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# Impaired Recognition of Faces and Objects in Dyslexia: Evidence for Ventral Stream Dysfunction?

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***Objective:*** The objective of this study was to establish whether or not dyslexics are impaired at the recognition of faces and other complex nonword visual objects. This would be expected based on a meta-analysis revealing that children and adult dyslexics show functional abnormalities within the left fusiform gyrus, a brain region high up in the ventral visual stream, which is thought to support the recognition of words, faces, and other objects. ***Method:*** 20 adult dyslexics ($M = 29$ years) and 20 matched typical readers ($M = 29$ years) participated in the study. One dyslexic-typical reader pair was excluded based on Adult Reading History Questionnaire scores and IS-FORM reading scores. Performance was measured on 3 high-level visual processing tasks: the Cambridge Face Memory Test, the Vanderbilt Holistic Face Processing Test, and the Vanderbilt Expertise Test. ***Results:*** People with dyslexia are impaired in their recognition of faces and other visually complex objects. Their holistic processing of faces appears to be intact, suggesting that dyslexics may instead be specifically impaired at part-based processing of visual objects. ***Conclusions:*** The difficulty that people with dyslexia experience with reading might be the most salient manifestation of a more general high-level visual deficit.

*Keywords:* face recognition, object recognition, fusiform gyrus, ventral visual stream, dyslexia, reading

Dyslexia is typically considered a disorder of language, in particular phonological processing which is indeed an important component of dyslexia (Catts, 1989; Pennington, Van Orden, Smith, Green, & Haith, 1990; Shaywitz & Shaywitz, 2005; Snowling, 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004). However, written language is a cultural development that almost surely requires the harnessing of other skills and mechanisms that humans have acquired through evolution. Reading a Western alphabet requires the analysis of the shape of letters and words, the discrimination of these visual stimuli from one another, and the ability to recognize them and link them to semantic information. These steps are taken for all visual objects and are thought to depend to a large extent on processing within the ventral visual stream (Desimone, Albright, Gross, & Bruce, 1984; Goodale & Milner, 1992; Gross, Rocha-Miranda, & Bender, 1972; Logothetis & Sheinberg, 1996; Milner & Goodale, 1995; Palmeri & Gauthier, 2004; K. Tanaka, Saito, Fukada, & Moriya, 1991; Ungerleider & Mishkin). Disruption of any of these steps could in theory lead to reading difficulties.

Hints that visual perceptual deficits might underlie dyslexia come from studies of brain damaged patients with pure alexia. Pure alexic patients were initially thought to be selectively impaired at recognizing print while other perceptual abilities were to a large extent spared (Behrmann, Nelson, & Sekuler, 1998). Several studies now indicate that these patients are also impaired at challenging tasks that rely on the perception of nonword visual objects. This includes discriminating between morphed faces (Behrmann & Plaut, 2014), face matching (Behrmann & Plaut, 2014), judging whether fragmented line drawings depict real or nonsense objects (Starrfelt, Habekost, & Gerlach, 2010), identifying visually complex objects (Behrmann et al., 1998), identifying objects presented for a very brief time (Friedman & Alexander, 1984), simultaneously recognizing more than one form (Kinsbourne & Warrington, 1962), or matching an object with an identical object among many similar ones (Farah & Wallace, 1991). The reading deficit in pure alexia may therefore not be so pure after all (for an extended discussion, see, e.g., Behrmann et al., 1998; Farah & Wallace, 1991).

Pure alexia tends to result from damage to the left ventral visual stream, in particular the left fusiform gyrus and adjacent tissue (Cohen et al., 2004; Leff, Spitsyna, Plant, & Wise, 2006; Pflugshaupt et al., 2009). It is therefore interesting to compare this to a recent meta-analysis of functional abnormalities in children and adults with dyslexia (Richlan, Kronbichler, & Wimmer, 2011). The only area of overlap between the two age groups was within the left fusiform gyrus. Both children and adults with dyslexia showed consistent hypoactivity in this part of the cortex. This might reflect a dysfunction of the visual word form area (VWFA).

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The VWFA is a region in the left fusiform gyrus showing greater responses to visually presented words or letter strings than during rest, visual fixation, or to visual control stimuli such as checkerboards (Cohen et al., 2000; Cohen et al., 2002; for a review, see, e.g., Dehaene & Cohen, 2011; Price & Devlin, 2003). Damage to the VWFA is predictive of pure alexia (Dehaene & Cohen, 2011; Pflugshaupt et al., 2009) and pure alexia symptoms can be transiently induced by electrical stimulation near the VWFA (Mani et al., 2008).

Like other regions of the ventral visual stream, the VWFA appears primarily visual because it responds better to written than spoken words (Dehaene, Le Clec'H, Poline, Le Bihan, & Cohen, 2002). Responses of the VWFA to visual words are not related to semantics in any obvious way (Dehaene et al., 2002). The possibility that VWFA neurons are tuned to word fragments larger than individual letters (Binder, Medler, Westbury, Liebenthal, & Buchanan, 2006; Glezer, Jiang, & Riesenhuber, 2009; Vinckier et al., 2007) is consistent with the letter-by-letter reading strategy of pure alexic patients (Behrmann et al., 1998) and developmental dyslexics (Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Korne, 2003; Zoccolotti et al., 1999), as if these people lack the machinery necessary to process letters in parallel (unlike typical readers, Weekes, 1997).

The VWFA could therefore be tuned to the structure of orthographic visual stimuli (Binder et al., 2006; Dehaene, Cohen, Sigman, & Vinckier, 2005; Dehaene et al., 2002; Whitney, 2001). If intact, it could support efficient reading strategies through parallel processing of multiple letters (Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008). If dysfunctional, reading should be slow and laborious.

As can be seen in Figure 1, there is considerable overlap between the VWFA and regions that are hypoactive in people with dyslexia. It might at first seem rather obvious that this would go hand in hand with specific reading problems that are restricted to the perception of written words, leaving the perception of other visual objects unaffected. This, however, does not necessarily follow.

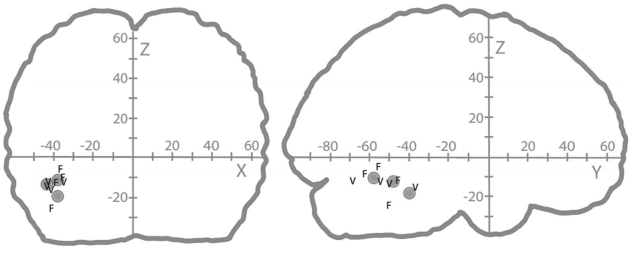

*Figure 1.* Several published Talairach coordinates for the left visual word form area (VWFA; denoted here as V), the left fusiform face area (FFA; denoted here as F), and fusiform regions hypoactive in dyslexics (gray dots). Cohen et al. (2002) VWFA: $x = -43$, $y = -54$, $z = -12$; Dehaene et al. (2010) VWFA: $x = -44$, $y = -50$, $z = -14$; Reinke, Fernandes, Schwindt, O'Craven, and Grady (2008) VWFA: $x = -34$, $y = -68$, $z = -12$; Szwed et al. (2011) VWFA: $x = -42$, $y = -38$, $z = -16$; Gauthier, Tarr, Anderson, Skudlarski, and Gore (1999) FFA: $x = -40$, $y = -46$, $z = -12$; Gauthier, Skudlarski, Gore, and Anderson (2000) FFA: $x = -38$, $y = -56$, $z = -6$; Kanwisher, McDermott, and Chun (1997) FFA: $x = -35$, $y = -63$, $z = -10$; Rossion et al. (2000) FFA: $x = -42$, $y = -50$, $z = -26$.Three peaks of left fusiform hypoactivation in dyslexics as reported by Richlan et al. (2011): children, local maxima $x = -40$, $y = -42$, $z = -20$; adults, local maxima $x = -46$, $y = -50$, $z = -14$; subpeak within cluster: $x = -40$, $y = -60$, $z = -12$.

First, although the VWFA might be particularly well suited to the visual processing of words, its role might not be restricted to that domain (see, e.g., Cohen & Dehaene, 2004; Dehaene & Cohen, 2011; Price & Devlin, 2003). Indeed, the VWFA selectively responds to several visual objects other than words, including meaningful symbols (Reinke et al., 2008), tools (Dehaene et al., 2010), and faces (Dehaene et al., 2010; Nestor, Behrmann, & Plaut, 2013). Its responses might increase as the demands for fine shape discrimination of objects increase (Starrfelt & Gerlach, 2007) and its activation predicts the success of subsequent memory retrieval of both words and other visual objects such as faces (Mei et al., 2010; Van Doren, Dupont, De Grauwe, Peeters, & Vandenberghe, 2010).

Second, the functional abnormalities of dyslexics might overlap with other subregions of the left fusiform gyrus, including the fusiform face area (FFA, Figure 1). The FFA responds to a greater degree to images of faces than to images of several other types of objects (Kanwisher et al., 1997; Kanwisher, Stanley, & Harris, 1999; for a review, see, e.g., Kanwisher & Yovel, 2006). The FFA is also increasingly activated for object categories other than faces as people develop greater expertise for these categories, especially if that expertise involves greater ability for within-category recognition, such as the ability to tell apart different kinds of birds or different types of cars (Gauthier et al., 2000; for a recent review on expertise and object recognition, see Sigurdardottir & Gauthier, in press).

Dehaene et al. (2010) suggest that learning how to read induces a reorganization of the responses of the left fusiform gyrus to faces and other objects. Consistent with this idea, VWFA activation for faces diminishes with increased literacy (Dehaene et al., 2010). Literacy also appears to slightly decrease this region's responses to checkerboards, and possibly to other objects such as houses and tools (Dehaene et al., 2010). Dehaene et al. (2010) furthermore report that reading experience interferes with the expansion of the representation of faces and houses into the cortex surrounding the VWFA. Literacy might therefore drive the recycling of cortical space within the fusiform gyrus where regions previously used for the processing of other visual objects might become increasingly dedicated to the processing of words— unusual but highly behaviorally relevant visual objects (Cohen & Dehaene, 2004; Dehaene & Cohen, 2007; Dehaene et al., 2010).

Dundas, Plaut, and Behrmann (2013, 2014) also provide evidence for the codependence of word and face processing. The left-lateralization of visual words appears to be driven by learning how to read, and more proficient readers show greater left lateralization (Dundas et al., 2014; Marcel, Katz, & Smith, 1974; Monzalvo, Fluss, Billard, Dehaene, & Dehaene-Lambertz, 2012). Consistent with a recently developed theoretical account and a computational model of the interdependence of the neural representations of words and faces (Plaut & Behrmann, 2011), greater literacy skills and the corresponding recruitment of left fusiform regions apparently drive the lateralization of face-specific responses toward the right hemisphere (Dehaene et al., 2010; Dundas et al., 2013, 2014; Monzalvo et al., 2012). Presumably, with greater reading expertise, some of the cortical space in the left fusiform gyrus previously utilized for the processing of faces is repurposed for word analysis, and the right hemisphere takes over the analysis of faces to some extent.

To summarize, dyslexic children and adults show an underactivation in the left fusiform gyrus high up in the ventral visual stream. This region appears to support the visual perception of words and faces, and possibly the discrimination of other homogeneous or visually complex objects. This leads to the hypothesis that dyslexics will show abnormal facial recognition abilities and possibly abnormal within-category recognition abilities for other visual objects.

There are two possible ways in which dyslexics might differ from typical readers. First, if the hypoactivity in the left fusiform in dyslexia is caused by the lack of experience with written words, dyslexics might show facial recognition abilities and possibly recognition abilities for other objects superior to those of typical readers because less of the left fusiform gyrus has been repurposed for word recognition, leaving more neurons tuned to the visual properties of other objects.

If, on the other hand, an underactivated left fusiform gyrus is indicative of a general disruption of that area, dyslexics might be expected to have difficulty with the recognition of faces and possibly other objects. Just like with pure alexia, the faulty recognition of visual words would only be the most obvious and serious expression of a more general perceptual deficit. This would be consistent with this region playing a causal role in the development of dyslexia.

While not much data is available on this topic, we want to acknowledge early work that showed that dyslexic children are more likely than nondyslexic children to draw specifically distorted ("neolithic") human faces (Pontius, 1976, 1981). Based on this, Pontius suggested that faces are perceived as a global pattern rather than abstract component parts. Even normal facial perception is nonetheless thought to be somewhat special because it is unusually reliant on global or holistic representations; the perception of a face, in other words, might not require the decomposition of the face into parts to the same extent that this is required for many other visual objects (Farah, Wilson, Drain, & Tanaka, 1998; but to note multiple definitions of holistic processing, see Richler & Gauthier, 2014; Richler, Palmeri, & Gauthier, 2012). Reading might depend more on part-based processing, but holistic processing also contributes to expert word reading (Wong et al., 2011).

In the current study, we compare the performance of dyslexics and typical readers on a number of tasks that are thought to rely on high level regions of the ventral visual stream. We focus on the perception of faces and probe for general facial recognition abilities as well as the holistic processing of faces. We also measure the ability of dyslexics and typical readers to recognize objects of several other visual categories. We measure performance on four visual tasks: the Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006), the Vanderbilt Holistic Face Processing Test (VHFPT; Richler, Floyd, & Gauthier, 2014), the Vanderbilt Expertise Test (VET; McGugin, Richler, Herzmann, Speegle, & Gauthier, 2012), and a color control test.

## Method

### Participants

Forty people participated in the study. Twenty were self-reported adult dyslexics (12 women), and 20 were self-reported typical readers (12 women). People in the two groups were matched, so for each dyslexic person, there was a typical reader of the same gender, same age (±5 years), and with a similar educational background (completed the first, second, or third stage of the Icelandic schooling system, which corresponds roughly to high school, gymnasium, and college, respectively). Participants were only included in the sample if they did not test positive when screened for color blindness.

The mean age in each group was 29 years (age range of dyslexics: 18 to 40 years; age range of typical readers: 18 to 43 years). In each group, four people had completed the first stage of schooling, five had completed the second stage, and 11 people had completed the third stage.

All participants were volunteers and were not paid for their participation, but could receive partial course credit for their participation if they were enrolled in such a course at the University of Iceland. All volunteers were offered a chance to participate in a lottery, and one randomly selected participant then received a gift card that could be used in a local shopping mall (value kr10.000 [Icelandic Krona], or approximately US$90).

### Procedure

The study was approved by the Icelandic Science Review Board and the Icelandic Data Protection Authority. The study took place in a quiet, well-lit room. The participants first gave informed consent (given the choice of either reading the consent form or hearing it read aloud). The participants partook in four visual experiments (CFMT, VHFPT, VET, and a color control test) and completed two tests intended to verify that the two groups were indeed dyslexic and typical readers, respectively (the Adult Reading History Questionnaire [ARHQ] and the Icelandic word form [IS-FORM] reading test).

**Adult Reading History Questionnaire.** The Icelandic version of ARHQ was administered first to evaluate each participant's history of reading problems. The questionnaire is a reliable screening tool for dyslexia in adults and its validity has been established in a large sample of both typical readers and people who received ICD-10 diagnoses of specific reading disorder when they were children (Bjornsdottir et al., 2014; Lefly & Pennington, 2000). The questionnaire consists of 23 questions that the participants answer on a scale from 0 to 4. The total score is divided by the maximum total score (92) to get a score that can range from 0 to 1. Higher scores are associated with dyslexia.

**IS-FORM reading test.** No standardized reading tests currently exist for Icelandic adults. We therefore designed the IS-FORM test, a new reading test that contains word forms of varying difficulty so as to capture a wide variety of reading ability. The test consists of two lists of words, one with 128 common Icelandic word forms and another one with 128 uncommon word forms. Icelandic is an inflected language so the same word can have many forms. For example, the word "hestur" (horse) can take the forms "hest," "hesti," "hests," "hestar," "hesta," "hestum," "hesturinn," and so forth, depending on context. Because the word forms were presented out of context, they could not easily be guessed based on only their first few letters. This was done to increase the likelihood of reading errors and selectively slow down letter-by-letter readers. Icelandic has a shallow orthography where there is a more or less one-to-one mapping between letters and sounds (Seymour, 2005). Unlike languages with a more opaque orthography such as English, dyslexia in regular orthographic languages often manifests as slow and laborious—but not necessarily incorrect—reading (Serrano & Defior, 2008; Wimmer, 1993; Ziegler et al., 2003).

The common word forms in IS-FORM were selected from a list of the 2,318 most common Icelandic word forms (Pind, Magnússon, & Briem, 1991). The uncommon word forms appeared only once in all of the reference texts on which the Icelandic word rate lexicon is based (Pind et al., 1991). Each list contains 92 nouns, 23 adjectives, eight verbs, and five adverbs. The words of each type in the lists were matched for number of syllables; each list contains 343 syllables. The common word form list contains 992 letters (1,050 characters with spaces) and the uncommon word form list contains 1,047 letters (1,174 characters with spaces). The order of the word forms in each list was originally randomized. This order was then kept fixed for all participants.

The IS-FORM was the last test to be administered in each experimental session. The common word form sheet was put in front of each participant, backside up. The participant was told that the experimenter would count to three and then flip the sheet over and was asked to start reading out loud as soon as the sheet was flipped, as fast as he or she could while making as few errors as possible. The procedure was repeated for the uncommon word form list. Our measures of interest were the words read per minute and the percentage of correctly read word forms.

**Measures of visual processing.** The participants were asked to sit in front of the computer screen (distance approximately 60 cm) and participate in four visual experiments: the CFMT, VHFPT, VET, and a color control test which was run concurrently with the VET. The order of the CFMT, the VHFPT and the VET + color control tasks was randomly determined with the constraint that matched participants (dyslexics and typical readers) completed them in the same order. A Dell Optoplex 760 computer with a 16-in. screen (resolution 1024 × 768 pixels) and a refresh rate of 85 Hz was used for all visual experiments.

**Cambridge Face Memory Test.** The CFMT is widely used to evaluate facial recognition abilities and has, among other things, been used to screen for face blindness or prosopagnosia (Duchaine & Nakayama, 2006). Briefly, participants are asked to memorize six previously unfamiliar faces and recognize them while they are presented exactly as originally shown, under different lighting conditions, from a different viewpoint, or embedded in visual noise. The test requires a three alternative forced choice (left, middle, or right face). The test was run from a precompiled Java program provided by the test's original authors. Before the test was run, participants heard prerecorded instructions in Icelandic.

The test was first run with all faces shown upright. The upright version was run in order to measure the ability to recognize faces under more-or-less normal circumstances. The test was then run with all faces shown upside down. The inverted version was primarily run as a comparison with the upright version. Unlike some other objects, the recognition of faces suffers greatly when they are inverted (Diamond & Carey, 1986; Duchaine & Nakayama, 2006; Scapinello & Yarmey, 1970; Yin, 1969); this face inversion effect might come about because the recognition of upright faces can both rely on the processing of individual facial features as well as holistic, relational, or configural processing while the recognition of inverted faces might primarily rely on the piecemeal processing of individual features (Carey & Diamond, 1977; Farah, Tanaka, & Drain, 1995; Freire, Lee, & Symons, 2000; Murray, Yong, & Rhodes, 2000; J. W. Tanaka & Farah, 1993; J. W. Tanaka & Sengco, 1997; Van Belle, De Graef, Verfaillie, Rossion, & Lefevre, 2010). The difference between the ability to recognize upright and inverted faces can be seen as one measure of the extent to which a participant relies on holistic processing for normal faces (but see Richler, Mack, Palmeri, & Gauthier, 2011).

**Vanderbilt Holistic Face Processing Test.** While it has been argued that people rely more on holistic processing for upright than inverted faces, the relationship between holistic perception and inversion is debatable (Richler et al., 2011). We therefore also ran the VHFPT (Richler et al., 2014), which is specifically designed to measure the degree to which people use holistic face processing. We used the version of this task that includes aligned trials only (see Richler et al., 2014). The original code for the VHFPT was contributed by Richler et al. (2014). The code was then modified by removing all written instructions and replacing them with recorded instructions in spoken Icelandic. The code was run from MATLAB using the Psychophysics Toolbox (Brainard, 1997).

Stimuli were grayscale images of faces that were a combination of two individuals' face parts such as the upper half of Face A combined with the lower half of Face B. On each trial, a composite face (study face) was shown for 2 s. One of the two face parts was considered the target part and was surrounded by a red outline box. Participants were told to only focus on the target part and ignore the rest of the face. The study face was replaced by a grayscale mask for 0.5 s. Three composite faces were then shown on the left, center, and right of the screen. The target part of each of the three faces was marked with a red box. Only one of the three faces had the correct target part (correct face); the other two faces were incorrect foils. The target part of the study face and the correct face were taken from two different images of the same person. Hair was removed from all study faces in cases where the target part was the top portion of the face because hair outline is a salient nonface feature.

The participants were asked to indicate which face contained the same target part as the study face by pressing one of three buttons on the keyboard. The buttons were specifically marked on the keyboard with white stickers and their corresponding letters (J, K, and L) were not visible. The left, middle, and right buttons corresponded to the left, middle, and right faces, respectively. The screen went blank after 10 s, or as soon as the participants pressed a response key, whichever happened first. Participants moved on to the next trial by pressing the spacebar.

On congruent trials, the target part of the correct face appeared in the same context as for the study face. For example, if the target part was the upper half of a face, both the study face and the correct face might be composed of the upper part of the face of Individual A and the lower part of the face of Individual B. On incongruent trials, the target part of the correct face appeared in a context different from that of the study face. For example, if the correct target part was the upper half of the face of Individual A, the study face might consist of this target part combined with the lower part of the face of Individual B, while the correct face might be a combination of this target part and the lower part of the face of Individual C.

There were 134 trials in total. Stimuli were shown in the same fixed order for all participants. To increase individual differences and the difficulty of the task, the type of target part, the size of the faces, and the gender of the faces varied from trial to trial. Nine possible types of target face parts were used and were shown in the following order: Lower two thirds of the face (14 trials), upper two thirds of the face (16 trials), lower half (16 trials), upper half (14 trials), lowest third (14 trials), uppermost third (14 trials), eyes (14 trials), mouth (14 trials), and nose (16 trials). At the start of each of these nine blocks, the participants were informed of the target part to which they were to pay attention. The faces on each trial could be all small (approximately 3 × 2 cm), all medium (approximately 6 × 3 cm), or all large (approximately 9 × 5 cm), and could be either all male or all female. The first two trials in each block, one congruent and one incongruent, were practice trials with composite faces of celebrities (18 trials total, not analyzed). On all other trials (58 congruent, 58 incongruent, 116 trials total), the composite faces were constructed from the faces of people unfamiliar to the participants.

**Vanderbilt Expertise Test.** The VET (McGugin et al., 2012) was run from MATLAB using the Psychophysics Toolbox add-on (Brainard, 1997). The code was contributed by the test's original authors, and was modified for in-house use by removing written instructions, replacing them with prerecorded auditory instructions in Icelandic. Written feedback was also replaced by auditory feedback (a "chink" for correct answers and a "thud" for incorrect answers). Unlike the original VET, no labels or names were provided for any stimuli. Otherwise, the format of the test was as described by McGugin et al. (2012).

Briefly, the participants were first asked to rate their experience with or expertise in six domains (birds, butterflies, cars, planes, houses, and colors—see Color Control Test section) on a scale from 1 to 9, where increasing numbers indicated greater expertise. They then completed three practice trials where they memorized six cartoon characters and had to recognize one of them (Bart Simpson) from different viewpoints.

The participants were then shown six photographs of things within a particular category, such as six butterflies. An overview of the six images was presented again as a reminder after the sixth and the 12th trial of each category. On each trial, three images were presented, only one of which was an image of one of the six things originally shown (e.g., same butterfly species). Participants were to indicate which image depicted an exemplar that matched any one of the original six objects (three alternative forced choice). The VET requires participants to recognize objects within a particular category, such as different types of butterflies or different types of cars. It is therefore a close analog of the CFMT, which also requires within-category discrimination (i.e., telling apart different people).

Five object categories were tested: birds, butterflies, cars, planes, and houses. A dyslexic participant and his or her matched typical reader completed the test for these five object categories and as well as the sixth control color category (see Color Control Test section) in the same order. The category order for the dyslexic—typical reader pair was randomized. All images were shown in grayscale. Fifty-one trials were run for each category. Feedback was given for the first 12 trials of each category. During the feedback trials, the correct choice image was identical to one of the six studied images. For the remainder of the task (36 trials of interest and three catch trials such as a butterfly among two dinosaurs), the correct choice was a different image that nonetheless depicted one of the memorized objects, such as the same type of butterfly seen from a different viewpoint. The test of the five object categories should provide a measure of the person's general within-category object recognition abilities.

**Color control test.** The sixth category, colors, was added by the current authors as a control test. Here, six colored squares were originally shown. On each trial, one of these six squares was presented with two other squares that were a different shade of the same general color (e.g., three greens, three blues etc.). The participants had to choose the square that was one of the original six squares. For both feedback and nonfeedback trials, the correct color was identical to one of the six studied colors. The format of the color control test was otherwise like that of the VET.

The color test shares many aspects with the CFMT and the original VET, such as the requirement to memorize six exemplars and making a challenging three alternative forced choice between stimuli that look much alike. It, however, does not in any way depend on the perception of shape. Shape processing, unlike color perception, is critical for the recognition of words. Like other visual object categories, words share many visual features with each other so distinguishing between them requires fine shape discrimination abilities. We expect dyslexics to have deficient general within-category object recognition abilities, but we do not expect the performance of the dyslexic group and the control group to significantly differ on the color test. If the groups significantly differ in both color recognition as well as general within-category object recognition, this might indicate that a component shared by all tasks, such as memory load, drives the effects.

It should be noted that color perception, like object perception, in all likelihood depends on the ventral visual stream. Both neuroimaging studies on color vision and a meta-analysis of brain damaged patients with severe deficits in color vision nonetheless mainly indicate the involvement of regions in the ventral visual stream of the right hemisphere (Bouvier & Engel, 2006), while dyslexics show consistent hypoactivation within the ventral visual stream of the left hemisphere (Richlan et al., 2011).

## Results

An alpha level of 0.05 was used for statistical tests which were all two-sided. The results of repeated measures ANOVAs were Greenhouse-Geisser corrected for deviations from sphericity in cases where Mauchly's test of sphericity was significant. Effect sizes were estimated using Pearson's $r$, Cohen's $d$ (mean difference/standard deviation of difference), and partial eta squared ($\eta_p^2$).

### Measures of Dyslexia

Five measures of dyslexia were used to verify that the two groups were indeed dyslexic and typical readers, respectively. These were ARHQ scores, common word forms read per minute in IS-FORM, uncommon word forms read per minute in IS-FORM, percentage of correctly read common word forms in IS-FORM, and percentage of correctly read uncommon word forms in IS-FORM.

All four IS-FORM measures were moderately to highly positively correlated (lowest correlation: $r = .38$, highest correlation: $r = .90$, all $ps < 0.05$), indicating that they all captured variability on the same underlying construct (reading ability). This was confirmed with a principal components analysis, where all four measures loaded on the same single component that explained 75% of the variance in the original four variables (common word forms per minute: 68%; uncommon word forms per minute: 85%; percent correct common word forms: 66%; percent correct uncommon word forms: 80%). Dyslexics and typical readers greatly differed in scores on this reading ability component (see Figure 2).

The two groups also differed greatly in their ARHQ scores as depicted in Figure 2. Scores on this questionnaire were moderately to highly negatively correlated with all four IS-FORM reading scores (common word forms per minute: $r = -0.84$; uncommon word forms per minute: $r = -0.86$; percent correct common word forms: $r = -0.51$; percent correct uncommon word forms: $r = -0.63$; all $p$s $< 0.001$). The higher the ARHQ scores, the slower and less accurately people read.

A single participant in the typical reader group was a clear outlier (marked with a circle in Figure 2). His reading ability and ARHQ score were close to the median of the dyslexic group. He and his matched participant were therefore excluded from the sample in all further analyses. One participant in the dyslexic group had an unusually low ARHQ score (marked with a square in Figure 2). She had been formally diagnosed with dyslexia and her reading ability was poorer than all typical readers except for the person already excluded. She was kept in the sample. Another participant in the dyslexic group (marked with a star in Figure 2) had an unusually low score on the reading ability measure. Because her reading ability was unusually poor—not unusually good—for the dyslexic group, she was kept in the sample.

The people remaining in the two groups greatly differed on all five measures of dyslexia (see Table 1). We are therefore confident that participants in the two groups were dyslexic and typical readers, respectively.

Table 1
*Five Measures of Dyslexia: Means (M) and Standard Deviations (SD) of Scores on the Adult Reading History Questionnaire (ARHQ) and the IS-FORM Reading Test*

| Measure | Typical readers *M* (*SD*) | Dyslexics *M* (*SD*) |
|---|---|---|
| ARHQ | 0.24 (0.08) | 0.60 (0.12) |
| IS-FORM: Common word forms per minute | 113 (18) | 73 (16) |
| IS-FORM: Uncommon word forms per minute | 80 (12) | 45 (16) |
| IS-FORM: Percent correct common word forms | 99 (1) | 94 (6) |
| IS-FORM: Percent correct uncommon word forms | 98 (2) | 86 (10) |

## Cambridge Face Memory Test

We first compared the performance of dyslexics and typical readers with previously reported norms from neurologically intact participants (Duchaine & Nakayama, 2006). On average, typical readers in our sample correctly identified upright faces on 79.1% of trials on the CFMT. Their performance was not significantly different from the published average performance of 80.4%: one-sample $t$ test, $t(18) = 0.35$, $p = .728$, $d = 0.08$. Dyslexics scored on average 68.4% correct. Their performance was significantly poorer than the reported average performance: one-sample $t$ test, $t(18) = 4.35$, $p = 3.9 \times 10^{-4}$, $d = 1.00$. The typical readers correctly identified inverted faces on 64.4% of trials. Their performance was significantly better than the reported norm of 58.4%: one-sample $t$ test, $t(18) = 2.29$, $p = .035$, $d = 0.52$. Dyslexics on average correctly identified inverted faces on 55.3% of trials, and this was not significantly different from the reported norm: one-sample $t$ test, $t(18) = -1.36$, $p = .190$, $d = 0.31$. Note that the previously reported average for inverted faces came from participants who had not previously completed the test with upright faces, and that our participants might have benefited from first completing the test with the same faces shown upright.

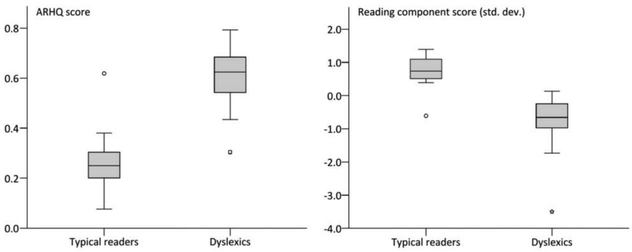

*Figure 2.* Adult Reading History Questionnaire (ARHQ) scores (left panel) and IS-FORM reading ability (right panel) of typical readers and dyslexics. Boxes mark the interquartile range (IQR). All scores except outliers are contained within the whiskers. Outliers are defined as scores that are 1.5 IQR lower than the first quartile or 1.5 IQR higher than the third quartile. The scores of three outlier participants are marked with a circle, a square, and a star, respectively.

A two-factor repeated-measures ANOVA was then run where the factors were group (dyslexic and typical readers) and facial orientation (upright and inverted), and the dependent measure was the percentage of correct trials (see Figure 3). There was a main effect of group, $F(1, 18) = 10.25$, $p = .005$, $\eta_p^2 = 0.36$. The facial recognition abilities of dyslexics were in general lower ($M = 61.8\%$) than those of typical readers (71.7%). As expected, there was also a main effect of facial orientation, $F(1, 18) = 78.17$, $p = 5.7 \times 10^{-8}$, $\eta_p^2 = 0.81$, where people in general found it harder to recognize inverted ($M = 59.9\%$) than upright faces ($M = 73.7\%$). The interaction between the two factors was not significant, $F(1, 18) = 0.30$, $p = .59$, $\eta_p^2 = 0.02$. In other words, the strength of the face inversion effect did not significantly differ between dyslexics and typical readers.

Our main analysis indicated that dyslexics in general found it harder than the typical readers to recognize faces, but that the holistic processing of faces, as measured by the face inversion effect (but see Richler et al., 2011), was equivalent in the two groups. The CFMT, however, consists of four stages: (a) practice (not analyzed), (b) identical images (c) novel images, and (d) novel images with noise. The faces in the second stage could potentially be identified with a low-level image-based strategy but higher-level shape or face processing would in all likelihood also be helpful. The to-be-recognized faces in the third stage are novel photographs of the studied faces taken under different lighting conditions or shown from a different viewpoint. This stage therefore requires higher level shape processing where superficial sim-

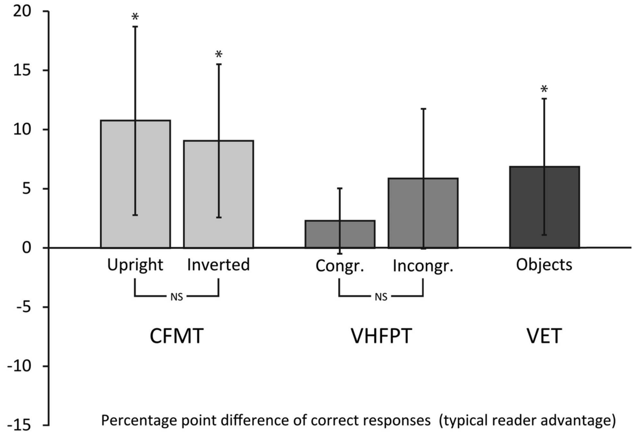

*Figure 3.* The performance difference of dyslexics and typical readers for the Cambridge Face Memory Test (CFMT), the Vanderbilt Holistic Face Processing Test (VHFPT), and the Vanderbilt Expertise Test (VET). The performance difference for the VET is based on performance for birds, butterflies, cars, houses, and planes. Significantly different performance levels for the two groups are marked with an asterisk. Error bars mark the 95% confidence interval of the difference. The magnitude of the group difference did not significantly (*ns*) depend on whether faces were shown upright or inverted in the CFMT. The magnitude of the group difference also did not significantly (*ns*) depend on whether trials on the VHFPT were congruent or incongruent with a studied face. In other words, no reliable group differences were found for two possible indicators of holistic processing (the CFMT face inversion effect and the VHFPT congruency effect).

ilarities or differences between faces have to be ignored. Faces in the fourth stage are also novel images of the studied faces, but these images are degraded with the addition of Gaussian noise. A low-level image-based strategy is unlikely to be of much use under such conditions. Performance in the third and fourth stages of upright facial recognition appears to a large extent to depend on the same abilities (Duchaine & Nakayama, 2006; McGugin et al., 2012), and there is reason to believe that normal facial recognition mechanisms contribute to the second stage (Duchaine & Nakayama, 2006).

To look more closely into group differences, we compared the performance of dyslexics and typical readers at Stages 2, 3, and 4 of the recognition of upright and inverted faces (paired *t* tests). For upright faces, the groups significantly differed in performance when images identical to the studied faces had to be recognized (Stage 2), dyslexics ($M$ = 97.1%), typical readers ($M$ = 100.0%), $t(18) = 2.54$, $p = .021$, $d = 0.58$, and when novel images of the studied faces had to be recognized (Stage 3), dyslexics ($M$ = 60.3%), typical readers ($M$ = 76.8%), $t(18) = 3.47$, $p = .003$, $d = 0.80$, but the groups did not significantly differ when novel images with added noise had to be recognized (Stage 4), dyslexics ($M$ = 56.8%), typical readers ($M$ = 66.2%), $t(18) = 1.60$, $p = .128$, $d = 0.37$. For inverted faces, typical readers significantly outperformed dyslexics on the identical images stage (Stage 2), dyslexics ($M$ = 81.0%), typical readers ($M$ = 90.9%), $t(18) = 2.74$, $p = .013$, $d = 0.63$, and on the novel images with noise stage (Stage 4), dyslexics ($M$ = 42.1%), typical readers ($M$ = 54.8%), $t(18) = 3.20$, $p = .005$, $d = 0.73$. The performance of the two groups was marginally significantly different at the novel images stage (Stage 3), dyslexics ($M$ = 50.5%), typical readers ($M$ = 58.2%), $t(18) = 1.88$, $p = .077$, $d = 0.43$. In sum, dyslexics appear to have impaired facial recognition abilities, both when identical and novel face images have to be recognized, but their holistic face processing abilities might be intact.

## Vanderbilt Holistic Face Processing Test

We analyzed data from the VHFPT with a 2 Group (Dyslexics, Typical Readers) × 2 Congruency (Congruent Trials, Incongruent Trials) repeated-measures ANOVA (see Figure 3). As expected, there was a highly significant main effect of congruency, $F(1, 18) = 252.35$, $p = 4.9 \times 10^{-12}$, $\eta_p^2 = 0.933$, where all participants performed better on congruent trials ($M$ = 73.0%) than on incongruent trials ($M$ = 49.7%). The performance of the typical readers ($M$ = 63.1%) was better than for the dyslexics ($M$ = 59.7%). This difference was marginally significant, $F(1, 18) = 4.33$, $p = .052$, $\eta_p^2 = 0.19$. There was no significant interaction between congruency and group, $F(1, 18) = 1.39$, $p = .254$, $\eta_p^2 = 0.07$. While dyslexics might possibly show some general face processing impairments on the VHFPT (as indicated by their poorer overall performance), there was no consistent evidence that their holistic face processing is different from that of typical readers (as indicated by their lack of a significantly smaller or greater congruency effect).

## Vanderbilt Expertise Test

**Self-reported experience.** Self-ratings of expertise or experience with object categories have previously been found to be rather poor predictors of perceptual performance, and people in general might have poor insight into their perceptual abilities (Gauthier et al., 2014). We nonetheless tested for differences in such self-reported experience or expertise with the five object categories because we wanted to rule out the possibility that dyslexics lacked confidence in their abilities; this could lead them to both give themselves lower object expertise ratings as well as lowering their effort on the object recognition tasks.

A 2 Groups (Dyslexics, Typical Readers) × 5 Categories (Birds, Butterflies, Cars, Houses, and Planes) repeated-measures ANOVA was performed on the self-reports. There was no main effect of group, $F(1, 18) = 1.41$, $p = .25$, $\eta_p^2 = 0.07$, so overall, the two groups did not significantly differ in their object expertise ratings. There was a main effect of category, with some categories receiving higher average ratings than others (birds: $M = 4.05$; butterflies: $M = 2.71$; cars: $M = 4.42$; houses: $M = 5.21$; planes: $M = 3.26$), $F(4, 72) = 17.67$, $p = 3.8 \times 10^{-10}$, $\eta_p^2 = 0.50$. Somewhat unexpectedly, there was an interaction between group and category, $F(4, 72) = 3.29$, $p = .016$, $\eta_p^2 = 0.16$. To follow up, we performed five paired *t* tests, one for each object category. This revealed that dyslexics rated themselves as greater car experts ($M = 5.05$) than the typical readers ($M = 3.79$), $t(18) = 2.317$, $p = .033$, $d = 0.53$. Differences in ratings were nonsignificant for all other categories (all $p$s $> 0.13$, all $d$s $< 0.37$). Numerially, dyslexics rated themselves as greater experts than their matched typical readers in three out of five categories on average. There was no indication that the dyslexics lacked confidence in their abilities.

**Catch trials.** To make sure that our results were not due to lack of effort, misunderstanding of the task instructions, or other nonspecific factors such as the confusion of the response buttons, we looked at the total percentage of correct responses on catch trials where the correct choice should in most cases be rather obvious. As expected, the performance for both dyslexics ($M$ = 99.3%) and typical readers ($M$ = 100.0%) was close to perfect for catch trials.

**Within-category object recognition.** A 2 × 5 repeated-measures ANOVA was performed with the percentage of correct trials as the dependent measure (see Figure 3). The factors were group (dyslexics and typical readers) and object category (birds, butterflies, cars, planes, and houses). There was a main effect of category, $F(2.545,45.812) = 32.47$, $p = 1.3 \times 10^{-10}$, $\eta_p^2 = 0.64$, indicating that the recognition task was in general harder for some categories than others (birds: $M$ = 74.5%; butterflies: $M$ = 63.2%; cars: $M$ = 54.4%; houses: $M$ = 79.8%; planes: $M$ = 71.9%). There was also a main effect of group, $F(1, 18) = 6.17$, $p = .023$, $\eta_p^2 = 0.26$. In general, the performance of dyslexics was lower (65.3%) than the performance of typical readers (72.2%). There was no significant interaction between category and group, $F(4, 72) = 0.55$, $p = .697$, $\eta_p^2 = 0.03$. The percent correct was numerically lower for dyslexics than for typical readers in all five categories but the magnitude of this difference did not significantly differ between the groups.

Like the CFMT, the VET for objects included trials where the correct choice was an image identical to one of the studied images as well as trials where novel images of a studied object were shown. In addition to our main analysis, we also looked at performance in these two stages of the VET. The group difference did not quite reach significance for the identical image stage: dyslexics ($M$ = 89.7%), typical readers ($M$ = 94.2%), $t(18) = 1.93$, $p = .069$, $d = 0.44$, but it was significant for the novel image stage: dyslexics ($M$ = 57.3%), typical readers ($M$ = 64.8%), $t(18) = 2.42$, $p = .026$, $d = 0.56$. The performance of dyslexics is worse than that of typical readers when novel images of a studied object need to be recognized.

## Color Control Test

The color control test shares many factors with the CFMT and the VET for objects. Because it does not involve any analysis of shape, however, we did not expect to see any differences between the groups for colors.

The groups did not significantly differ in their assessment of their experience or expertise with colors: dyslexics ($M$ = 7.47), typical readers ($M$ = 7.16), paired-samples $t$ test: $t(18) = 0.69$, $p = .500$, $d = 0.16$. The performance of both groups on catch trials was good, although the performance of typical readers was lower than we expected: dyslexics ($M$ = 96.5%), typical readers ($M$ = 89.5%). The correct choice on catch trials (e.g., a correct color square among two gray squares) might not have been obvious because the perception of the hue of the foils could have been influenced by the context of the correct color square. Catch trials are therefore more appropriately labeled easy trials.

Both groups performed significantly above the chance level of 33.3% correct on the noncatch trials on the color control task: one-sample $t$ test, dyslexics ($M$ = 51.2%), $t(18) = 13.06$, $p = 1.3 \times 10^{-10}$, $d = 3.00$; typical readers ($M$ = 53.8%), $t(18) = 6.24$, $p = 7.0 \times 10^{-6}$, $d = 1.43$. The performance of the two groups did not significantly differ: paired-samples $t$ test, $t(18) = 0.74$, $p = .467$, $d = 0.17$.

## Correlations Between Reading and Visual Performance

While controlling for age, gender, and education (coded as 1, 2, and 3, indicating completion of the first, second, or third stage of the Icelandic schooling system, respectively), we looked at the partial correlations between the reading component (from our factor analysis of common word forms per minute, uncommon word forms per minute, percent correct common word forms, and percent correct uncommon word forms; see Results: Measures of Dyslexia section) and overall accuracy on the CFMT, VHFPT, and VET.

Across groups, the reading component was positively correlated with overall accuracy on the three tasks, and was significant for the CFMT, $r(33) = 0.34$, $p = .049$, marginally significant for the VHFPT, $r(33) = 0.28$, $p = .099$, and did not reach significance for the VET, $r(33) = 0.27$, $p = .111$. Within each group, the reading component was not significantly correlated with overall accuracy on the three tasks (all $r$s $< 0.18$, all $p$s $> 0.25$). The correlations across groups therefore appear to mainly reflect overall group differences between dyslexics and typical readers, that is, what matters most is whether people are dyslexic or not.

# Discussion

Our results show that dyslexics have impaired facial recognition, as shown by the overall performance on the CFMT (both upright and inverted faces) and overall performance on the VHFPT (both congruent and incongruent face trials). Furthermore, the results indicate that dyslexics show impairments on other recognition tasks that also require the individuation of same-category objects, as measured by performance on the VET. The difficulty that people with dyslexia experience with reading might therefore be the most obvious manifestation of a more general high-level visual deficit. A "deficit" might even be a misnomer as dyslexics might simply tend to be at the lower end of a normal range of object perception abilities. For objects other than words, this might not cause serious problems; it would probably not matter much for people's day-to-day functioning if they were not particularly good at telling apart really similar faces, or birds, or butterflies, and so forth. The lack of the fine-grained shape analysis required by such tasks might on the other hand be devastating for reading, which requires the very rapid discrimination between and recognition of hundreds of thousands of highly visually similar objects, that is, words. We want to note that lower-than-typical object recognition abilities do not go against the possibility that dyslexics might excel at other visual tasks. In fact, several dyslexics in our sample professionally draw or paint, and the prevalence of dyslexia has been reported to be particularly high among art students (Wolff & Lundberg, 2002). A large literature now exists that supports that vision-for-recognition and vision-for-action (e.g., drawing) are behaviorally and neurally separable (Goodale & Milner, 1992; Milner & Goodale, 1995; Ungerleider & Mishkin, 1982).

While dyslexics show evidence for facial recognition problems, they do not seem to show atypical holistic processing of faces, one of the hallmarks of face processing. In this regard, dyslexics might differ from illiterates (i.e., people who received no early schooling during childhood and are unable to read even simple words) who, compared to literates, show greater holistic processing of both faces and houses, as measured by the composite task (Ventura et al., 2013). Face perception is probably neither purely holistic nor purely part-based, and these two methods of analyzing a face might depend on different neural structures. Consistent with the general idea that the right hemisphere is more involved in holistic processing and the left with part-based processing, Rossion et al. (2000) have reported a double dissociation between the right and left FFA, with the former being more involved in the analysis of the whole face, and the latter being more important for the analysis of the individual parts of the face (see also Bourne, Vladeanu, & Hole, 2009). It might therefore be that dyslexics are specifically impaired at the part-based processing of words, faces, and other objects, consistent with their primarily left-lateralized dysfunction of the fusiform gyrus (Richlan et al., 2011).

The diagnosis for dyslexia in Iceland can be made by people of different disciplines who may use different criteria. During study recruitment, we therefore advertised for people with dyslexia but did not require official documentation for their diagnosis. We deemed it a better strategy to measure people's reading skills as well as judging everyone on the same reliable measure (ARHQ) that has been validated on a large sample of adults diagnosed using the same criteria based on the World Health Organization's ICD-10 (Bjornsdottir et al., 2014; Lefly & Pennington, 2000). Note that if some people in our dyslexia group were actually not dyslexic and some people in the typical reader group were dyslexic, we would have been less likely—not more likely—to find the observed group differences.

We consider our results to be an important step toward establishing that dyslexics are impaired at the perception of faces and other complex visual objects. Nonetheless, other studies need to probe for the replicability of these effects. First, the primary language of our participants is Icelandic, a language with a shallow orthography (Seymour, 2005). It needs to be established that the effects reported here hold for other samples, especially for dyslexics and typical readers whose primary language has an opaque orthography, such as English. The contribution of phonological awareness to reading performance has been found to be greater for languages with opaque orthographies than shallow orthographies (Ziegler et al., 2010) so it is possible that visual factors play a relatively smaller role in languages with opaque orthographies. We nonetheless think that it is highly likely that visual processing skills play a role in reading deficits in all languages, although exactly which visual processes are most important may depend on the structure of the language (e.g., alphabetical written languages like Icelandic and English vs. logosyllabic written languages like Chinese).

Second, while our dyslexic and typical readers were matched in terms of their age, their level of schooling, and their gender, we of course cannot say with certainty that they did not differ in any other possible way (besides having or not having dyslexia) that might have influenced the results. For example, we did not measure people‘s general processing speed or attention deficits which could affect performance on some visual tasks. These factors are unlikely to significantly affect our results, however. First, the performance of the dyslexic and typical reader groups did not significantly differ on the color control test that nonetheless shared many important components with both the CFMT and the VET. Second, both groups did very well on catch trials, consistent with the idea that they were trying their best and paying attention. Third, note that speedy processing was neither particularly important nor emphasized in our visual tasks. In the VET, for example, the participants could look at the example objects for as long as they deemed necessary and could take as much time as they needed when choosing an object on each trial.

Lexical knowledge and vocabulary are also unlikely to play a large role in our visual tasks, and we specifically kept this in mind when choosing the tasks. In the upright and inverted CFMT, all faces are unfamiliar. Similarly, all trials of interest in the VHFPT involve unfamiliar faces. Had we used familiar faces, we would have worried that the participants might use a verbal or semantic strategy to remember and recognize the faces (e.g., "This is Jennifer Aniston"), but such a strategy is not useful for unfamiliar faces.

Nonexperts tend to use basic-level verbal labels, such as "car" or "butterfly," when identifying and naming objects (Jolicoeur, Gluck, & Kosslyn, 1984; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). In the VET (and in our color control test), such verbal labels would not have been helpful at all because people always had to choose among three different exemplars of the same category with the same basic-level verbal label (e.g., three different cars or three different butterflies). Experts in a particular domain, on the other hand, are likely to use more specific subordinate-level verbal labels for objects that fall within their domain of expertise (e.g., "Toyota"; J. W. Tanaka & Taylor, 1991), and such a verbal labeling strategy could potentially help them in a visual recognition task. Our results, on the other hand, indicate that the groups did not differ in their expertise or experience with any of the categories used with the possible exception of cars, where dyslexics reported greater expertise, not less expertise, than the typical readers. If anything, a verbal strategy would have been more helpful for the dyslexics and yet their visual recognition of objects in general was poorer. As with the CFMT and the VHFPT, we therefore think that any possible differences in the groups' lexical knowledge and vocabulary could not explain our results for the VET.

Further studies are needed to establish the specificity of our effects. We include one control test, color recognition, and do not find any consistent differences between dyslexics and typical readers on this test. This is consistent with the interpretation that our effects for faces and objects are not due to nonspecific factors such as memory load. The absence of an effect is hard to interpret, however, and rigorous control conditions should be run in future studies. While general memory ability might not be a large contributing factor here, neurons in high level regions of the ventral visual stream might be involved in both object perception and object memory (Woloszyn & Sheinberg, 2009). It would be interesting and important to see whether or not our effects would hold under conditions of simultaneous presentation where complex objects need to be discriminated but not recognized.

It remains to be established to what extent atypical face and object recognition abilities in dyslexics depend on the function of the fusiform gyrus, and to what extent this is experience-dependent given that the fusiform is an important site for cortical plasticity driven by experience with visual objects (Sigurdardottir & Gauthier, in press; Tarr & Gauthier, 2000). In this context it should be noted that dyslexic children are reported to show decreased activation for faces in the right fusiform gyrus (Monzalvo et al., 2012). This may reflect that left fusiform regions are not recruited for word perception to the same degree as for typically reading children, decreasing the competition with face representations in the left fusiform. Still, compared to normal readers, the dyslexics in this same study also appeared to show decreased responses to faces in the left fusiform gyrus (Monzalvo et al., 2012). This is consistent with the possibility that abnormal functioning of the left fusiform gyrus contributes to the problems dyslexics have with recognizing faces and words.

Finally, we want to emphasize that finding a deficit in high-level object recognition does not automatically argue against other theories of the causes of dyslexia. Future studies need to establish the extent to which high-level visual problems go hand in hand with other deficits such as difficulties in phonological processing (Catts, 1989; Pennington et al., 1990; Shaywitz & Shaywitz, 2005; Snowling, 2001; Vellutino et al., 2004) or rapid automatized naming (Denckla & Rudel, 1976a, 1976b).

## References

Behrmann, M., Nelson, J., & Sekuler, E. B. (1998). Visual complexity in letter-by-letter reading: "Pure" alexia is not pure. *Neuropsychologia, 36,* 1115–1132. http://dx.doi.org/10.1016/S0028-3932(98)00005-0

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,* 1102–1118. http://dx.doi.org/10.1093/cercor/bhs390

Binder, J. R., Medler, D. A., Westbury, C. F., Liebenthal, E., & Buchanan, L. (2006). Tuning of the human left fusiform gyrus to sublexical orthographic structure. *NeuroImage, 33,* 739–748. http://dx.doi.org/10.1016/j.neuroimage.2006.06.053

Bjornsdottir, G., Halldorsson, J. G., Steinberg, S., Hansdottir, I., Kristjansson, K., Stefansson, H., & Stefansson, K. (2014). The Adult Reading History Questionnaire (ARHQ) in Icelandic: Psychometric properties and factor structure. *Journal of Learning Disabilities, 47,* 532–542. http://dx.doi.org/10.1177/0022219413478662

Bourne, V. J., Vladeanu, M., & Hole, G. J. (2009). Lateralised repetition priming for featurally and configurally manipulated familiar faces: Evidence for differentially lateralised processing mechanisms. *Laterality, 14,* 287–299. http://dx.doi.org/10.1080/13576500802383709

Bouvier, S. E., & Engel, S. A. (2006). Behavioral deficits and cortical damage loci in cerebral achromatopsia. *Cerebral Cortex, 16,* 183–191. http://dx.doi.org/10.1093/cercor/bhi096

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10,* 433–436. http://dx.doi.org/10.1163/156856897X00357

Carey, S., & Diamond, R. (1977). From piecemeal to configurational representation of faces. *Science, 195,* 312–314. http://dx.doi.org/10.1126/science.831281

Catts, H. W. (1989). Defining dyslexia as a developmental language disorder. *Annals of Dyslexia, 39,* 50–64. http://dx.doi.org/10.1007/BF02656900

Cohen, L., & Dehaene, S. (2004). Specialization within the ventral streaM = The case for the visual word form area. *NeuroImage, 22,* 466–476. http://dx.doi.org/10.1016/j.neuroimage.2003.12.049

Cohen, L., Dehaene, S., Naccache, L., Lehéricy, S., Dehaene-Lambertz, G., Hénaff, M. A., & Michel, F. (2000). The visual word form area: Spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain: A Journal of Neurology, 123,* 291–307. http://dx.doi.org/10.1093/brain/123.2.291

Cohen, L., Dehaene, S., Vinckier, F., Jobert, A., & Montavont, A. (2008). Reading normal and degraded words: Contribution of the dorsal and ventral visual pathways. *NeuroImage, 40,* 353–366. http://dx.doi.org/10.1016/j.neuroimage.2007.11.036

Cohen, L., Henry, C., Dehaene, S., Martinaud, O., Lehéricy, S., Lemer, C., & Ferrieux, S. (2004). The pathophysiology of letter-by-letter reading. *Neuropsychologia, 42,* 1768–1780. http://dx.doi.org/10.1016/j.neuropsychologia.2004.04.018

Cohen, L., Lehéricy, S., Chochon, F., Lemer, C., Rivaud, S., & Dehaene, S. (2002). Language-specific tuning of visual cortex? Functional properties of the visual word form area. *Brain: A Journal of Neurology, 125,* 1054–1069. http://dx.doi.org/10.1093/brain/awf094

Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron, 56,* 384–398. http://dx.doi.org/10.1016/j.neuron.2007.10.004

Dehaene, S., & Cohen, L. (2011). The unique role of the visual word form area in reading. *Trends in Cognitive Sciences, 15,* 254–262. http://dx.doi.org/10.1016/j.tics.2011.04.003

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

Dehaene, S., Le Clec'H, G., Poline, J. B., Le Bihan, D., & Cohen, L. (2002). The visual word form area: A prelexical representation of visual words in the fusiform gyrus. *Neuroreport: For Rapid Communication of Neuroscience Research, 13,* 321–325. http://dx.doi.org/10.1097/00001756-200203040-00015

Dehaene, S., Pegado, F., Braga, L. W., Ventura, P., Nunes Filho, G., Jobert, A., . . . Cohen, L. (2010). How learning to read changes the cortical networks for vision and language. *Science, 330,* 1359–1364. http://dx.doi.org/10.1126/science.1194140

Denckla, M. B., & Rudel, R. G. (1976a). Naming of object-drawings by dyslexic and other learning disabled children. *Brain and Language, 3,* 1–15. http://dx.doi.org/10.1016/0093-934X(76)90001-8

Denckla, M. B., & Rudel, R. G. (1976b). Rapid "automatized" naming (R. A. N): Dyslexia differentiated from other learning disabilities. *Neuropsychologia, 14,* 471–479. http://dx.doi.org/10.1016/0028-3932(76)90075-0

Desimone, R., Albright, T. D., Gross, C. G., & Bruce, C. (1984). Stimulus-selective properties of inferior temporal neurons in the macaque. *The Journal of Neuroscience, 4,* 2051–2062.

Diamond, R., & Carey, S. (1986). Why faces are and are not special: An effect of expertise. *Journal of Experimental Psychology: General, 115,* 107–117.

Duchaine, B., & Nakayama, K. (2006). The Cambridge Face Memory Test: Results for neurologically intact individuals and an investigation of its validity using inverted face stimuli and prosopagnosic participants. *Neuropsychologia, 44,* 576–585. http://dx.doi.org/10.1016/j.neuropsychologia.2005.07.001

Dundas, E. M., Plaut, D. C., & Behrmann, M. (2013). The joint development of hemispheric lateralization for words and faces. *Journal of Experimental Psychology: General, 142,* 348–358. http://dx.doi.org/10.1037/a0029503

Dundas, E. M., Plaut, D. C., & Behrmann, M. (2014). An ERP investigation of the co-development of hemispheric lateralization of face and word recognition. *Neuropsychologia, 61,* 315–323.

Farah, M. J., Tanaka, J. W., & Drain, H. M. (1995). What causes the face inversion effect? *Journal of Experimental Psychology: Human Perception and Performance, 21,* 628–634. http://dx.doi.org/10.1037/0096-1523.21.3.628

Farah, M. J., & Wallace, M. A. (1991). Pure alexia as a visual impairment: A reconsideration. *Cognitive Neuropsychology, 8,* 313–334. http://dx.doi.org/10.1080/02643299108253376

Farah, M. J., Wilson, K. D., Drain, M., & Tanaka, J. N. (1998). What is "special" about face perception? *Psychological Review, 105,* 482–498. http://dx.doi.org/10.1037/0033-295X.105.3.482

Freire, A., Lee, K., & Symons, L. A. (2000). The face-inversion effect as a deficit in the encoding of configural information: Direct evidence. *Perception, 29,* 159–170. http://dx.doi.org/10.1068/p3012

Friedman, R. B., & Alexander, M. P. (1984). Pictures, images, and pure alexia: A case study. *Cognitive Neuropsychology, 1,* 9–23. http://dx.doi.org/10.1080/02643298408252014

Gauthier, I., McGugin, R. W., Richler, J. J., Herzmann, G., Speegle, M., & Van Gulick, A. E. (2014). Experience moderates overlap between object and face recognition, suggesting a common ability. *Journal of Vision, 14,* 7. http://dx.doi.org/10.1167/14.8.7

Gauthier, I., Skudlarski, P., Gore, J. C., & Anderson, A. W. (2000). Expertise for cars and birds recruits brain areas involved in face recognition. *Nature Neuroscience, 3,* 191–197. http://dx.doi.org/10.1038/72140

Gauthier, I., Tarr, M. J., Anderson, A. W., Skudlarski, P., & Gore, J. C. (1999). Activation of the middle fusiform 'face area' increases with expertise in recognizing novel objects. *Nature Neuroscience, 2,* 568–573. http://dx.doi.org/10.1038/9224

Glezer, L. S., Jiang, X., & Riesenhuber, M. (2009). Evidence for highly selective neuronal tuning to whole words in the "visual word form area." *Neuron, 62,* 199–204. http://dx.doi.org/10.1016/j.neuron.2009.03.017

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15,* 20–25. http://dx.doi.org/10.1016/0166-2236(92)90344-8

Gross, C. G., Rocha-Miranda, C. E., & Bender, D. B. (1972). Visual properties of neurons in inferotemporal cortex of the Macaque. *Journal of Neurophysiology, 35,* 96–111.

Jolicoeur, P., Gluck, M. A., & Kosslyn, S. M. (1984). Pictures and names: Making the connection. *Cognitive Psychology, 16,* 243–275. http://dx.doi.org/10.1016/0010-0285(84)90009-4

Kanwisher, N., McDermott, J., & Chun, M. M. (1997). The fusiform face area: A module in human extrastriate cortex specialized for face perception. *The Journal of Neuroscience, 17,* 4302–4311.

Kanwisher, N., Stanley, D., & Harris, A. (1999). The fusiform face area is selective for faces not animals. *Neuroreport: For Rapid Communication of Neuroscience Research, 10,* 183–187. http://dx.doi.org/10.1097/00001756-199901180-00035

Kanwisher, N., & Yovel, G. (2006). The fusiform face area: A cortical region specialized for the perception of faces. *Philosophical Transactions of the Royal Society of London Series B, Biological Sciences, 361,* 2109–2128. http://dx.doi.org/10.1098/rstb.2006.1934

Kinsbourne, M., & Warrington, E. K. (1962). A disorder of simultaneous form perception. *Brain: A Journal of Neurology, 85,* 461–486. http://dx.doi.org/10.1093/brain/85.3.461

Leff, A. P., Spitsyna, G., Plant, G. T., & Wise, R. J. (2006). Structural anatomy of pure and hemianopic alexia. *Journal of Neurology, Neurosurgery & Psychiatry, 77,* 1004–1007. http://dx.doi.org/10.1136/jnnp.2005.086983

Lefly, D. L., & Pennington, B. F. (2000). Reliability and validity of the adult reading history questionnaire. *Journal of Learning Disabilities, 33,* 286–296. http://dx.doi.org/10.1177/002221940003300306

Logothetis, N. K., & Sheinberg, D. L. (1996). Visual object recognition. *Annual Review of Neuroscience, 19,* 577–621. http://dx.doi.org/10.1146/annurev.ne.19.030196.003045

Mani, J., Diehl, B., Piao, Z., Schuele, S. S., Lapresto, E., Liu, P., . . . Lüders, H. O. (2008). Evidence for a basal temporal visual language center: Cortical stimulation producing pure alexia. *Neurology, 71,* 1621–1627. http://dx.doi.org/10.1212/01.wnl.0000334755.32850.f0

Marcel, T., Katz, L., & Smith, M. (1974). Laterality and reading proficiency. *Neuropsychologia, 12,* 131–139. http://dx.doi.org/10.1016/0028-3932(74)90034-7

McGugin, R. W., Richler, J. J., Herzmann, G., Speegle, M., & Gauthier, I. (2012). The Vanderbilt Expertise Test reveals domain-general and domain-specific sex effects in object recognition. *Vision Research, 69,* 10–22. http://dx.doi.org/10.1016/j.visres.2012.07.014

Mei, L., Xue, G., Chen, C., Xue, F., Zhang, M., & Dong, Q. (2010). The "visual word form area" is involved in successful memory encoding of both words and faces. *NeuroImage, 52,* 371–378. http://dx.doi.org/10.1016/j.neuroimage.2010.03.067

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.

Monzalvo, K., Fluss, J., Billard, C., Dehaene, S., & Dehaene-Lambertz, G. (2012). Cortical networks for vision and language in dyslexic and normal children of variable socio-economic status. *NeuroImage, 61,* 258–274. http://dx.doi.org/10.1016/j.neuroimage.2012.02.035

Murray, J. E., Yong, E., & Rhodes, G. (2000). Revisiting the perception of upside-down faces. *Psychological Science, 11,* 492–496. http://dx.doi.org/10.1111/1467-9280.00294

Nestor, A., Behrmann, M., & Plaut, D. C. (2013). The neural basis of visual word form processing: A multivariate investigation. *Cerebral Cortex, 23,* 1673–1684. http://dx.doi.org/10.1093/cercor/bhs158

Palmeri, T. J., & Gauthier, I. (2004). Visual object understanding. *Nature Reviews Neuroscience, 5,* 291–303. http://dx.doi.org/10.1038/nrn1364

Pennington, B. F., Van Orden, G. C., Smith, S. D., Green, P. A., & Haith, M. M. (1990). Phonological processing skills and deficits in adult dyslexics. *Child Development, 61,* 1753–1778. http://dx.doi.org/10.2307/1130836

Pflugshaupt, T., Gutbrod, K., Wurtz, P., von Wartburg, R., Nyffeler, T., de Haan, B., . . . Mueri, R. M. (2009). About the role of visual field defects in pure alexia. *Brain: A Journal of Neurology, 132,* 1907–1917. http://dx.doi.org/10.1093/brain/awp141

Pind, J., Magnússon, F., & Briem, S. (1991). *Íslensk orðtíðnibók* [Frequency dictionary of Icelandic]. Reykjavik, Iceland: Orðabók Háskólans.

Plaut, D. C., & Behrmann, M. (2011). Complementary neural representations for faces and words: A computational exploration. *Cognitive Neuropsychology, 28,* 251–275. http://dx.doi.org/10.1080/02643294.2011.609812

Pontius, A. A. (1976). Dyslexia and specifically distorted drawings of the face - a new subgroup with prosopagnosia-like signs. *Experientia, 32,* 1432–1435. http://dx.doi.org/10.1007/BF01937417

Pontius, A. A. (1981). Geometric figure-rotation task and face representation in dyslexia: Role of spatial relations and orientation. *Perceptual and Motor Skills, 53,* 607–614. http://dx.doi.org/10.2466/pms.1981.53.2.607

Price, C. J., & Devlin, J. T. (2003). The myth of the visual word form area. *NeuroImage, 19,* 473–481. http://dx.doi.org/10.1016/S1053-8119(03)00084-3

Reinke, K., Fernandes, M., Schwindt, G., O'Craven, K., & Grady, C. L. (2008). Functional specificity of the visual word form area: General activation for words and symbols but specific network activation for words. *Brain and Language, 104,* 180–189. http://dx.doi.org/10.1016/j.bandl.2007.04.006

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

Richler, J. J., Floyd, R. J., & Gauthier, I. (2014). The Vanderbilt holistic face processing test: A short and reliable measure of holistic face processing. *Journal of Vision, 14,* 10. http://dx.doi.org/10.1167/14.11.10

Richler, J. J., & Gauthier, I. (2014). A meta-analysis and review of holistic face processing. *Psychological Bulletin, 140,* 1281–1302. http://dx.doi.org/10.1037/a0037004

Richler, J. J., Mack, M. L., Palmeri, T. J., & Gauthier, I. (2011). Inverted faces are (eventually) processed holistically. *Vision Research, 51,* 333–342. http://dx.doi.org/10.1016/j.visres.2010.11.014

Richler, J. J., Palmeri, T. J., & Gauthier, I. (2012). Meanings, mechanisms, and measures of holistic processing. *Frontiers in Psychology, 3,* 553. http://dx.doi.org/10.3389/fpsyg.2012.00553

Rosch, E., Mervis, C. B., Gray, W., Johnson, D., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8,* 382–439. http://dx.doi.org/10.1016/0010-0285(76)90013-X

Rossion, B., Dricot, L., Devolder, A., Bodart, J. M., Crommelinck, M., De Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of Cognitive Neuroscience, 12,* 793–802. http://dx.doi.org/10.1162/089892900562606

Scapinello, K. F., & Yarmey, A. D. (1970). The role of familiarity and orientation in immediate and delayed recognition of pictorial stimuli. *Psychonomic Science, 21,* 329–330. http://dx.doi.org/10.3758/BF03335807

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

Seymour, P. H. K. (2005). Early reading development in European orthographies. In M. J. Snowling & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 296–315). Oxford, UK: Blackwell. http://dx.doi.org/10.1002/9780470757642.ch16

Shaywitz, S. E., & Shaywitz, B. A. (2005). Dyslexia (specific reading disability). *Biological Psychiatry, 57,* 1301–1309. http://dx.doi.org/10.1016/j.biopsych.2005.01.043

Sigurdardottir, H. M., & Gauthier, I. (in press). Expertise and object recognition. In A. Toga, M. Mesulam, & S. Kastner (Eds.), *Brain mapping: An encyclopedic reference*. Oxford, UK: Elsevier. http://www.elsevier.com/books/brain-mapping/toga/978-0-12-397025-1

Snowling, M. J. (2001). From language to reading and dyslexia. *Dyslexia, 7,* 37–46. http://dx.doi.org/10.1002/dys.185

Starrfelt, R., & Gerlach, C. (2007). The visual what for area: Words and pictures in the left fusiform gyrus. *NeuroImage, 35,* 334–342. http://dx.doi.org/10.1016/j.neuroimage.2006.12.003

Starrfelt, R., Habekost, T., & Gerlach, C. (2010). Visual processing in pure alexia: A case study. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior, 46,* 242–255. http://dx.doi.org/10.1016/j.cortex.2009.03.013

Szwed, M., Dehaene, S., Kleinschmidt, A., Eger, E., Valabrègue, R., Amadon, A., & Cohen, L. (2011). Specialization for written words over objects in the visual cortex. *NeuroImage, 56,* 330–344. http://dx.doi.org/10.1016/j.neuroimage.2011.01.073

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 46,* 225–245. http://dx.doi.org/10.1080/14640749308401045

Tanaka, J. W., & Sengco, J. A. (1997). Features and their configuration in face recognition. *Memory & Cognition, 25,* 583–592. http://dx.doi.org/10.3758/BF03211301

Tanaka, J. W., & Taylor, M. (1991). Object categories and expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology, 23,* 457–482. http://dx.doi.org/10.1016/0010-0285(91)90016-H

Tanaka, K., Saito, H., Fukada, Y., & Moriya, M. (1991). Coding visual images of objects in the inferotemporal cortex of the macaque monkey. *Journal of Neurophysiology, 66,* 170–189.

Tarr, M. J., & Gauthier, I. (2000). FFA: A flexible fusiform area for subordinate-level visual processing automatized by expertise. *Nature Neuroscience, 3,* 764–769. http://dx.doi.org/10.1038/77666

Ungerleider, L. G., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549–586). Cambridge, MA: MIT Press.

Van Belle, G., De Graef, P., Verfaillie, K., Rossion, B., & Lefevre, P. (2010). Face inversion impairs holistic perception: Evidence from gaze-contingent stimulation. *Journal of Vision, 10,* 1–13. http://dx.doi.org/10.1167/10.5.10

Van Doren, L., Dupont, P., De Grauwe, S., Peeters, R., & Vandenberghe, R. (2010). The amodal system for conscious word and picture identification in the absence of a semantic task. *NeuroImage, 49,* 3295–3307. http://dx.doi.org/10.1016/j.neuroimage.2009.12.005

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? *Journal of Child Psychology and Psychiatry, 45,* 2–40. http://dx.doi.org/10.1046/j.0021-9630.2003.00305.x

Ventura, P., Fernandes, T., Cohen, L., Morais, J., Kolinsky, R., & Dehaene, S. (2013). Literacy acquisition reduces the influence of automatic holistic processing of faces and houses. *Neuroscience Letters, 554,* 105–109. http://dx.doi.org/10.1016/j.neulet.2013.08.068

Vinckier, F., Dehaene, S., Jobert, A., Dubus, J. P., Sigman, M., & Cohen, L. (2007). Hierarchical coding of letter strings in the ventral streaM = Dissecting the inner organization of the visual word-form system. *Neuron, 55,* 143–156. http://dx.doi.org/10.1016/j.neuron.2007.05.031

Weekes, B. S. (1997). Differential effects of number of letters on word and nonword naming latency. *The Quarterly Journal of Experimental Psychology: Section A, 50,* 439–456. http://dx.doi.org/10.1080/713755710

Whitney, C. (2001). How the brain encodes the order of letters in a printed word: The SERIOL model and selective literature review. *Psychonomic Bulletin & Review, 8,* 221–243. http://dx.doi.org/10.3758/BF03196158

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. *Applied Psycholinguistics, 14,* 1–33. http://dx.doi.org/10.1017/S0142716400010122

Wolff, U., & Lundberg, I. (2002). The prevalence of dyslexia among art students. *Dyslexia, 8,* 34–42. http://dx.doi.org/10.1002/dys.211

Woloszyn, L., & Sheinberg, D. L. (2009). Neural dynamics in inferior temporal cortex during a visual working memory task. *The Journal of Neuroscience, 29,* 5494–5507. http://dx.doi.org/10.1523/JNEUROSCI.5785-08.2009

Wong, A. C., Bukach, C. M., Yuen, C., Yang, L., Leung, S., & Greenspon, E. (2011). Holistic processing of words modulated by reading experience. *PLoS ONE, 6,* e20753. http://dx.doi.org/10.1371/journal.pone.0020753

Yin, R. K. (1969). Looking at upside-down faces. *Journal of Experimental Psychology, 81,* 141–145. http://dx.doi.org/10.1037/h0027474

Ziegler, J. C., Bertrand, D., Tóth, D., Csépe, V., Reis, A., Faísca, L., . . . Blomert, L. (2010). Orthographic depth and its impact on universal predictors of reading: A cross-language investigation. *Psychological Science, 21,* 551–559. http://dx.doi.org/10.1177/0956797610363406

Ziegler, J. C., Perry, C., Ma-Wyatt, A., Ladner, D., & Schulte-Körne, G. (2003). Developmental dyslexia in different languages: Language-specific or universal? *Journal of Experimental Child Psychology, 86,* 169–193. http://dx.doi.org/10.1016/S0022-0965(03)00139-5

Zoccolotti, P., De Luca, M., Di Pace, E., Judica, A., Orlandi, M., & Spinelli, D. (1999). Markers of developmental surface dyslexia in a language (Italian) with high grapheme–phoneme correspondence. *Applied Psycholinguistics, 20,* 191–216. http://dx.doi.org/10.1017/S0142716499002027

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