive functions; VA=Visual attention.
Source: Compiled by the author.

compensatory initiatives to eliminate barriers in academic settings, with the aim of avoiding school failure in children with dyslexia. An example of compensation for WM deficits in text composition might be to provide a structure with mnemotechnical cues and prior preparation of the orthography of vocabulary involved so that it can be activated in the WM (Hebert et al., 2018).

Third level of intervention: metalinguistic and linguistic skills

Phonological awareness training appears to have an impact on decoding processes, but the positive impact of this training does not extend to competencies requiring orthographic memory representations, such as orthographically correct spelling and correct reading of foreign words, nor does it affect reading fluency (Wimmer, 2000). *Decoding processes* (DPs), which involve understanding the alphabetic principle, begin by associating the phoneme sound with its graphic representation (phoneme/grapheme conversion) until the mechanics of decoding larger units are mastered. This acquisition is crucial for learning to read in first grade (Ergül et al., 2023), although, used isolatedly, it seems to be less effective than as part of multicomponent teaching programs (Donegan et al., 2021).

Received: 13/06/2023 Accepted: 05/12/2023

In transparent alphabetic languages, where spoken words can be broken down into syllables, beginner readers have been found to learn to read and write more effectively when they are taught grapheme-phoneme units rather than grapho-syllabic sound units (Sargiani et al., 2021). Table V lists the linguistic and metalinguistic skills included in each PGV.

Four of the programs work on decoding, which is addressed by means of tasks related to recognizing graphemes, syllables, words and pseudowords of different complexity and in increasing order of difficulty. Six of the eight programs work on certain aspects of phonological awareness, although none of them deals with this metalinguistic competence in all its facets. In none of the programs does lexical awareness appear as the first in a sequence of tasks of increasing difficulty upon which a PA intervention should be structured, given that auditory processing deficits also affects the segmentation of the spoken string at word level (Schaadt et al., 2019), followed by syllabic awareness, intrasyllabic or rhyme awareness and, finally, phonemic awareness from the age of 6-7 (Defior & Serrano, 2011).

Furthermore, syllabic awareness should be structured in line with the complexity of the syllabic structures (CV, VC, CVC, etc.), and phonemic awareness in relation to the order phonemes are acquired (Susanibar et al. 2013). In this sense, Tradislexia, Glifing and DytectiveU all sequence the activities in accordance with syllabic structure.

TABLE V. Linguistic and metalinguistic skills in the PGVs

Program	**PA**	**SA**	**ISA**	**MA**	**V**	**SP**	**D**
Tradislexia	×	×	×		×	×	
Ubinding	×	×		×	×	×	
DytectiveU	×	×	×	×	×	×	×
Galexia	×						×
Glifing		×	×	×	×	×	×
Jellys							
Minecraft					×		
GraphoGame	×						×

Note. PA=Phonological awareness; SA=Syllabic awareness; ISA=Intra-syllabic awareness; MA=Morphological awareness; V=Vocabulary; SP=Syntactic processing; D= decodifing.
Source: Compiled by the author.

Received: 13/06/2023 Accepted: 05/12/2023

Derivational morphology is closely linked to semantic morphology. It is also considered to bridge phonology and orthography (Bahr et al., 2020). The orthographic transparency of Spanish may encourage fine-grained encoding strategies, but delay reliance on significant grains for automatic word reading, and thus the morphological effect emerges late, around sixth grade. (Lázaro et al., 2018). Morphological awareness in Spanish is related to reading comprehension, as it provides access to semantic and syntactic information in new words (D'Alessio, et al., 2019). Oral instruction in derivational and inflectional morphology may involve a preparatory strategy for reading at preschool age in transparent languages (Cohen-Mimran, 2022), being more effective for DD than for typically developing children (Deacon et al., 2019). Three of the programs address some form of morphology: UBinding, DytectiveU, and Glifing.

Empirical attention to *semantics* in DD intervention is limited (Deacon et al., 2019). The lexical quality hypothesis holds that literacy involves the successful integration of phonology, orthography, and semantic information, and that phonological representations alone are insufficient to achieve fluent reading. Furthermore, rapid decoding alone does not enhance comprehension (Perfetti, 2007), while individuals with dyslexia appear to rely more on semantic context than their peers with similar reading abilities, which could be interpreted as a compensatory mechanism (Deacon et al., 2019).

It has been suggested that a more specific and redundant lexicon might facilitate phonological awareness (van Rijthoven et al., 2018). Although the semantic network of children with dyslexia seems to be well evidenced, such children retrieve elements from the network more slowly, resulting in lower semantic fluency (Mengisidou et al., 2020), which aligns with the double deficit hypothesis. According to Viersen et al. (2017), however, children at family risk of dyslexia that were later diagnosed with DD present a delay in the both the receptive and productive development of vocabulary. Interventions should thus incorporate this component. Most of the programs analyzed here include a vocabulary component in their interventions.

With regard to *syntactic processing*, or the knowledge of the functions of words in sentences, two activities have been shown to help students with syntactic problems to improve their sentence writing: 1) rearranging the words in scrambled sentences into the correct; 2) creating sentences from a set of words (nouns, verbs, adjectives and adverbs) and a set of function words (prepositions, conjunctions, pronouns and articles)

(Berninger et al. (2019). This component features in four of the PGVs: Tradislexia, Ubinding, DytectiveU and Glifing.

Fourth level of intervention: Performance measures

Performance measures are ways of operationalizing reading performance based on the symptoms that characterize DD. The tasks offered by the PGVs are designed to optimize these measures. Table VI shows the performance measures featured in the PGVs.

Reading fluency (RF) refers to a way of reading in which all sublexical units, words and text, as well as the perceptual, linguistic and cognitive processes involved, are processed accurately and automatically, allowing sufficient time and resources to be allocated to comprehension and deeper thought (Norton & Wolf, 2012). Meanwhile, reading speed (RS) is a measure referring to the reading aloud of elements of language (typically words or pseudowords). It is important to distinguish between the two concepts, as the former does not necessarily imply the text is understood. Intervention in RS is crucial in improving RF (Lopez-Escribano, 2016; Rakhlin et al., 2019). This involves automating decoding by means of rapid reading tasks with letters, syllables, and words.

TABLE VI. Performance measures in the PGVs

Program	***O***	***RF***	***RAN***	***RC***	***RS***	***WS***	***MAS***	***ER***	***EC***
Tradislexia	×								
Ubinding	×		×	×	×		×		
DytectiveU	×			×	×	×		×	×
Galexia	×	×							
Glifing	×			×	×				
Jellys									
Minecraft		×							
GraphoGame									

Note. O=Orthography; RF=reading fluency; RAN=Rapid automatized naming or naming speed; RC= Reading comprehension; RS=Reading speed; WS=Writing speed; MAS=Motor articulation speed; ER=Error recognition; EC=Error correction.
Source: Compiled by the authors.

Received: 13/06/2023 Accepted: 05/12/2023

However, RF encompasses RS, but further involves other cognitive and linguistic processes that can only be assessed in the reading of a text from which meaning is simultaneously extracted. To date, Galexia is the only program that specifically addresses the improvement of RF, while UBinding, DytectiveU and Glifing work on RS.

Orthography is the most neglected area of study, and there remain many gaps in this field of research (Williams et al., 2017; Dymora & Niemiec, 2019). Writing deficits (dysorthogrpahy and dysgraphia) in DD are associated with functional abnormalities in the neural network of multiple brain regions involved in motor execution, visual-orthographic processing, and cognitive control (Yang et al., 2022). According to Berninger et al. (2019), literacy learning should include language by mouth, by eye and by hand, as well as motor planning, motor timing, and control and output skills. When teaching the alphabetic principle, harnessing the visual attributes of letters and explicitly teaching the motor pattern of the corresponding spelling is a strategy that has been found to be effective in automating the graphomotor pattern, thus resulting in a reduced WM load, targeted as the cause of DD-related dysgraphia (Hebert et al., 2018).

Auditory processing disorder involves difficulty in identifying syllable stress and prominent syllables (Jiménez-Fernández et al., 2015), resulting in problems to apply the rules of accentuation and punctuation. According to Toffalini et al. (2017), the high rate of children with spelling disorder in transparent languages could be due to the specific characteristics of such languages, in which reading errors tend to be eliminated at a certain age, but difficulties in the correct writing of words persist, especially when under stress or when specific arbitrary features of spelling must be added. In transparent languages, the difficulty arguably lies in constructing an orthographic lexicon and, therefore, in gaining automatic access to orthographic selection and production, varying significantly depending on the orthographic system of each language (Habib, 2021).

All the programs, except Jellys and GraphoGame, include tasks focused on orthographic recognition through the lexical pathway. DytectiveU uses the strategy of recognizing and self-correcting typical errors in the writing of children with DD, awareness of which improves reading performance and spelling (Rello, 2018).

We found no activities involving the construction of the orthographic lexicon for retrieval in writing tasks, addressing the order of the string of letters that make up words and their specific arbitrary spelling rules. The strategies that have been shown to be most effective in this sense incorporate handwriting for repetition and self-correction (Williams et al., 2017), as well as retention of letter order in visual memory, using games such as "Photographic Leprechaun" and the "Proofreaders' Trick" (Berninger et al., 2013), that could be incorporated into PGVs by digitizing handwriting. Additionally, the explicit instruction in using the computer keyboard, as well as the use of spell checkers, may be considered for interventions in DD, not only from a rehabilitative perspective (the effectiveness of which is yet to be evidenced) or a compensatory perspective, but as part of the technological and academic competence demanded today by society and education (Berninger et al., 2019).

As well as phonological difficulties, the double deficit theory (Wolf & Bowers, 2000), includes the deficit in RAN as an independent core factor of phonological awareness. RAN is a measure of the speed with which we can identify and name objects, colors, numbers, and letters. In transparent orthographies, the negative impacts of the factors underlying early deficit in PA and RAN emerge when reading fluency and orthography become important, despite appropriate instruction and acquisition in first grade (Ergül et al., 2023). Recent studies have found its neurological correlate, associating it with structural white matter anomalies in the left arcuate fasciculus, which is part of the dorsal pathway (Vander Stappen et al., 2020). These abnormalities disrupt connectivity with frontotemporal regions involved in articulation, speech fluency and verbal working memory (Mohammad et al., 2022).

According to Norton & Wolf (2012), the main reason RAN predicts subsequent reading skills is because it measures the ability to automate access to individual linguistic and perceptual components, as well as the connections between them, in serial visual tasks. In regular writing systems, dyslexia is less closely related to decoding accuracy than reading speed is (Padeliadu et al., 2021). Consequently, RAN measures have greater discriminatory power in these languages and at earlier stages of development (Luque et al., 2013). Vander Stappen and Reybroeck (2018) report that RAN-objects training improves reading speed, while PA training enhances orthographic representations. Georgiou et al. (2016) and Papadopoulos et al. (2016) found that RAN is related to fluency when reading aloud, but not to fluency in silent reading, supporting the hypothesis of a relationship between RAN and articulation. Only UBinding includes tasks for RAN and MAS (López-Olóriz, 4-5-2023).

Received: 13/06/2023 Accepted: 05/12/2023

Conclusions

The overall objective of this study was to provide an update on the hypotheses to explain DD and to examine the rehabilitation oriented PGVs available in Spain, supported or not by scientific evidence, from four levels of intervention. Our study reviews the current research on the explanatory hypotheses and examines the efficacy of the most scientifically supported interventions, looking at whether they are addressed in the activities contained in the PGVs analyzed.

With respect to the first specific objective, and in light of our literature review, none of the PGVs brings together all the key components of an intervention in DD, although the most prominent ones are present in them all. It is worth noting that that there are promising elements of DD intervention that are, as yet insufficiently addressed by the PGVs, such as the motor and articulation aspects (Papadopoulos et al., 2016; Liu and Georgiou, 2017; Berninger et al., 2019; Yang et al., 2022) and auditory processing (Bonacina et al., 2015; Habib, 2021). Considering these elements could help develop more comprehensive interventions in DD.

Regarding the second specific objective, we provide clinical and educational professionals with an updated grounding in the neurocognitive and psycholinguistic elements related to DD. This information is hoped to contribute to informed decision making on the use of technological tools in the rehabilitation of DD. It is important for the various types of professionals involved in DD to consider the various explanatory hypotheses and their possible complementarity, considering the potential existence of DD subtypes (Habib, 2021; Lorusso and Toraldo, 2023) and under the adoption of a multiple deficit approach (Pennington et al., 2012). For example, it is worth bearing in mind that, although phonological awareness and decoding processes are crucial to interventions for DD, approximately 25% of cases fail to respond to such interventions (Seiler et al., 2019). In this sense, each individual with DD may present a unique profile of strengths and weaknesses that may require different targets and methods of intervention.

In general terms, methodological weaknesses have been detected in studies examining PGVs, such as limited sample sizes or the lack of a control group (Ostiz-Blanco et al., 2021). In addition, isolating the effects of these programs from those of schooling and the practice effect of PGVs tasks can be complex (Łuniewska et al., 2018). In the case of PGVs in Spanish, there remains scant empirical evidence. Moreover, it would be desirable for PGVs to include a technical manual in which the neurological and/or cognitive explanatory hypotheses they are based on, the population they have been applied in, and the results of such application are made explicit, as is done with any assessment test or intervention program. While the play-based or gamified environment created by PGVs can create a psychologically stimulating environment for persistence and self-improvement (Dymora & Niemiec, 2019), evidence of the efficacy of the interventions collected by means of rigorous and realistic trials is needed before recommending their implementation in educational settings or specialized centers (Snowling & Hulme, 2011). They should also include a detailed catalog of their activities and, within the framework of rehabilitation, the purpose for which they are designed.

Bibliographic references

Bahr, R. H., Silliman, E. R., & Berninger, V. W. (2020) Derivational Morphology Bridges Phonology and Orthography: Insights into the Development of Word-Specific Spellings by Superior, Average, and Poor Spellers. *Language, Speech, and Hearing Services in Schools*. https://doi.org/10.1044/2020_LSHSS-19-00090

Berninger, V. W., Lee, Y. L., Abbott, R. D., & Breznitz, Z. (2013). Teaching children with dyslexia to spell in a reading-writers'workshop. *Annals of Dyslexia, 63*, 1–24. https://doi.org/10.1007/s11881-011-0054-0

Berninger, V. W., Richards, T. L., Nielsen, K. H., Dunn, M. W., Raskind, M. H., & Abbott, R. D. (2019). Behavioral and brain evidence for language by ear, mouth, eye, and hand and motor skills in literacy learning. *International journal of school y educational psychology, 7* (Suppl 1), 182–200. https://doi.org/10.1080/21683603.2018.1458357

Bertoni, S., Franceschini, S., Puccio, G., Mancarella, M., Gori, S., & Facoetti, A. (2021). Action Video Games Enhance Attentional Control and Phonological Decoding in Children with Developmental Dyslexia. *Brain sciences, 11*(2), 171. https://doi.org/10.3390/brainsci11020171

Bonacina, S., Cancer, A., Lanzi, P. L., Lorusso, M. L., & Antonietti, A. (2015). Improving reading skills in students with dyslexia: the efficacy of a sublexical training with rhythmic background. *Frontiers in psychology, 6*, 1510. https://doi.org/10.3389/fpsyg.2015.01510

Received: 13/06/2023 Accepted: 05/12/2023

Centanni, T. M., Norton, E. S., Ozernov-Palchik, O., Park, A., Beach, S. D., Halverson, K., Gaab, N., & Gabrieli, J. D. E. (2019). Disrupted left fusiform response to print in beginning kindergartners is associated with subsequent reading. *NeuroImage: Clinical*, 22, 101715. https://doi.org/10.1016/j.nicl.2019.101715

Clark, K. A., Helland, T., Specht, K., Narr, K. L. Manis, F. R., Toga, A.W., & Hugdahl, K. (2014). Neuroanatomical precursors of dyslexia identified from pre-reading through to age 11. *Brain, 137*(12), 3136–3141, https://doi.org/10.1093/brain/awu229

Cohen-Mimran, R., Reznik-Nevet, L., Gott, D., & Share, D. L. (2022). Preschool morphological awareness contributes to word reading at the very earliest stages of learning to read in a transparent orthography. *Reading and writing*, 1–21. https://doi.org/10.1007/s11145-022-10340-z

D'Alessio, M. J., Jaichenco, V., & Wilson, M. A. (2019). The relationship between morphological awareness and reading comprehension in Spanish-speaking children. *Scandinavian journal of psychology, 60*(6), 501–512. https://doi.org/10.1111/sjop.12578

Deacon, S., Tong, X., & Mimeau, C. (2019). Morphological and Semantic Processing in Developmental Dyslexia. In L. Verhoeven, C. Perfetti, y K. Pugh (Eds.), *Developmental Dyslexia across Languages and Writing Systems* (327-349). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781108553377.015

Defior, S., & Serrano, F. (2011). Procesos Fonológicos Explícitos e Implícitos, Lectura y Dislexia. *Revista Neuropsicología, Neuropsiquiatría y Neurociencias, 11*(1), 79-94.

Donegan, R. E., & Wanzek, J. (2021). Effects of reading interventions implemented for upper elementary struggling readers: A look at recent research. *Reading and Writing, 34(*8), 1943–1977. https://doi.org/10.1007/s11145-021-10123-y

Doyle, C., Smeaton, A. F., Roche, R. A. P., & Boran, L. (2018). Inhibition and Updating, but Not Switching, Predict Developmental Dyslexia and Individual Variation in Reading Ability. *Frontiers in psychology, 9(*795). https://doi.org/10.3389/fpsyg.2018.00795

Dymora, P., & Niemiec, K. (2019). Gamification as a Supportive Tool for School Children with Dyslexia. *Informatics, 6*(4), 48. https://doi.org/10.3390/informatics6040048

Ergül, C., Zeynep Bahap Kudret, Z.B., Meral Çilem Ökcün-Akçamuş, M.C., & Akoglu, G. (2023). Double-Deficit Hypothesis and Reading

Difficulties: A Longitudinal Analysis of Reading and Reading Comprehension Performance of Groups Formed According to This Hypothesis. *Education and Science, 48*(213), 1–23. https://doi.org/10.15390/EB.2022.11002

Fernández-Andrés, M. I., Tejero, P., & Vélez-Calvo, X. (2019). Visual Attention, Orthographic Word Recognition, and Executive Functioning in Children With ADHD, Dyslexia, or ADHD + Dyslexia. *Journal of Attention Disorders, 25*(7), 942–953. https://doi.org/10.1177/1087054719864637

Forne, S., López-Sala, A., Mateu-Estivill, R., Adan, A., Caldu, X., Rifa-Ros, X., & Serra-Grabulosa, J. M. (2022). Improving Reading Skills Using a Computerized Phonological Training Program in Early Readers with Reading Difficulties. *International Journal of Environmental Research and Public Health, 19*(18), 11526. https://doi.org/10.3390/ijerph191811526

García i Ortiz, M., González i Calderon, M., & Garcia-Campomanes, B. (2016). *Glifing: Cómo detectar y vencer las dificultades de la lectura*. Barcelona: Horsori editorial.

Georgiou, G. K., Aro, M., Liao, C. H., & Parrila, R. (2016). Modeling the relationship between rapid automatized naming and literacy skills across languages varying in orthographic consistency. *Journal of experimental child psychology*, *143*, 48–64. https://doi.org/10.1016/j.jecp.2015.10.017

Giraldo-Chica, M., & Schneider, K. A. (2018). Hemispheric asymmetries in the orientation and location of the lateral geniculate nucleus in dyslexia. *Dyslexia, 24*(2), 197–203. https://doi.org/10.1002/dys.1580

Gori, S., Seitz, A. R., Ronconi, L., Franceschini, S., & Facoetti, A. (2016). Multiple Causal Links Between Magnocellular-Dorsal Pathway Deficit and Developmental Dyslexia. *Cerebral cortex, 26*(11), 4356–4369. https://doi.org/10.1093/cercor/bhv206

Goswami, U. (2019). Speech rhythm and language acquisition: an amplitude modulation phase hierarchy perspective. *Annals of the New York Academy of Sciences, 1453*(1), 1–12. https://doi.org/10.1111/nyas.14137

Habib, M. (2021). The Neurological Basis of Developmental Dyslexia and Related Disorders: A Reappraisal of the Temporal Hypothesis, Twenty Years on. *Brain Science, 1*(6), 798. https://doi.org/10.3390/brainsci11060708

Hebert, M., Kearns, D. M., Hayes, J. B., Bazis, P., & Cooper, S. (2018). Why children with dyslexia struggle with writing and how to help them.

Language, speech, and hearing services in schools, 49(4), 843–863. https://doi.org/10.1044/2018_LSHSS-DYSLC-18-0024

Helland, T., Morken, F., Bless, J. J., Valderhaug, H. V., Eiken, M., Helland, W. A., & Torkildsen, J. V. K. (2018). Auditive training effects from a dichotic listening app in children with dyslexia. *Dyslexia, 24*(4), 336–356. https://doi.org/10.1002/dys.1600

Jiménez, A. M., & Díez, E. (2018). Impacto de videojuegos en la fluidez lectora en niños con y sin dislexia. El caso de Minecraft. *Revista Latinoamericana de Tecnología Educativa, 17*(1), 77–90. https://doi.org/10.17398/1695-288X.17.1.77

Jiménez, J. E., & Rojas, E. (2008). Efectos del videojuego Tradislexia en la conciencia fonológica y reconocimiento de palabras en niños disléxicos. *Psicothema, 20*(3), 347–353.

Jiménez-Fernández, G., Gutiérrez-Palma, N., & Defior, S. (2015). Impaired stress awareness in Spanish children with developmental dyslexia. *Research in Developmental Disabilities,* 37, 152–161. https://doi.org/10.1016/j.ridd.2014.11.002

Klimovich-Gray, A., Di Liberto, G., Amoruso, L., Barrena, A., Agirre E., & Molinaro, N. (2023). Increased top-down semantic processing in natural speech linked to better reading in dyslexia. *NeuroImage,* en prensa. https://doi.org/10.1016/j.neuroimage.2023.120072

Kuhl, U., Neef, N. E., Kraft, I., Schaadt, G., Dörr, L., Brauer, J., Czepezauer, I., Müller, B., Wilcke, A., Kirsten, H., Emmrich, F., Boltze, J., Friederici, A. D., & Skeide, M. A. (2020). The emergence of dyslexia in the developing brain. *NeuroImage*, *211*, 116633. https://doi.org/10.1016/j.neuroimage.2020.116633

Lázaro, M., Illera, V., Acha, J., Escalonilla, A., García, S., & Sainz, J. S. (2018). Morphological effects in word identification: tracking the developmental trajectory of derivational suffixes in Spanish. *Reading and Writing, 31*(7), 1669–1684. https://doi.org/10.1007/s11145-018-9858-1

Liu, C., & Georgiou, G. K. (2017). Cognitive and environmental correlates of rapid automatized naming in Chinese kindergarten children. *Journal of Educational Psychology*, *109*(4), 465–476. https://doi.org/10.1037/edu0000151

Lonergan, A., Doyle, C., Cassidy, C., MacSweeney Mahon, S., Roche, R. A. P., Boran, L., & Bramham, J. (2019). A meta-analysis of executive functioning in dyslexia with consideration of the impact of comorbid ADHD. *Journal of Cognitive Psychology, 31*(7), 725–749. https://doi.org/10.1080/20445911.2019.1669609

López-Escribano, C. (2016). Training Reading Fluency and Comprehension of Spanish Children with Dyslexia. In: Khateb, A., Bar-Kochva, I. (eds) Reading Fluency. *Literacy Studies, 12*. https://doi.org/10.1007/978-3-319-30478-6_9

López-Olóriz, J. (2023). Comunicación personal Proyecto Ubinding [correo electrónico].

López-Olóriz, J., Pina, V., Ballesta, S., Bordoy, S., & Pérez-Zapata, L. (2020). Proyecto Petit UBinding: Método de adquisición y mejora de la lectura en primero de primaria. Estudio de eficacia. *Revista de logopedia, foniatría y audiología, 40*(1), 12–22.

Lorusso, M. L., & Toraldo, A. (2023). Revisiting Multifactor Models of Dyslexia: Do They Fit Empirical Data and What Are Their Implications for Intervention? *Brain Science*, *13,* 328. https://doi.org/10.3390/

Łuniewska, M., Chyl, K., Dębska, A., Kacprzak, A., Plewko, J., Szczerbiński, M., Szewczyk, J., Grabowska, A., & Jednoróg, K. (2018). Neither action nor phonological video games make dyslexic children read better. *Scientific reports, 8*(1), 549. https://doi.org/10.1038/s41598-017-18878-7

Luque, J. L., López-Zamora, M., Álvarez, C. J., & Bordoy, S. (2013). Beyond decoding deficit: inhibitory effect of positional syllable frequency in dyslexic Spanish children. *Annals of Dyslexia, 63*(3-4), 239–252. doi:10.1007/s11881-013-0082-z

Maehler, C., Joerns, C., & Schuchardt, K. (2019). Training Working Memory of Children with and without Dyslexia. *Children, 6*(3), 47. https://doi.org/10.3390/children6030047

Mengisidou, M., Marshall, C. R., & Stavrakaki, S. (2020). Semantic fluency difficulties in developmental dyslexia and developmental language disorder (DLD): poor semantic structure of the lexicon or slower retrieval processes? *International journal of language y communication disorders, 55*(2), 200–215. https://doi.org/10.1111/1460-6984.12512

Mohammad, S. A., Nashaat, N. H., Okba, A. A. M. B., Kilany, A., Abdel-Rahman, A. S., Abd-Elhamed, A. M., & Abdelraouf, E. R. (2022). Asymmetry Matters: Diffusion Tensor Tractography of the Uncinate Fasciculus in Children with Verbal Memory Deficits. AJNR. *American journal of neuroradiology, 43*(7), 1042–1047. https://doi.org/10.3174/ajnr.A7535

Norton, E. S., & Wolf, M. (2012). Rapid automatized naming (RAN) and reading fluency: Implications for understanding and treatment of reading disabilities. *Annual Review of Psychology,* 63, 427–452.

Received: 13/06/2023 Accepted: 05/12/2023

Ostiz-Blanco, M., Bernacer, J., Garcia-Arbizu, I., Diaz-Sanchez, P., Rello, L., Lallier, M., & Arrondo, G. (2021). Improving Reading Through Videogames and Digital Apps: A Systematic Review. *Frontiers in psychology*, *12*, 652948. https://doi.org/10.3389/fpsyg.2021.652948

Ostiz-Blanco, M., Lallier, M., Grau, S., Rello, L., Bigham, J. P., & Carreiras, M. (2018). Jellys: Towards a Videogame that Trains Rhythm and Visual Attention for Dyslexia. Assets'18: Proceedings of the 20th International Acm Sigaccess Conference on Computers and Accessibility, 447–449. https://doi.org/10.1145/3234695.3241028

Padeliadu, S., Giazitzidou, S., & Stamovlasis, D. (2021). Developing reading fluency of students with reading difficulties through a repeated reading intervention program in a transparent orthography. *Learning Disabilities: A Contemporary Journal, 19(*1), 49–67.

Papadopoulos, T. C., Spanoudis, G. C., & Georgiou, G. K. (2016). How is RAN related to reading fluency? A comprehensive examination of the prominent theoretical accounts. *Frontiers in psychology*, *7*, 1217. https://doi.org/10.3389/fpsyg.2016.01217

Pennington, B. F., Santerre–Lemmon, L., Rosenberg, J., MacDonald, B., Boada, R., Friend, A., … Olson, R. K. (2012). Individual prediction of dyslexia by single versus multiple deficit models. *Journal of Abnormal Psychology, 121*(1), 212–224. https://doi.org/10.1037/a0025823

Perfetti, C. (2007). Reading Ability: Lexical Quality to Comprehension. *Scientific Studies of Reading, 11*(4), 357–383. https://doi.org/10.1080/10888430701530730

Rakhlin, N. V., Mourgues, C., Cardoso-Martins, C., Kornev, A. N., & Grigorenko, E. L. (2019). Orthographic processing is a key predictor of reading fluency in good and poor readers in a transparent orthography. *Contemporary Educational Psychology, 56*, 250–261. https://doi.org/10.1016/j.cedpsych.2018.12.002

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: insights from a multiple case study of dyslexic adults. *Brain: a journal of neurology, 126*(4), 841–865. https://doi.org/10.1093/brain/awg076

Rello, L. (2018) *Superar la dislexia. Una experiencia personal a través de la investigación*. Barcelona: Paidós educación.

Rosas, R., Escobar, J. P., Ramírez, M. P., Meneses, A., & Guajardo, A. (2017). Impact of a computer-based intervention in Chilean children at risk of manifesting reading difficulties. *Infancia y Aprendizaje: Journal for* *the Study of Education and Development, 40*(1), 158-188. https://doi.org/10.1080/02103702.2016.1263451

Ruffino, M., Gori, S., Boccardi, D., Molteni, M., & Facoetti, A. (2014). Spatial and temporal attention in developmental dyslexia. *Frontiers in human neuroscience*, *8*, 331. https://doi.org/10.3389/fnhum.2014.00331

Sánchez-Doménech, I. (2022). Revisión sistemática e implicaciones para el diagnóstico psicopedagógico: comorbilidad Dislexia/TDAH. *REOP - Revista Española de Orientación y Psicopedagogía, 33*(2), 63–84. https://doi.org/10.5944/reop.vol.33.num.2.2022.34360

Sargiani, R. de A., Ehri, L. C., & Maluf, M. R. (2021). Teaching Beginners to Decode Consonant–Vowel Syllables Using Grapheme–Phoneme Subunits Facilitates Reading and Spelling as Compared with Teaching Whole-Syllable Decoding. *Reading Research Quarterly, 57*(2). https://doi.org/10.1002/rrq.432

Schaadt, G., & Männel, C. (2019). Phonemes, words, and phrases: Tracking phonological processing in pre-schoolers developing dyslexia. *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology, 130*(8), 1329–1341. https://doi.org/10.1016/j.clinph.2019.05.018

Seiler, A., Leitão, S., & Blosfelds, M. (2019). WordDriver-1: evaluating the efficacy of an app-supported decoding intervention for children with reading impairment. *International journal of language y communication disorders, 54*(2), 189–202. https://doi.org/10.1111/1460-6984.12388

Serrano, F., Bravo Sanchez, J. F., & Gomez-Olmedo, M. (2016). Galexia: Evidence-Based Software for Intervention in Reading Fluency and Comprehension. En L. G. Chova, A. L. Martinez, y I. C. Torres (Eds.), Inted2016: 10th International Technology, Education and Development Conference. 2001-2007. Iated-Int Assoc Technology Education and Development.

Snowling, M. J., Gooch, D., McArthur, G., & Hulme, C. (2018). Language Skills, but Not Frequency Discrimination, Predict Reading Skills in Children at Risk of Dyslexia. *Psychological science, 29*(8), 1270–1282. https://doi.org/10.1177/0956797618763090

Snowling, M. J., & Hulme, C. (2011). Evidence-based interventions for reading and language difficulties: creating a virtuous circle. *The British journal of educational psychology, 81*(1), 1–23. https://doi.org/10.1111/j.2044-8279.2010.02014.x

Susaníbar, F., Huamaní, O., & Dioses, A. (2013). Adquisición fonética-fonológica. *EOS*, *1*(1), 19–36.

Toffalini, E., Giofrè, D., & Cornoldi, C. (2017). Strengths and Weaknesses in the Intellectual Profile of Different Subtypes of Specific Learning Disorder. *Clinical Psychological Science, 5*(2), 402–409. https://doi.org/10.1177/2167702616672038

Tulloch, K., & Pammer, K. (2019). Tablet computer games to measure dorsal stream performance in good and poor readers. *Neuropsychologia, 130*, 92–99. https://doi.org/10.1016/j.neuropsychologia.2018.07.019

Van Herck, S., Vanden Bempt, F., Economou, M., Vanderauwera, J., Glatz, T., Dieudonné, B., Vandermosten, M., Ghesquière, P., & Wouters, J. (2022). Ahead of maturation: Enhanced speech envelope training boosts rise time discrimination in pre-readers at cognitive risk for dyslexia. *Developmental Science*, *25*, e13186. https://doi.org/10.1111/desc.13186

Van Hirtum, T., Moncada-Torres, A., Ghesquière, P., & Wouters, J. (2019). Speech Envelope Enhancement Instantaneously Effaces Atypical Speech Perception in Dyslexia. *Ear and hearing, 40*(5), 1242–1252. https://doi.org/10.1097/AUD.0000000000000706

Van Rijthoven, R., Kleemans, T., Segers, E., & Verhoeven, L. (2018). Beyond the phonological deficit: Semantics contributes indirectly to decoding efficiency in children with dyslexia. *Dyslexia, 24*(4), 309–321. https://doi.org/10.1002/dys.1597

Vander Stappen, C., Dricot, L., & Van Reybroeck, M. (2020). RAN training in dyslexia: Behavioral and brain correlates. *Neuropsychologia*, *146*, 107566. https://doi.org/10.1016/j.neuropsychologia.2020.107566

Vander Stappen, C., & Reybroeck, M. V. (2018). Phonological Awareness and Rapid Automatized Naming Are Independent Phonological Competencies with Specific Impacts on Word Reading and Spelling: An Intervention Study. *Frontiers in Psychology*, *9*. https://doi.org/10.3389/fpsyg.2018.00320

Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: a deficit in visuo-spatial attention, not in phonological processing. *Trends in cognitive sciences, 14*(2), 57–63. https://doi.org/10.1016/j.tics.2009.12.003

Viersen, S., Bree, E., Verdam, M., Krikhaar, E., Maassen, B., Leij, A., & Jong, P. (2017). Delayed Early Vocabulary Development in Children at Family Risk of Dyslexia. *Journal of speech, language, and hearing research, 60*(4). https://doi.org/10.1044/2016_JSLHR-L-16-0031

Willcutt, E. G., McGrath, L. M., Pennington, B. F., Keenan, J. M., DeFries, J. C., Olson, R. K., & Wadsworth, S. J. (2019). Understanding Comorbidity Between Specific Learning Disabilities. *New Directions for Child and Adolescent Development, 165,* 91–109. https://doi.org/10.1002/cad.20291

Williams, K. J., Walker, M. A., Vaughn, S., & Wanzek, J. (2017). A Synthesis of Reading and Spelling Interventions and Their Effects on Spelling Outcomes for Students with Learning Disabilities. *Journal of learning disabilities, 50*(3), 286–297. https://doi.org/10.1177/0022219415619753

Wimmer, H., Mayringer, H., & Landerl, K. (2000). The double-deficit hypothesis and difficulties in learning to read a regular orthography. *Journal of Educational Psycholgy,* 92, 668–680. https://doi.org/10.10371/0022-0663.92.4.668

Wokuri, S., Gonthier, C., Marec-Breton, N., & Majerus, S. (2023). Heterogeneity of short-term memory deficits in children with dyslexia. *Dyslexia*. https://doi.org/10.1002/dys.1749

Wolf, M., & Bowers, P. G. (2000). Naming speed and developmental reading disabilities. An introduction to the special issue on the double-deficit hypothesis. *Journal of Learning Disabilities, 33*(4), 322–324.

Yang, Y., Zuo, Z., Tam, F., Graham, S. J., Li, J., Ji, Y., Meng, Z., Gu, C., Bi, H. Y., Ou, J., & Xu, M. (2022). The brain basis of handwriting deficits in Chinese children with developmental dyslexia. *Developmental science, 25*(2), e13161. https://doi.org/10.1111/desc.13161

Zhou, D., Cai, Q., Luo, J. yi, Z., Li, Y., Seger, C. A., & Chen, Q. (2021). The neural mechanism of spatial-positional association in working memory: A fMRI study. *Brain and Cognition*, 152, 105756. https://doi.org/10.1016/j.bandc.2021.105756

Contact address: Iluminada Sanchez-Domenech. Universidad Internacional de La Rioja. Avenida de la Paz 137, 26006 Logrono, La Rioja, Espana. E-mail: iluminada.sanchez@unir.net

Received: 13/06/2023 Accepted: 05/12/2023