

## Double trouble: Co-occurring visual and phonological impairments in childhood dyslexia

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### ABSTRACT

Extensive research has characterised developmental dyslexia as a disorder associated with phonological impairment, but increasing evidence suggests that visual processing difficulties may also contribute. Whether visual deficits are evident early in development remains unclear, since most evidence derives from adult samples or language-related tasks and accuracy-based measurements. The present study investigated visual processing in children with dyslexia using a validated, non-linguistic test battery previously employed in adults. Phonological functioning was indexed using a measure of phonological working memory to examine whether any visual performance differences occurred alongside deficits in a core phonological domain. Children with dyslexia performed significantly worse than neurotypical readers on visual tasks and on the phonological measure. Discriminant function analysis revealed that measures from both domains distinguished between the two groups. Deficits were most pronounced for visually complex and similar stimuli and were associated with severity of reading impairment. By examining visual processing using non-linguistic tasks that eliminate orthographic confounds, this study addresses an important developmental gap and suggests that visual processing deficits may be evident alongside phonological weakness in childhood dyslexia. These findings are consistent with multidimensional accounts of dyslexia and highlight the value of domain-inclusive approaches to assessment and intervention.

### 1. Introduction

Developmental dyslexia (DD) is a neurodevelopmental disorder affecting approximately 15% of the global population (for review see: [Wydell, 2023](#)). Despite age-appropriate education, individuals with dyslexia experience persistent difficulties acquiring fluent reading, often leading to lifelong academic, occupational, and psychosocial consequences ([Astle et al., 2022](#); [Elliott & Grigorenko, 2014](#); [Eloranta et al., 2019](#); [Hulme & Snowling, 2015](#); [Nergard-Nilssen & Hulme, 2014](#); [Shrewsbury, 2016](#); [Snowling et al., 2020](#)). Although a phonological impairment has traditionally been viewed as the primary cognitive mechanism underlying dyslexia, accumulating evidence suggests that the disorder is heterogeneous and may involve broader impairments, including visual processing (for behavioural and neural reviews see: [Behrmann et al., 2025](#); [Chalmepe & Vlachos, 2025](#); [Kristjansson & Sigurdardottir, 2023](#); [Sigurdardottir et al., 2021](#); [Stein, 2025](#)).

Understanding the cognitive factors that may contribute to dyslexia is therefore critical for diagnosis and for designing targeted, developmentally sensitive interventions. The present study aims to advance this understanding by examining visual processing in children and its potential contribution to reading impairment.

The phonological deficit hypothesis (PDH) remains the dominant account of dyslexia, proposing that impaired phonological processing – particularly grapheme-to-phoneme conversion and phonological awareness – disrupts the acquisition of phonological decoding skills and the formation of stable lexical representations, thereby impeding the development of fluent reading ([Castles & Friedmann, 2014](#); [Ramus & Szenkovits, 2008](#); [Snowling, 1981](#); [Snowling, 1998](#); [Snowling, 2005](#); [Snowling et al., 2020](#); [Vellutino et al., 2004](#)). The dual-route cascaded (DRC) model ([Coltheart et al., 2001](#)) frames reading inefficiencies in terms of domain-specific impairments to two reading pathways: a lexical route that retrieves whole-word pronunciations and a sub-lexical route

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that applies grapheme-phoneme correspondence rules. This model has been influential in explaining patterns of reading performance and developmental reading profiles, such as surface dyslexia reflecting impairment of the lexical route, and phonological dyslexia reflecting impairment of the sub-lexical route (for review of developmental cases see: Bartha-Doering et al., 2024; Castles & Coltheart, 1993; Kohnen et al., 2018). These examples illustrate two of several developmental reading profiles described in the literature, and the DRC model accounts for many observed patterns of reading impairment. However, dyslexia is widely recognised as heterogeneous, and additional factors, including potential domain-general contributions such as visual processing, have also been proposed to play a role in this variability.

Reading is fundamentally a visual activity, requiring rapid, parallel extraction of abstract visual information. Inefficient parallel processing of letters can disrupt whole-word perception forcing reliance on serial grapheme-to-phoneme conversion (Valdois, 2022; Vialatte et al., 2023). Although phonological impairment remains central to accounts of dyslexia, converging evidence suggests that not all individuals exhibit impaired phonology; some appear to show primary impairments in visual processing (Bosse et al., 2007; Elliott & Grigorenko, 2014; Gibbs & Elliott, 2020; Giofre et al., 2019; Vidyasagar & Pammer, 2010). Importantly, such deficits are not always confined to orthographic material and have been observed for non-linguistic stimuli including faces, objects, and abstract patterns (Asberg Johnels et al., 2022; Brachacki et al., 1995; Brady et al., 2021; Collins et al., 2017; Gabay et al., 2017; Huestegge et al., 2014; Kuhn et al., 2021; Li & Zhao, 2025; Menghini et al., 2010; Peskin et al., 2024; Pitchford et al., 2025; Provazza, Adams, et al., 2019; Provazza et al., 2022; Sigurdardottir et al., 2015; Sigurdardottir et al., 2018). This suggests that visual impairments may represent one cognitive pathway contributing to dyslexia for a subset of individuals (Behrmann et al., 2025; Behrmann & Plaut, 2013, 2014, 2015, 2020; Dehaene et al., 2015; Giofre et al., 2019; Liu et al., 2022; Mancarella et al., 2026; Nischal & Behrmann, 2023; Sigurdardottir et al., 2021).

These findings have motivated multidimensional frameworks of dyslexia (Behrmann et al., 2025; Chalme & Vlachos, 2024; Giofre et al., 2019; Mancarella et al., 2026; Menghini et al., 2010; Peterson et al., 2013; Provazza, Adams, et al., 2019; Share, 2021; Wolf & Bowers, 1999; Zoubrinetzky et al., 2016), which conceptualise reading and its disorders as arising from interactions amongst multiple cognitive systems. One such account is the primary systems, or triangle, model (Chang et al., 2024; Hoffman et al., 2015; Patterson & Lambon Ralph, 1999; Plaut et al., 1996; Woollams et al., 2018), which emphasises the coordinated contributions of domain-general visual, phonological, and semantic systems to reading performance. Within this framework, impairments in any component system may affect reading and also manifest in non-linguistic tasks supported by the same underlying processes.

The DRC and triangle perspectives need not be viewed as competing accounts here; rather, they emphasise different components and levels of the reading architecture. The DRC model provides a detailed specification of domain-specific processes involved in reading, whereas the triangle framework complements this account by situating reading within broader interacting cognitive systems, rather than focusing exclusively on orthographic processing (Woollams, 2014). Within this broader framework, recent studies have used non-linguistic paradigms to examine whether visual processing differences associated with dyslexia extend beyond written language.

For example, adult studies (Giofre et al., 2019; Provazza, Adams, et al., 2019) employing visual discrimination tasks using checkerboard and kanji (Japanese logographic script) patterns have reported slower processing of visually complex and similar stimuli, together with phonological deficits, with measures from both domains emerging as strong predictors of dyslexia status and severity. These findings indicate that reading and non-linguistic impairments in dyslexia may reflect a multidimensional impairment in phonological and visual mechanisms,

with the magnitude of visual deficits varying dynamically with linguistic demands and processing requirements.

However, it remains unclear whether visual processing impairments are already present in childhood. Establishing if such deficits emerge early in development is important for understanding their potential role in dyslexia. To address this gap, the present study examined visual processing in children with dyslexia using a validated, non-linguistic test battery previously employed in adults (e.g., Provazza et al., 2022). A measure indexing phonological working memory was included to examine if any visual performance differences occurred alongside deficits in a core phonological domain, and to explore their relation to reading. This approach enables direct developmental comparison with prior adult findings and tests whether visual processing deficits are evident in childhood and reflect early characteristics of the disorder.

We hypothesised that children with dyslexia would exhibit weaker performance than neurotypical readers (NTR) on both phonological and visual tasks, with the largest group differences expected for stimuli requiring discrimination of visually complex or similar patterns, particularly in processing speed.

## 2. Methods

### 2.1. Participants

Forty English-speaking participants aged 11–14 were recruited from a London school providing specialist education needs (SEN) provision. Written informed consent was obtained from parents or guardians and assent from the children, to conduct and publish the study. Ethical approval was granted by Brunel University of London Research Ethics Committee (39907-MHR-Dec/2022-42964-2). Participants comprised 23 children diagnosed with developmental dyslexia (DD) or identified by the London Special Educational Needs Department (L-SEND) as having significant reading impairment and awaiting a formal diagnosis, and 17 NTR children. All participants in the DD group met the study's reading-based inclusion criteria. In the UK, access to formal dyslexia assessment can be delayed due to cost and waiting times, particularly when assessments are obtained privately. Importantly, group classification was based on objective standardised reading criteria rather than diagnostic status alone. Participants had normal or corrected vision, were matched on age and education level, and in the same ability classes. The reading level of both groups was assessed using the Renaissance STAR computer-based assessment (Renaissance Renaissance Learning, 2023), administered by L-SEND and routinely used in schools to assess reading level. Table 1 presents participant demographics, STAR reading age, percentile, and standardised scores for the two groups.

As expected, ANOVA with group (DD [ $N = 23$ ], NTR [ $N = 17$ ]) as a between-subject factor revealed significant differences with large effect sizes for STAR reading age ( $F[1,39] = 60.37, p < .001, \eta^2 = 0.61$ ), percentile ( $F[1,38] = 167.25, p < .001, \eta^2 = 0.82$ ) and standardised score ( $F[1,38] = 162.64, p < .001, \eta^2 = 0.82$ ), with NTR outperforming

**Table 1**  
Participant demographics.

	DD	NTR
Gender		
Male	11	8
Female	12	9
Age		
Mean	12.22	12.41
SD	1.04	1.0
Range	11–14	11–14
STAR Reading		
Reading age*	9.33 (0.80)	12.30 (1.13)
Percentile*	41.18 (10.09)	75.35 (4.61)
Standardised score*	95.59 (3.97)	110.35 (2.26)

Note. DD = developmental dyslexics; NTR = neurotypical readers.

\*  $p < .001$ .

DD. Participants with dyslexia were stratified by their STAR reading percentile, and split into three severity-based subgroups based on the 33rd and 66th percentiles: mild ( $N = 8$ ), moderate ( $N = 7$ ), and severe ( $N = 7$ ). Data for one dyslexic participant were missing for the STAR reading percentile; severity analyses in the proceeding sections therefore included 22 dyslexic participants in the DD group. For the checkerboard and kanji tasks, one NTR participant was absent on the day of testing, resulting in a sample of 16 NTR.

2.2. Materials

Some of the materials utilised in the present study have been previously reported in research involving adult populations (Provazza, Adams, et al., 2019); however, the current focus is on children. For more details of the tasks below, please refer to the original manuscripts.

2.2.1. Visual processing tasks (Roberts et al., 2013)

Two visual discrimination tasks were administered to assess visual processing and are described below. These tasks aimed to characterise performance recognising unfamiliar stimuli whilst minimising the role

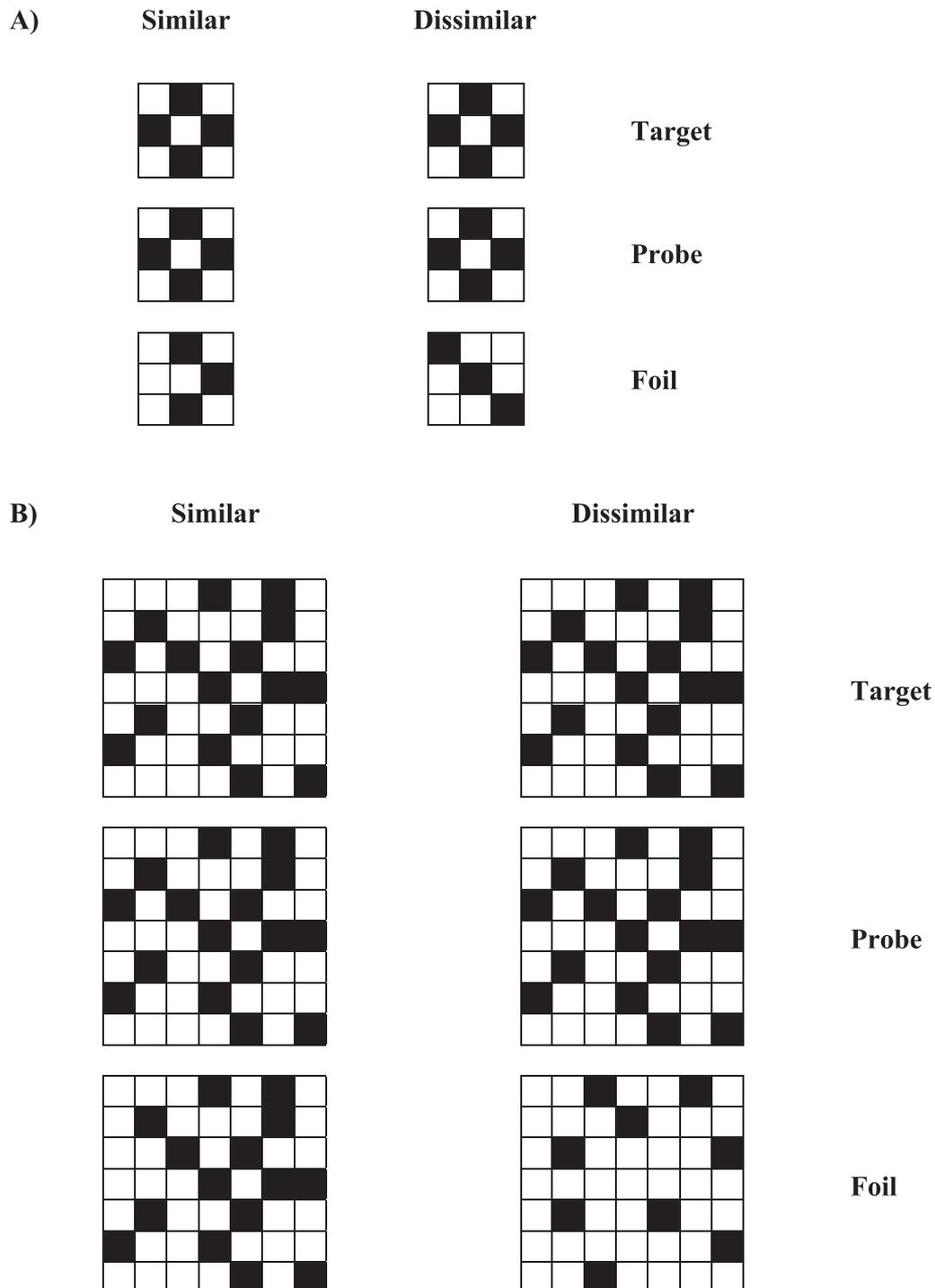


Fig. 1. Example checkerboard stimuli for (A) visually simple condition and (B) visually complex condition with similar and dissimilar foils (Roberts et al., 2013).

of top-down signals, derived from visual-phonological mapping and semantic representations. We also aimed to investigate whether any deficit was affected by the visual complexity and similarity of the stimuli. Visual complexity was manipulated by adjusting the size of the matrix and the number and spatial distribution of squares for the checkerboards, and by varying the number of strokes in each kanji character. It was predicted that performance would be disproportionately affected for visually complex and similar items. For each of these tasks, RT and accuracy data were collected.

### 2.2.2. Checkerboards

A set of 32 black and white checkerboards were used (Fig. 1). The number of squares in each matrix was either 9 ( $3 \times 3$ ) or 49 ( $7 \times 7$ ), forming a visually simple ( $N = 16$ ) and visually complex ( $N = 16$ ) set, respectively. Grids were constructed by avoiding placement of blocks of the same colour together or any other regularity in the patterns (that might simplify visual processing). In a match-to-sample task participants reported which of two checkerboards, placed above and below, matched the central probe. The position (above/below) of target and foil was randomised. Two types of foil ( $N = 32$ ) were created and paired with each target checkerboard: the similar condition ( $N = 16$ ) reflected foil patterns that differed by only one block from the target pattern; the dissimilar ( $N = 16$ ) condition reflected foils that differed from the target considerably (by several blocks), such that each foil could be easily distinguished (a total of four conditions with 64 trials: simple target similar foil  $N = 16$ ; simple target dissimilar foil  $N = 16$ ; complex target similar foil  $N = 16$ ; complex target dissimilar foil  $N = 16$ ).

### 2.2.3. Kanji (Japanese logographic script)

A set of 60 kanji characters were used (Fig. 2). All characters were unknown to participants, as none had prior exposure to Japanese language. Visual complexity was defined by the number of strokes per character. Characters with 2–4 strokes constituted the simple items ( $N = 30$ ), and those with 13 strokes formed the complex set ( $N = 30$ ). Visual performance was tested with a match-to-sample task where the target and the foil were placed above and below the central probe character. The position of the target was randomised across trials. In half the trials, the foil was a character differing only slightly from the target to give the similar condition; in the other half, the foil was appreciably different from the probe (a total of four conditions with 120 trials: simple target similar foil  $N = 30$ ; simple target dissimilar foil  $N = 30$ ; complex target similar foil  $N = 30$ ; complex target dissimilar foil  $N = 30$ ).

### 2.2.4. Procedure

For checkerboard and kanji experiments, stimuli were presented on a Dell laptop with a 15" panel at 1920  $\times$  1080 resolution and ~ 60 Hz refresh rate, using E-Prime 3.0 (Psychology Software Tools, Inc. [E-Prime 3.0], 2002). Each trial featured three vertically aligned stimuli, randomly presented across conditions. The central stimulus served as the probe, and participants identified the matching stimulus (above or below) by pressing corresponding keys (green for above; red for below). Participants were instructed to respond as quickly and as accurately as possible, with stimuli remaining on screen until a response was given. A 1-second pause preceded each subsequent trial. Participants completed a block of 10 practice trials before each experiment to familiarise themselves with the process. The session lasted approximately 15 minutes. Because participants were recruited within an SEN provision setting, the experimenter was not blind to participant status.

### 2.2.5. Phonological index (Wechsler Intelligence Scale for Children - Fifth Edition [WISC-V]; Wechsler, 2014)

Phonological processing was indexed using the digit span task, administered following instructions in the WISC-V administrator manual (Wechsler, 2014). This consists of three subtasks: digit forward, where participants recall as many of the digits as possible in the same order they were presented; digit backward, where they recall the digits

in the reverse order; and digit sequential, where they recall digits in ascending order of magnitude. The total digit span score is the sum of scores from the three subtasks. This measure was included to examine if visual processing deficits occurred alongside deficits in a core phonological domain, rather than to provide a comprehensive assessment of phonological processing.

### 2.2.6. Power analysis

A priori power analysis was conducted using G\*Power 3.1.9.7 (Faul et al., 2007; Faul et al., 2009). Assuming a moderate effect size ( $F = 0.25$ ; Cohen, 1988),  $\alpha = 0.05$ , and a conservative correlation amongst repeated measures ( $r = 0.05$ ), analysis indicated a minimum sample of approximately 32 participants would be required to detect the highest-order interaction with 80% power. Accordingly, a target sample size of 40 participants was established prior to recruitment; this sample size exceeds the maximum threshold identified across all planned comparisons and affords power above 90% to detect a significant effect of the between-subjects factor.

## 3. Results

To examine whether visual processing performance varied as a function of reading severity, children with dyslexia were stratified according to their STAR reading percentile. The group was divided into three severity-based subgroups: mild ( $N = 8$ ), moderate ( $N = 7$ ), and severe ( $N = 7$ ). All analyses were conducted using IBM SPSS Statistics (Version 31).

### 3.1. Visual processing tasks

Repeated-measures ANOVA was conducted with severity (NTR; mild; moderate; severe) as a between-subject factor and visual complexity (complex; simple) and similarity (similar; dissimilar) as within-subject factors to test the hypothesis that children with dyslexia show reduced performance when processing complex or similar stimuli. Holm-Bonferroni corrections were applied to control family-wise error rate. Fig. 3 shows that RTs for checkerboards were modulated by complexity ( $F[1,34] = 186.02, p < .001, \eta^2 = 0.85$ , Holm-Bonferroni  $p < .001, \alpha = 0.013$ ), similarity ( $F[1,34] = 236.31, p < .001, \eta^2 = 0.87$ , Holm-Bonferroni  $p < .001, \alpha = 0.008$ ), and an interaction between the two ( $F[1,34] = 202.27, p < .001, \eta^2 = 0.86$ , Holm-Bonferroni  $p < .001, \alpha = 0.01$ ). Interactions between severity and complexity ( $F[3,34] = 5.56, p = .003, \eta^2 = 0.33$ , Holm-Bonferroni  $p = .003, \alpha = 0.05$ ), severity and similarity ( $F[3,34] = 13.01, p < .001, \eta^2 = 0.53$ , Holm-Bonferroni  $p < .001, \alpha = 0.017$ ), and a 3-way interaction between severity, complexity, and similarity ( $F[3,34] = 10.94, p < .001, \eta^2 = 0.49$ , Holm-Bonferroni  $p < .001, \alpha = 0.03$ ) were present.

Comparable ANOVA performed on kanji RT (Fig. 3) revealed identical main effects of complexity ( $F[1,34] = 146.34, p < .001, \eta^2 = 0.81$ , Holm-Bonferroni  $p < .001, \alpha = 0.01$ ), similarity ( $F[1,34] = 191.31, p < .001, \eta^2 = 0.85$ , Holm-Bonferroni  $p < .001, \alpha = 0.008$ ), and an interaction between the two ( $F[1,34] = 35.79, p < .001, \eta^2 = 0.51$ , Holm-Bonferroni  $p < .001, \alpha = 0.03$ ). Interactions between severity and complexity ( $F[3,34] = 6.07, p = .002, \eta^2 = 0.34$ , Holm-Bonferroni  $p < .008, \alpha = 0.013$ ) and a 3-way interaction between severity, complexity, and similarity ( $F[3,34] = 8.22, p < .001, \eta^2 = 0.42$ , Holm-Bonferroni  $p < .001, \alpha = 0.017$ ) were present.

### 3.2. Phonological processing

Two ANOVAs were conducted on digit span scores, with group (DD; NTR) and severity (NTR; mild; moderate; severe) as between-subjects factors to test the hypothesis that children with dyslexia also show reduced phonological performance. Results indicated that DD performed significantly worse than NTR with modest effect sizes for group ( $F[1, 38] = 8.76, p = .005, \eta^2 = 0.19$ ) and severity ( $F[3, 35] = 3.76, p =$

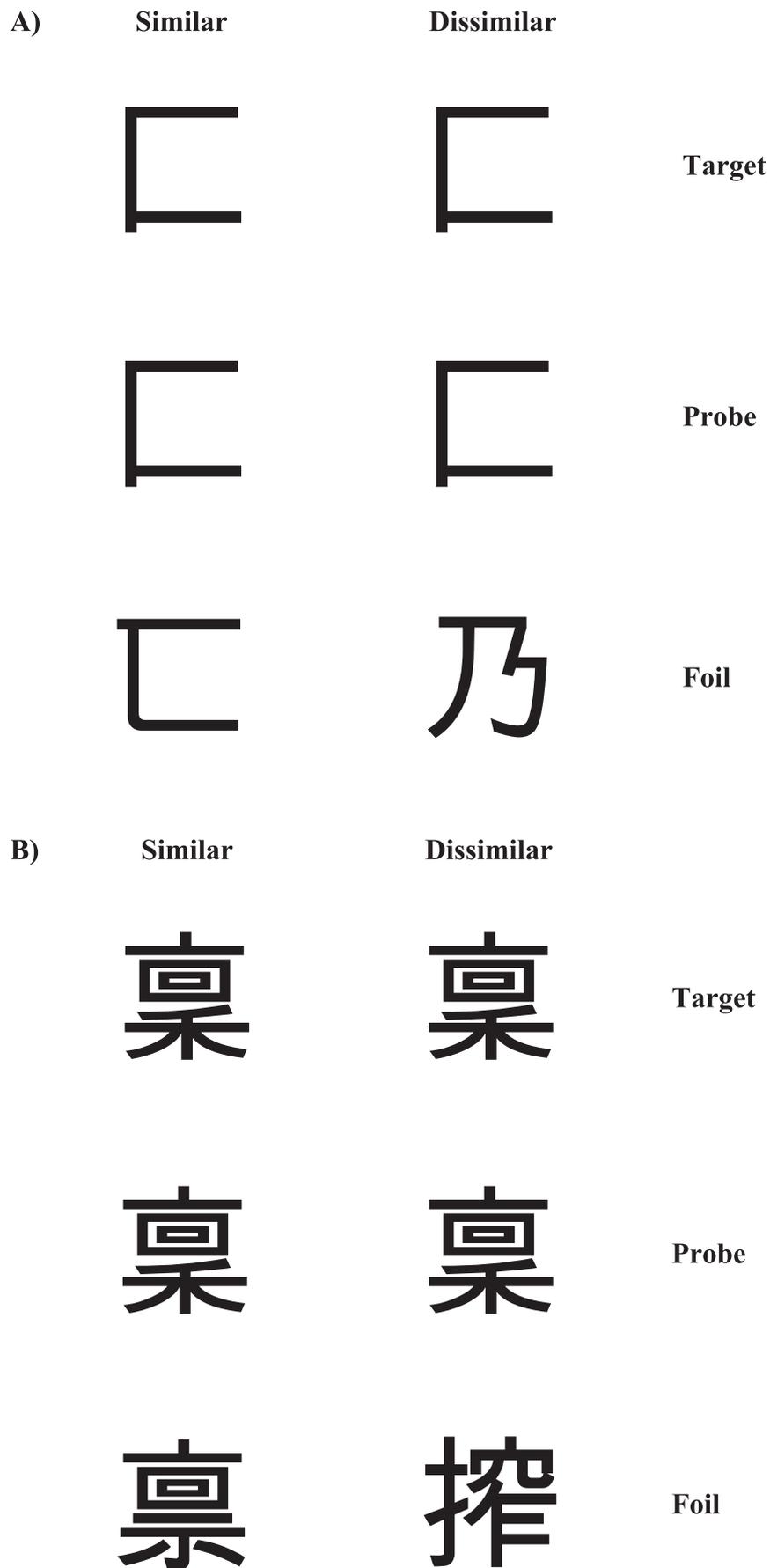


Fig. 2. Example kanji character stimuli for (A) visually simple condition and (B) visually complex condition with similar and dissimilar foils (Roberts et al., 2013).

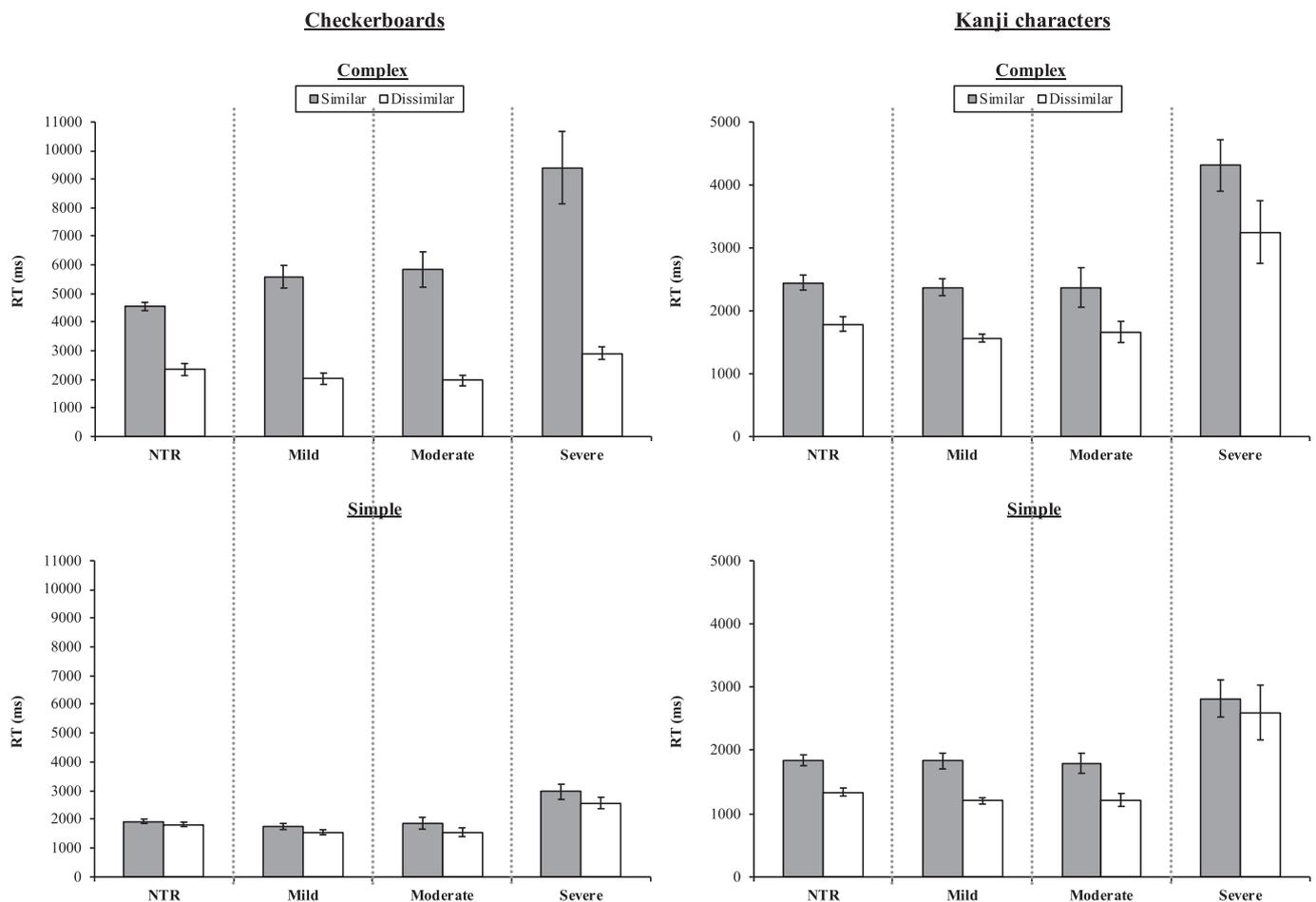


Fig. 3. Average correct RTs for the checkerboard and kanji tasks for NTR and DD subgroups split by severity. Error bars represent standard error.

.019,  $\eta^2 = 0.24$ ).

### 3.3. Exploratory discriminant function analysis

A stepwise discriminant function analysis was conducted to examine which visual and visualphonological task conditions best discriminated between the DD and NTR groups. The assumption that the smallest group size exceeded the number of predictors was satisfied. The final model included checkerboard RT for complex similar, complex dissimilar, and digit span. The model yielded Wilks'  $\lambda = 0.54$  and was significant,  $\chi^2(3) = 21.52, p < .001$ . Using these predictors 81.3% of the NTR group (13/16) and 86.3% of the DD group (19/22) were correctly classified, resulting in an overall correct classification accuracy of 83.8%. Since this analysis was exploratory, these findings should be considered preliminary; however, both visual and phonological measures contributed to group differentiation.

## 4. Discussion

### 4.1. Summary of findings

The present study investigated whether children with dyslexia exhibit not only phonological weaknesses, consistent with the PDH and DRC model (Coltheart et al., 2001), but also visual processing deficits consistent with multidimensional frameworks, including the triangle model (Patterson & Lambon Ralph, 1999; Plaut et al., 1996). Using non-linguistic tasks, children with dyslexia performed significantly worse than NTR across both domains, with group differences most pronounced in processing speed. These findings provide developmental evidence

that visual processing deficits can occur alongside phonological deficits and may be detectable in childhood using non-linguistic paradigms.

The delays observed in the dyslexic group were limited to conditions with high visual-perceptual demands. This specificity suggests that the group differences reflect targeted visual processing inefficiencies rather than generalised slowing. These results are consistent with adult dyslexia studies reporting slowed processing of the same visually complex and similar stimuli (Provazza, Adams, et al., 2019; Provazza et al., 2022), developmental evidence implicating broader higher-level visual mechanisms (Behrmann et al., 2025; Kristjansson & Sigurdardottir, 2023; Pitchford et al., 2025), and neuropsychological research demonstrating that visual processing impairments can impede orthographic processing in developmental and acquired dyslexias (Behrmann et al., 2025; Behrmann, Nelson, et al., 1998; Behrmann & Plaut, 2014, 2015, 2020; Behrmann, Plaut, et al., 1998; Roberts et al., 2010; Roberts et al., 2013; Roberts et al., 2015; Robotham et al., 2023; Woollams et al., 2014).

### 4.2. Theoretical implications

The findings are compatible with perspectives that situate reading within interacting cognitive systems. Importantly, domain-specific accounts such as the DRC model and multidimensional frameworks such as the triangle model need not be viewed as competing explanations, but rather as addressing different components and levels of the reading architecture. Consistent with recent neurobehavioural findings (for reviews see: Behrmann et al., 2025; Chalme & Vlachos, 2025; Kristjansson & Sigurdardottir, 2023; Sigurdardottir et al., 2021), the present results highlight that visual inefficiencies may play a significant

role in reading impairments. The deficits observed generalised to abstract, non-linguistic stimuli, suggesting that the challenges experienced by many children with dyslexia may reflect broader visual-perceptual constraints rather than impairments limited to linguistic material, including processes involved in parsing visual word forms into constituent letters and phonemes for reading (Stein, 2025).

The concurrence of visual and phonological deficits in our sample further reflects the multidimensional profile we reported previously (Provazza, Adams, et al., 2019; Provazza et al., 2022; Provazza, Giofre, et al., 2019). For example, Provazza, Giofre, et al. (2019) identified subgroups characterised by isolated phonological deficits or by combined visual-phonol deficits. Similarly, Provazza, Adams, et al. (2019) reported that co-occurring deficits exacerbate reading challenges. The present findings extend this work by demonstrating, for the first time, that these same deficits are detectable in childhood using identical non-linguistic tasks, suggesting that they are unlikely to reflect compensatory consequences of prolonged reading impairments. Consistent with this, exploratory discriminant function analysis provided preliminary evidence that measures from both domains contributed to group differentiation.

Interpreted within the triangle framework (Patterson & Lambon Ralph, 1999; Plaut, 1999), the occurrence of visual and phonological deficits is consistent with the view that reading draws on interacting cognitive systems, such that vulnerabilities in one may extend beyond strictly linguistic tasks. The conditions with the greatest group differences – those requiring discrimination of visually complex or similar patterns – place demands on fine-grained perceptual differentiation, analogous to the rapid and precise discrimination of visually similar letters required during reading. Within this framework, both reading and non-linguistic visual discrimination are assumed to draw on partially shared system resources; consequently, inefficiencies in visual processing may therefore affect performance across tasks that rely on the same underlying mechanisms. Moreover, greater reading impairment was associated with slower performance under visually demanding conditions, suggesting that visual processing inefficiencies may relate to the severity of reading impairment.

This multidimensional perspective is supported by cross-linguistic evidence indicating that the relative contributions of visual, phonological, and semantic systems to reading vary as a function of orthographic depth (Provazza et al., 2022). Within the triangle framework, reading performance reflects the dynamic weighting of these interacting systems. In shallow orthographies such as Italian, where grapheme-phoneme correspondences are highly consistent (e.g., *pinta*), reading relies heavily on rapid and precise vision-phonology mappings. As a result, inefficiencies in visual processing may be more likely to manifest behaviourally since the emergence of successful decoding depends strongly on the visual system when learning to read.

In contrast, deeper orthographies such as English, involve irregular mappings (e.g., *pint*, which deviates from analogous mappings in *hint* or *mint*) and place greater demands on semantic and phonological mediation to resolve inconsistencies. Consequently, visual processing deficits may be less behaviourally prominent (in accuracy) because reading can be supported by compensatory mechanisms within the broader system. This account offers one possible explanation for why visual deficits appear more salient in shallow orthographies, whereas phonological-sem factors exert greater influence in deeper systems (Elliott & Grigorenko, 2014; Georgiou & Parrila, 2020; Helland & Morken, 2016; Provazza et al., 2022; Share, 2021; Wimmer et al., 2000; Ziegler & Goswami, 2005).

Thus, experience and mastery of a specific writing system may shape the relative contribution and functional balance of visual, phonological, and semantic systems during reading, whilst also influencing performance on non-linguistic stimuli that place similar perceptual demands on visual processing (Behrmann et al., 2025). Within this framework, weaknesses in one or more of these interacting systems may contribute

to dyslexia and its associated cognitive profile. Taken together, by accommodating cross-linguistic variability and multiple pathways to reading outcomes, the triangle model provides a useful account for understanding heterogeneity in dyslexia.

Clinically, this perspective has important practical implications. Diagnostic practices often prioritise phonological assessments, which may overlook children whose deficits arise from visual processing impairment. Our findings highlight the value of incorporating visual-perceptual tasks, particularly using RT, into evaluation batteries. In future, simple and quick tasks targeting high-level visual processing (e.g., Ramamurthy et al., 2025) may help identify individuals at risk of dyslexia or reading impairments. Interventions could focus on training readers to better use their impaired visual processing, adopt alternative strategies, or strengthen unimpaired abilities. Future research should investigate the effectiveness of such interventions in both children and adults.

In conclusion, the present study supports the view that dyslexia may be driven by interactive impairments across visual and phonological systems. The observed pattern of performance is consistent with multidimensional accounts of dyslexia. Extending previous adult findings using identical non-linguistic tasks, the results provide evidence that these combined deficits are detectable in childhood, suggesting they reflect core features of the disorder, rather than later emerging consequences of poor reading experience. The findings extend orthography-focused models by highlighting the potential contribution of domain-general visual mechanisms as part of the reading system. By employing non-linguistic paradigms that isolate visual contributions, the present study provides novel evidence regarding the cognitive architecture of dyslexia and highlights the importance of considering visual as well as phonological factors. A clearer characterisation of the cognitive pathways contributing to reading impairment will be important for informing assessment and for developing targeted interventions that address the full spectrum of dyslexic profiles.

#### 4.3. Limitations

The findings should be interpreted within the context of several limitations. The sample was drawn from a school that includes SEN provision and was modest due to ethical and practical constraints including parental consent, child assent, and school-level approvals, which may limit generalisability. Testing was not conducted blind to group, and although RTs were recorded automatically, subtle expectancy or interaction differences cannot be excluded. In addition, discriminant function analysis was exploratory without cross-validation, and phonological functioning was indexed using a single measure, warranting replication in larger samples using broader assessments. The correlational design also precludes causal inferences; the data cannot fully determine if visual processing impairments contribute directly to the reading impairment, emerge because of reduced reading experience, or reflect shared underlying vulnerabilities. Furthermore, RT may be influenced by attentional or strategic factors, and the absence of a general cognitive measure may limit the ability to fully exclude alternative explanations. Future longitudinal, cross-linguistic, and intervention studies incorporating attentional control (e.g., eye-tracking) and broader cognitive measures will be important for clarifying developmental directionality. However, it is important to note that group differences were circumscribed to visually demanding conditions rather than reflecting global slowing, suggesting a degree of specificity. Despite these constraints, the findings and their association with reading severity provide developmentally relevant evidence that visual processing may contribute to dyslexia in some children.

#### CRedit authorship contribution statement

**Daniel Roberts:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation,

Conceptualization. **Serena Provazza**: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Taeko Wydell**: Writing – review & editing, Writing – original draft.

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## Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Daniel Roberts reports was provided by University of Liverpool. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

The data that has been used is confidential.

## References

- Asberg Johnels, J., Hadjikhani, N., Sundqvist, M., & Galazka, M. A. (2022). Face processing in school children with dyslexia: Neuropsychological and eye-tracking findings. *Developmental Neuropsychology*, 47(2), 78–92. <https://doi.org/10.1080/87565641.2022.2034828>
- Astle, D. E., Holmes, J., Kievit, R., & Gathercole, S. E. (2022). Annual research review: The transdiagnostic revolution in neurodevelopmental disorders. *Journal of Child Psychology and Psychiatry*, 63(4), 397–417. <https://doi.org/10.1111/jcpp.13481>
- Bartha-Doering, L., Roberts, D., Baumgartner, B., Yildirim, M. S., Giordano, V., Spagna, A., ... Seidl, R. (2024). Developmental surface dyslexia and dysgraphia in a child with corpus callosum agenesis: An approach to diagnosis and treatment. *Cognitive Neuropsychology*, 41(3–4), 148–170. <https://doi.org/10.1080/02643294.2024.2368876>
- Behrmann, M., Blauch, N. M., & Plaut, D. C. (2025). The emergence of topography and hemispheric lateralization in high-level vision. *Quarterly Journal of Experimental Psychology (Hove)*, Article 17470218251395631. <https://doi.org/10.1177/17470218251395631>
- Behrmann, M., Nelson, J., & Sekuler, E. B. (1998). Visual complexity in letter-by-letter reading: “pure” alexia is not pure. *Neuropsychologia*, 36(11), 1115–1132. [https://doi.org/10.1016/s0028-3932\(98\)00005-0](https://doi.org/10.1016/s0028-3932(98)00005-0)
- Behrmann, M., & Plaut, D. C. (2013). Distributed circuits, not circumscribed centers, mediate visual recognition. *Trends in Cognitive Sciences*, 17(5), 210–219. <https://doi.org/10.1016/j.tics.2013.03.007>
- Behrmann, M., & Plaut, D. C. (2014). Bilateral hemispheric processing of words and faces: Evidence from word impairments in prosopagnosia and face impairments in pure alexia. *Cerebral Cortex*, 24(4), 1102–1118. <https://doi.org/10.1093/cercor/bhs390>
- Behrmann, M., & Plaut, D. C. (2015). A vision of graded hemispheric specialization [article]. *Annals of the New York Academy of Sciences*, 1359, 30–46. <https://doi.org/10.1111/nyas.12833>
- Behrmann, M., & Plaut, D. C. (2020). Hemispheric organization for visual object recognition: A theoretical account and empirical evidence. *Perception*, 49(4), 373–404. <https://doi.org/10.1177/0301006619899049>
- Behrmann, M., Plaut, D. C., & Nelson, J. (1998). A literature review and new data supporting an interactive account of letter-by-letter reading. *Cognitive Neuropsychology*, 15(1–2), 7–51. <https://doi.org/10.1080/026432998381212>
- Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition*, 104(2), 198–230. <https://doi.org/10.1016/j.cognition.2006.05.009>
- Brachacki, G. W., Nicolson, R. I., & Fawcett, A. J. (1995). Impaired recognition of traffic signs in adults with dyslexia. *Journal of Learning Disabilities*, 28(5), 297–301. <https://doi.org/10.1177/002221949502800505>
- Brady, N., Darmody, K., Newell, F. N., & Cooney, S. M. (2021). Holistic processing of faces and words predicts reading accuracy and speed in dyslexic readers. *PLoS One*, 16(12), Article e0259986. <https://doi.org/10.1371/journal.pone.0259986>
- Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition*, 47(2), 149–180. [https://doi.org/10.1016/0010-0277\(93\)90003-e](https://doi.org/10.1016/0010-0277(93)90003-e)
- Castles, A., & Friedmann, N. (2014). Developmental dyslexia and the phonological deficit hypothesis. *Mind & Language*, 29(3), 270–285. <https://doi.org/10.1111/mila.12050>
- Chalmepe, M., & Vlachos, F. (2024). Are there distinct subtypes of developmental dyslexia? *Frontiers in Behavioral Neuroscience*, 18(1512892), Article 1512892. <https://doi.org/10.3389/fnbeh.2024.1512892>
- Chalmepe, M., & Vlachos, F. (2025). Heterogeneity in the neurocognitive characteristics of developmental dyslexia: Theoretical approaches and research findings. In J. Glazzard (Ed.), *Understanding developmental disorders [working title]*. IntechOpen. <https://doi.org/10.5772/intechopen.1009240>
- Chang, Y. N., Welbourne, S., Furber, S., & Lambon Ralph, M. A. (2024). Simultaneous simulations of pure, surface and phonological acquired dyslexia within a full computational model of the primary systems hypothesis. *Cortex*, 179, 112–125. <https://doi.org/10.1016/j.cortex.2024.07.006>
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.
- Collins, E., Dundas, E., Gabay, Y., Plaut, D. C., & Behrmann, M. (2017). Hemispheric organization in disorders of development. *Visual Cognition*, 25(4–6), 416–429. <https://doi.org/10.1080/13506285.2017.1370430>
- 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. <https://doi.org/10.1037/0033-295x.108.1.204>
- Dehaene, S., Cohen, L., Morais, J., & Kolinsky, R. (2015). Illiterate to literate: Behavioural and cerebral changes induced by reading acquisition [perspectives]. *Nature Reviews Neuroscience*, 16(4), 234–244. <https://doi.org/10.1038/nrn3924>
- Elliott, J. G., & Grigorenko, E. L. (2014). *The dyslexia debate*. Cambridge University Press. <https://doi.org/10.1017/cbo9781139017824>
- Eloranta, A. K., Narhi, V. M., Eklund, K. M., Ahonen, T. P. S., & Aro, T. I. (2019). Resolving reading disability-childhood predictors and adult-age outcomes. *Dyslexia*, 25(1), 20–37. <https://doi.org/10.1002/dys.1605>
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G\*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41(4), 1149–1160. <https://doi.org/10.3758/BRM.41.4.1149>
- 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. <https://doi.org/10.3758/bf03193146>
- Gabay, Y., Dundas, E., Plaut, D., & Behrmann, M. (2017). Atypical perceptual processing of faces in developmental dyslexia. *Brain and Language*, 173, 41–51. <https://doi.org/10.1016/j.bandl.2017.06.004>
- Georgiou, G. K., & Parrila, R. (2020). What mechanism underlies the rapid automatized naming-reading relation? [article]. *Journal of Experimental Child Psychology*, 194 (104840), Article 104840. <https://doi.org/10.1016/j.jecp.2020.104840>
- Gibbs, S. J., & Elliott, J. G. (2020). The dyslexia debate: Life without the label. *Oxford Review of Education*, 46(4), 487–500. <https://doi.org/10.1080/03054985.2020.1747419>
- Giofre, D., Toffalini, E., Provazza, S., Calcagni, A., Altoe, G., & Roberts, D. J. (2019). Are children with developmental dyslexia all the same? A cluster analysis with more than 300 cases. *Dyslexia*, 25(3), 284–295. <https://doi.org/10.1002/dys.1629>
- Helland, T., & Morken, F. (2016). Neurocognitive development and predictors of L1 and L2 literacy skills in dyslexia: A longitudinal study of children 5–11 years old. *Dyslexia*, 22(1), 3–26. <https://doi.org/10.1002/dys.1515>
- Hoffman, P., Lambon Ralph, M. A., & Woollams, A. M. (2015). Triangulation of the neurocomputational architecture underpinning reading aloud. *Proceedings of the National Academy of Sciences of the United States of America*, 112(28), E3719–E3728. <https://doi.org/10.1073/pnas.1502032112>
- Huestegge, L., Rohrsen, J., van Ermingen-Marbach, M., Pape-Neumann, J., & Heim, S. (2014). Devil in the details? Developmental dyslexia and visual long-term memory for details [original research]. *Frontiers in Psychology*, 5, 686. <https://doi.org/10.3389/fpsyg.2014.00686>
- Hulme, C., & Snowling, M. J. (2015). Learning to read: What we know and what we need to understand better. *Child Development Perspectives*, 7(1), 1–5. <https://doi.org/10.1111/cdep.12005>
- Kohnen, S., Nickels, L., Geigis, L., Coltheart, M., McArthur, G., & Castles, A. (2018). Variations within a subtype: Developmental surface dyslexias in English. *Cortex*, 106, 151–163. <https://doi.org/10.1016/j.cortex.2018.04.008>
- Kristjansson, A., & Sigurdardottir, H. M. (2023). The role of visual factors in dyslexia. *Journal of Cognition*, 6(1), 31. <https://doi.org/10.5334/joc.287>
- Kuhn, C. D., Gerlach, C., Andersen, K. B., Poulsen, M., & Starrfelt, R. (2021). Face recognition in developmental dyslexia: Evidence for dissociation between faces and words. *Cognitive Neuropsychology*, 38(1), 107–115. <https://doi.org/10.1080/02643294.2020.1847060>
- Li, Y., & Zhao, X. (2025). The face processing deficit in developmental dyslexia: A meta-analysis. *Dyslexia*, 31(2), Article e70007. <https://doi.org/10.1002/dys.70007>
- Liu, T., Thiebaut de Schotten, M., Altarelli, I., Ramus, F., & Zhao, J. (2022). Neural dissociation of visual attention span and phonological deficits in developmental dyslexia: A hub-based white matter network analysis. *Human Brain Mapping*, 43(17), 5210–5219. <https://doi.org/10.1002/hbm.25997>
- Mancarella, M., Wouters, J., Facioetti, A., & Ghesquiere, P. (2026). Insights into the multifactorial nature of reading difficulties: Exploring phonological, visual, and attentional challenges in children. *Journal of Communication Disorders*, 119, Article 106606. <https://doi.org/10.1016/j.jcomdis.2025.106606> (Article Pmid 260316)
- Menghini, D., Finzi, A., Benassi, M., Bolzani, R., Facioetti, A., Giovagnoli, S., ... Vicari, S. (2010). Different underlying neurocognitive deficits in developmental dyslexia: A comparative study. *Neuropsychologia*, 48(4), 863–872. <https://doi.org/10.1016/j.neuropsychologia.2009.11.003>

- Nergard-Nilssen, T., & Hulme, C. (2014). Developmental dyslexia in adults: Behavioural manifestations and cognitive correlates. *Dyslexia*, 20(3), 191–207. <https://doi.org/10.1002/dys.1477>
- Nischal, R. P., & Behrmann, M. (2023). Developmental emergence of holistic processing in word recognition. *Developmental Science*, 26(4), Article e13372. <https://doi.org/10.1111/desc.13372>
- Patterson, K., & Lambon Ralph, M. A. (1999). Selective disorders of reading? *Current Opinion in Neurobiology*, 9(2), 235–239. [https://doi.org/10.1016/S0959-4388\(99\)80033-6](https://doi.org/10.1016/S0959-4388(99)80033-6)
- Peskin, N., Behrmann, M., Gabay, S., & Gabay, Y. (2024). Atypical reliance on monocular visual pathway for face and word recognition in developmental dyslexia. *Brain and Cognition*, 174(106106), Article 106106. <https://doi.org/10.1016/j.bandc.2023.106106>
- Peterson, R. L., Pennington, B. F., & Olson, R. K. (2013). Subtypes of developmental dyslexia: Testing the predictions of the dual-route and connectionist frameworks. *Cognition*, 126(1), 20–38. <https://doi.org/10.1016/j.cognition.2012.08.007>
- Pitchford, B., Devillez, H., & Sigurdardottir, H. M. (2025). Distinct neural processing underlying visual face and object perception in dyslexia. *Neuropsychologia*, 219, Article 109268. <https://doi.org/10.1016/j.neuropsychologia.2025.109268>
- Plaut, D. C. (1999). A connectionist approach to word reading and acquired dyslexia: Extension to sequential processing [article]. *Cognitive Science*, 23(4), 543–568. [https://doi.org/10.1016/S0364-0213\(99\)00015-4](https://doi.org/10.1016/S0364-0213(99)00015-4)
- Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review*, 103(1), 56–115. <https://doi.org/10.1037/0033-295x.103.1.56>
- Provazza, S., Adams, A. M., Giofre, D., & Roberts, D. J. (2019). Double trouble: Visual and phonological impairments in English dyslexic readers [original research]. *Frontiers in Psychology*, 10(2725), 2725. <https://doi.org/10.3389/fpsyg.2019.02725>
- Provazza, S., Carretti, B., Giofre, D., Adams, A. M., Montesano, L., & Roberts, D. (2022). Shallow or deep? The impact of orthographic depth on visual processing impairments in developmental dyslexia. *Annals of Dyslexia*, 72(1), 171–196. <https://doi.org/10.1007/s11881-021-00249-7>
- Provazza, S., Giofre, D., Adams, A. M., & Roberts, D. J. (2019). The clock counts - Length effects in English dyslexic readers [original research]. *Frontiers in Psychology*, 10(2495), 2495. <https://doi.org/10.3389/fpsyg.2019.02495>
- Psychology Software Tools, Inc. [E-Prime 3.0]. (2016).
- Ramamurthy, M., Kanopka, K., Richie-Halford, A., Domingue, B. W., Pei, F., Bell, P., ... Yeatman, J. D. (2025). Design and validation of a rapid visual processing measure for screening reading difficulties in early childhood. *Behavior Research Methods*, 57(9), Article 237. <https://doi.org/10.3758/s13428-025-02739-7>
- Ramus, F., & Szenkovits, G. (2008). What phonological deficit? [conference paper]. *Q J Exp Psychol (Hove)*, 61(1), 129–141. <https://doi.org/10.1080/17470210701508822>
- Renaissance Learning. (2023). *Star Assessments™ for Reading Technical Manual*. London, UK.
- Roberts, D. J., Lambon Ralph, M. A., Kim, E., Tainturier, M. J., Beeson, P. M., Rapcsak, S. Z., & Woollams, A. M. (2015). Processing deficits for familiar and novel faces in patients with left posterior fusiform lesions. *Cortex*, 72(0), 79–96. <https://doi.org/10.1016/j.cortex.2015.02.003>
- Roberts, D. J., Lambon Ralph, M. A., & Woollams, A. M. (2010). When does less yield more? The impact of severity upon implicit recognition in pure alexia. *Neuropsychologia*, 48(9), 2437–2446. <https://doi.org/10.1016/j.neuropsychologia.2010.04.002>
- Roberts, D. J., Woollams, A. M., Kim, E., Beeson, P. M., Rapcsak, S. Z., & Lambon Ralph, M. A. (2013). Efficient visual object and word recognition relies on high spatial frequency coding in the left posterior fusiform gyrus: Evidence from a case-series of patients with ventral occipito-temporal cortex damage. *Cerebral Cortex*, 23(11), 2568–2580. <https://doi.org/10.1093/cercor/bhs224>
- Robotham, J. R., Rice, E. G., Leff, P. A., Ralph, L. A. M., & Starrfelt, R. (2023). Systematic evaluation of high-level visual deficits and lesions in posterior cerebral artery stroke. *Brain Communications*, 5(2). <https://doi.org/10.1093/braincomms/fcad050>
- Share, D. L. (2021). Common misconceptions about the phonological deficit theory of dyslexia. *Brain Sciences*, 11(11). <https://doi.org/10.3390/brainsci11111510>
- Shrewsbury, D. (2016). Dyslexia in general practice education: Considerations for recognition and support [article]. *Education for Primary Care*, 27(4), 267–270. <https://doi.org/10.1080/14739879.2016.1194170>
- Sigurdardottir, H. M., Fridriksdottir, L. E., Gudjonssdottir, S., & Kristjansson, A. (2018). Specific problems in visual cognition of dyslexic readers: Face discrimination deficits predict dyslexia over and above discrimination of scrambled faces and novel objects [article]. *Cognition*, 175, 157–168. <https://doi.org/10.1016/j.cognition.2018.02.017>
- Sigurdardottir, H. M., Ivarsson, E., Kristinsdottir, K., & Kristjansson, A. (2015). Impaired recognition of faces and objects in dyslexia: Evidence for ventral stream dysfunction? *Neuropsychology*, 29(5), 739–750. <https://doi.org/10.1037/neu0000188>
- Sigurdardottir, H. M., Olafsdottir, I. M., & Devillez, H. (2021). Words as visual objects: Neural and behavioral evidence for high-level visual impairments in dyslexia. *Brain Sciences*, 11(11), 1427. <https://doi.org/10.3390/brainsci11111427>
- Snowling, M. (1998). Dyslexia as a phonological deficit: Evidence and implications. *Child and Adolescent Mental Health*, 3(1), 4–11. <https://doi.org/10.1111/1475-3588.00201>
- Snowling, M. J. (1981). Phonemic deficits in developmental dyslexia [article]. *Psychological Research*, 43(2), 219–234. <https://doi.org/10.1007/BF00309831>
- Snowling, M. J. (2005). Phonological processing and developmental dyslexia [article]. *Journal of Research in Reading*, 18(2), 132–138. <https://doi.org/10.1111/j.1467-9817.1995.tb00079.x>
- Snowling, M. J., Hulme, C., & Nation, K. (2020). Defining and understanding dyslexia: Past, present and future. *Oxford Review of Education*, 46(4), 501–513. <https://doi.org/10.1080/03054985.2020.1765756>
- Stein, J. (2025). Visual dyslexia. *Current Developmental Disorders Reports*, 12(1), 5. <https://doi.org/10.1007/s40474-025-00316-3>
- Valdois, S. (2022). The visual-attention span deficit in developmental dyslexia: Review of evidence for a visual-attention-based deficit [article]. *Dyslexia*, 28(4), 397–415. <https://doi.org/10.1002/dys.1724>
- Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? [review]. *Journal of Child Psychology and Psychiatry*, 45(1), 2–40. <https://doi.org/10.1046/j.0021-9630.2003.00305.x>
- Vialatte, A., Chabanat, E., Witko, A., & Pisella, L. (2023). Toward the characterization of a visual form of developmental dyslexia: Reduced visuo-attentional capacity for processing multiple stimuli made of separable features. *Cognitive Neuropsychology*, 40(3–4), 186–213. <https://doi.org/10.1080/02643294.2023.2266179>
- Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: a deficit in visuo-spatial attention, not in phonological processing [article]. *Trends in Cognitive Sciences*, 14(2), 57–63. <https://doi.org/10.1016/j.tics.2009.12.003>
- Wechsler, D. (2014). *WISC-V: Technical and interpretive manual*. Incorporated: NCS Pearson.
- Wimmer, H., Mayringer, H., & Landerl, K. (2000). The double-deficit hypothesis and difficulties in learning to read a regular orthography [article]. *Journal of Educational Psychology*, 92(4), 668–680. <https://doi.org/10.1037/0022-0663.92.4.668>
- Wolf, M., & Bowers, P. G. (1999). The double-deficit hypothesis for the developmental dyslexias. *Journal of Educational Psychology*, 91(3), 415–438. <https://doi.org/10.1037/0022-0663.91.3.415>
- Woollams, A. M. (2014). Connectionist neuropsychology: Uncovering ultimate causes of acquired dyslexia. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 369(1634), Article 20120398. <https://doi.org/10.1098/rstb.2012.0398>
- Woollams, A. M., Halai, A., & Lambon Ralph, M. A. (2018). Mapping the intersection of language and reading: The neural bases of the primary systems hypothesis [article]. *Brain Structure & Function*, 223(8), 3769–3786. <https://doi.org/10.1007/s00429-018-1716-z>
- Woollams, A. M., Hoffman, P., Roberts, D. J., Lambon Ralph, M. A., & Patterson, K. E. (2014). What lies beneath: A comparison of reading aloud in pure alexia and semantic dementia. *Cognitive Neuropsychology*, 31(5–6), 461–481. <https://doi.org/10.1080/02643294.2014.882300>
- Wydell, T. N. (2023). Are phonological skills as crucial for literacy acquisition in Japanese as in English as well as in accounting for developmental dyslexia in English and in Japanese? *Journal of Cultural Cognitive Science*, 7(2), 175–196. <https://doi.org/10.1007/s41809-023-00126-2>
- Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory [review]. *Psychological Bulletin*, 131(1), 3–29. <https://doi.org/10.1037/0033-2909.131.1.3>
- Zoubrinetzky, R., Collet, G., Serniclaes, W., Nguyen-Morel, M. A., & Valdois, S. (2016). Relationships between categorical perception of phonemes, phoneme awareness, and visual attention span in developmental dyslexia [article]. *PLoS One*, 11(3), Article e0151015. <https://doi.org/10.1371/journal.pone.0151015>