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Own-race and other-race face recognition problems without visual expertise problems in dyslexic readers

Heida Maria Sigurdardottir

Kristjan Helgi Hjartarson

Gudbjorn Larus Gudmundsson

Árni Kristjánsson

University of Iceland

Abstract

Both intact and deficient neural processing of faces has been found in dyslexic readers. Similarly, behavioral studies have shown both normal and abnormal face processing in developmental dyslexia. We tested whether dyslexic adults are impaired in tests of own- and other-race face recognition. As both face and word recognition rely considerably on visual expertise, we wished to investigate whether face recognition problems of dyslexic readers might stem from difficulties with experience-driven expert visual processing. We utilized the finding that people tend to be worse at discriminating other-race faces compared to own-race faces, the so-called other-race effect, thought to reflect greater experience with own-race faces. If visual expertise is compromised in dyslexic readers, so that their visual system is not effectively shaped by experience, then they might show a diminished other-race effect. Matched dyslexic and typical readers completed two tests of own- and other-race face recognition. The results show that dyslexic readers have problems with recognizing faces, and these difficulties are not fully accounted for by general problems with attention or memory. However, recognition is compromised for both own- and other-race faces, and the strength of the other-race effect does not differ between dyslexic and typical readers. There was individual variability in both groups, and an exploratory analysis revealed that while dyslexic readers with no university education showed deficits in face recognition, the dyslexic participants with higher education did not. We conclude that dyslexic readers as a group have face recognition problems. These are potentially modulated by educational level but compromised visual expertise cannot demonstrably account for the face recognition problems associated with dyslexia. We discuss the implications of these findings for theoretical accounts of dyslexia and for theories of word and face recognition.

Dyslexia is a developmental disorder primarily characterized by slow and inaccurate reading, and these difficulties are not readily explained by impairments in general mental abilities, inadequate schooling, or uncorrected sensory deficits (Peterson & Pennington, 2015; Shaywitz, 1998). People with dyslexia tend to have trouble with processing and manipulating linguistic sounds, and this is commonly seen as the primary cause of their reading problems (e.g. Catts, 1989; Liberman, Shankweiler, Fischer, & Carter, 1974; Peterson & Pennington, 2015; Snowling, 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Wagner & Torgesen, 1987). Recent behavioral and neuroimaging research suggests, however, that problems with high-level visual processing may contribute to dyslexia.

Visual categorization and recognition are often considered the endpoints of processing within the ventral visual stream (Logothetis & Sheinberg, 1996; Grill-Spector & Weiner, 2014). People with dyslexia show consistent functional as well as potential structural abnormalities of certain high-level regions of the ventral visual stream and this might even predate reading acquisition (see e.g. Kronbichler & Kronbichler, 2018; Perrachione et al., 2016; Richlan, Kronbichler, & Wimmer, 2011; Van der Mark et al., 2009). These regions likely include the visual word form area (VWFA) which responds relatively selectively to visually presented words and pseudowords and plays a role in fast and accurate visual word recognition (for a review on the VWFA, see e.g. Dehaene & Cohen, 2011; for a critical approach, see Price & Devlin, 2011). Importantly, ventral visual stream regions have not only been found to be hypoactive in dyslexic readers when they visually process words but also when processing other visual stimuli, such as when naming line drawings of objects (McCrory, Mechelli, Frith, & Price, 2005), and there are reports of abnormal ventral stream processing for visual objects even under passive viewing conditions (Perrachione et al., 2016). This is consistent with the possibility of unusual or faulty object perception mechanisms in dyslexia.

However, McCrory et al. (2005) themselves attribute their results to an impairment in integrating phonology and visual information, and Perrachione et al. (2016) note that even “passive” visual processing of nameable objects could involve automatic activation of their linguistic labels. For this reason, Perrachione et al. (2016) also asked people to passively view unfamiliar – and thus presumably nonnameable – faces, and crucially found that neural processing in the ventral visual stream was abnormal in dyslexic readers when they viewed such faces. Monzalvo, Fluss, Billard, Dehaene, & Dehaene-Lambertz (2012) also reported reduced activation for unfamiliar faces in the ventral visual stream of dyslexic children, and so did Rüsseler, Ye, Gerth, Szycik, & Münte (2018) for adults with dyslexia when viewing an unfamiliar moving/speaking face. Rüsseler, Gerth, Heldmann, & Münte (2015) found decreased N170 amplitude (a face-selective EEG component) for moving/speaking faces, (Bentin, Allison, Puce, Perez, & McCarthy, 1996) whose primary source might be high-level regions of the ventral visual stream (although sources could be task-specific, see Deffke et al., 2007; Itier & Taylor, 2004), which again could indicate that dyslexic readers have problems with the structural encoding of faces. The same group (Rüsseler, Johannes, & Münte, 2003) however did not find any differences in the N170 for dyslexic and typical readers when static faces were shown (but see Collins, Dundas, Plaut, & Behrmann, 2017). There are other reports of apparently normal neural processing for faces in the ventral visual stream of dyslexic readers (Tarkiainen, Helenius, & Salmelin, 2003), leading those authors to conclude that ventral stream functional abnormalities might be largely restricted to processing letter-strings.

There are similarly inconsistent behavioral reports of face processing problems in dyslexic readers (for an extended discussion, see Sigurdardottir, Fridriksdottir, Gudjonsdottir, & Kristjánsson, 2018; for a review on the dependence or independence of face and word recognition, see Robotham & Starrfelt, 2017). Our previous studies (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015; Sigurdardottir et al., 2018) indicate that people with dyslexia find it difficult to recognize or individuate exemplars of familiar object classes such as faces, and that this cannot be fully accounted for by low-level visual deficits. This is consistent with the possibility that the reading problems of dyslexic readers might in some cases be a salient manifestation of a more general high-level visual deficit. Others have also reported unusual (Pontius, 1976; 1983; Smith-Spark & Moore, 2009) or problematic (Collins et al., 2017; Aaron, 1978; Gabay, Dundas, Plaut, & Behrmann, 2017; Tarkiainen et al., 2003) face processing in at least some dyslexic readers. Several studies, however, report no significant differences in facial processing abilities of people with and without reading problems (Brachacki, Fawcett, & Nicolson, 1994; Holmes & McKeever, 1979; Korinth, Sommer, & Breznitz, 2012; Liberman, Mann, Shankweiler, & Werfelman, 1982; Rüsseler et al., 2003).

If we accept that dyslexic readers even have problems with visually processing faces in addition to words, the question remains why this would be the case. One possibility is that dyslexic readers have particular problems with individuating visually homogeneous objects, such as faces and words, with which people have extensive prior experience. Visual experience is highly important for shaping ventral stream neural representations of words, faces, and other visual objects (Binder, Medler, Westbury, Liebenthal, & Buchanan, 2006; Dehaene & Cohen, 2011; Kourtzi & DiCarlo, 2006; McCandliss, Cohen, & Dehaene, 2003; Sigurdardottir & Gauthier, 2015). People have varying degrees of experience with recognizing or telling apart different objects at the individual level. They tend to have extensive experience with individuating faces and words (objects of expertise), some experience with individuating other object classes (e.g. bird species) and have no experience with other object classes. Sigurdardottir et al. (2015, 2018) found that dyslexic readers had problems with individuating faces and at least some other familiar objects, such as birds, butterflies, planes, cars, and/or houses. Interestingly, no detectable problems were found when exemplars of an unfamiliar object class, so-called YUFOs, had to be individuated (Sigurdardottir et al., 2018). The high-level visual problems of dyslexic readers could therefore be experience-dependent and mainly involve familiar objects.

This visual expertise account of dyslexia supposes that experience might not effectively shape the visual system of dyslexic readers. In alignment with this idea, people with dyslexia were found to be impaired at implicitly learning which simple nonsense shapes tended to co-occur (Sigurdardottir, Danielsdottir, Gudmundsdottir, Hjartarson, Thorarinsdottir, & Kristjánsson, 2017). Further support for an experience-driven deficit comes from the study of Smith-Spark & Moore (2008) who reported that while no overall differences were found between dyslexic and non-dyslexic adults in the speed or accuracy with which they named familiar faces, the non-dyslexic group was faster at naming early- compared to late-acquired faces, while the dyslexic group showed no such significant age of acquisition effect. More general impairments in learning from experience have also been reported for people with developmental dyslexia (e.g. Lum, Ullman, & Conti-Ramsden, 2013).

While experiential effects are a plausible explanation for diverging results on developmental dyslexia for the processing of familiar versus unfamiliar objects, other possibilities certainly exist. Words and faces are arguably much more complex and multidimensional than YUFOs or other artificial novel object classes, as any single letter of an individual word is shared by thousands of other candidate words, and faces differ from each other on dozens of dimensions (Valentine, Lewis, & Hills, 2016). To assess the potential role of compromised visual expertise in dyslexia, visual complexity must be constant. Luckily, there are different "categories" of faces which should be comparably complex but with which people have different experience.

People are not experts at individuating all faces to the same degree. They tend to be worse at recognizing and differentiating other-race faces compared to own-race faces, a phenomenon known as the other-race effect, in general thought to reflect greater experience with faces of one's own race (e.g. Malpass & Kravitz, 1969; Meissner & Brigham, 2001; Rhodes, Hayward, & Winkler, 2006; Lebrecht, Pierce, Tarr, & Tanaka, 2009; Lindsay, Jack, & Christian, 1991; McGugin, Tanaka, Lebrecht, Tarr, & Gauthier, 2011). While no differences are found in physiognomic variability among several races, some facial characteristics tend to distinguish particular races (Meissner & Brigham, 2001; Salah, Alyüz & Akarun, 2008) and these diagnostic features or dimensions likely need to be learned through experience. Experience with visual words (i.e. learning how to read) induces significant changes in high-level regions of the left ventral visual stream in typical readers (Dehaene & Cohen, 2011). Better recognition of own- compared to other-race faces, which is likely experience-dependent, is also associated with greater activity in high-level regions of the left ventral visual stream (Golby, Gabrieli, Chiao, & Eberhardt, 2001). These regions correspond quite well to regions consistently found to be hypoactive in dyslexic readers (Richlan et al., 2011).

The aims of the current study are two-fold. Given the mixed evidence for face recognition problems in developmental dyslexia, our first aim is to look for such a deficit, and to rule out its mediation by non-specific factors. Second, given that visual experience plays a critical role in shaping the activity of ventral stream regions hypoactive in dyslexia, and the important role of experience in bringing about the other-race effect in face recognition, we expect face recognition abilities for own-race faces but not other-race faces to be associated with dyslexia, and we expect to see a reduced or absent other-race effect in dyslexia, i.e. no better performance when recognizing/individuating own-race compared to other-race faces. This would suggest that the visual system of dyslexic readers, unlike that of typical readers, is less able to become finely tuned to processing visual features or dimensions that previously have been diagnostic for individuating exemplars of particular object classes. Such results would strongly support the role of visual experience in developmental dyslexia.

To foreshadow our results, dyslexic readers as a group do have difficulties with recognizing faces, and these problems are not fully accounted for by general problems with attention or memory. We show for the first time that face recognition and verbal short-term memory problems in dyslexia appear to be independent deficits. Not all dyslexic readers have noticeable problems with face recognition, and this deficit might be modulated by educational level. Contrary to expectations, however, face recognition problems of dyslexic readers are independent of race, as dyslexic readers are worse than typical readers at recognizing both own- and other-race faces, and the two groups thus show a comparable other-race effect. These results set important boundary conditions on hypothesized high-level visual deficits in dyslexia. High-level vision might therefore be compromised in dyslexia, but this deficit is not demonstrably experience-dependent and does not fit well with a visual expertise account of dyslexia.

Method

Participants

48 people participated (see also section Method: Data exclusion and analysis). 24 reported a previous diagnosis of dyslexia (15 women; mean age: 30.0 years, range 19-64) and 24 were self-reported typical readers (15 women; mean age: 29.2, range 18-64). Participants were recruited though various means, e.g. advertisements on social media, radio, listservs, contact with the Icelandic Dyslexia Foundation, word of mouth. Participants in the two groups were matched: for each dyslexic participant there was a typical reader of the same gender, age (±5 years), and educational background. All participants reported normal hearing and normal or corrected-to-normal vision. In each group, five people had completed the first level of schooling (compulsory education, currently 10 years of schooling completed at around age 16), 7 the second level (gymnasium, often a four-year degree completed after compulsory education), 9 the third level (college/university at the undergraduate level, often a three-year degree completed after gymnasium), and 3 had completed the fourth level (finished college/university at the graduate level). All were native Icelandic speakers. Participants were unpaid volunteers but were invited to enter a lottery where five

randomly selected participants received a gift certificate at a local shopping mall (value: 10,000 ISK, approximately $100). Furthermore, participants from the University of Iceland could receive partial course credit for participation.

Procedure

The study was approved by the National Bioethics Committee of Iceland (protocol 14-027) and reported to the Icelandic Data Protection Authority. The study took place in a quiet, well lit room. Participants gave informed consent (the consent form was read aloud to participants if needed). Reading problems were assessed by administering a questionnaire that screens for dyslexia in adults (the Adult Reading History Questionnaire, or ARHQ), and by asking people to to read aloud real words and pseudowords (IS-FORM and IS-PSEUDO tests, respectively). The Digit Span subtest of the Wechsler Adult Intelligence Scale-III was administered to measure verbal short-term memory. As ADHD is highly comorbid with dyslexia (Germanó, Gagliano, & Curatolo, 2010), two questionnaires that measure current and childhood ADHD symptoms were also administered. Participants filled out a race contact questionnaire to assess their degree of contact with individuals of European and Asian descent, and completed two tests of the other-race effect (from here on referred to as the Cambridge Face Memory Test – Caucasian/Asian, or CFMT-CA, and the Other Race Caucasian Asian Test, or ORCA).

Reading Abilities

Adult Reading History Questionnaire. The Icelandic version of the ARHQ (ARHQ-Ice; Bjornsdottir et al., 2014) consists of self-report questions on a 5-point Likert scale that assess participants' history of reading difficulties. ARHQ-Ice has 23 questions, but question 15 was excluded when calculating total scores as recommended by Bjornsdottir et al. (2014). Total scores range from zero to one; where a score of 0.43 or more is considered indicative of dyslexia. The Icelandic version has been found to be a reliable and valid screening instrument for dyslexia (Bjornsdottir et al., 2014).

IS-FORM and IS-PSEUDO reading tests. The tests were included to assess participants' current reading ability. IS-FORM consists of two lists of words (Sigurdardottir et al., 2015), the first with 128 common Icelandic word forms and the second with 128 uncommon word forms. IS-PSEUDO contains 128 pseudowords (Sigurdardottir et al., 2017). Difficulty with reading phonologically valid pseudowords is considered highly predictive of dyslexia (Shaywitz et al., 1998). Words read per minute and percentage of correctly read (pseudo)word forms are the main outcome scores.

Verbal Short-Term Memory

The Digit Span subtest of the Icelandic version of the Wechsler Adult Intelligence Scale-III was administered to measure verbal short-term memory (Líndal, Jónsdóttir, Másson, Andrason, & Skúlason, 2005; Wechsler, 1998). Participants repeated digits read aloud by the experimenter, either in the same order or backwards. The digits range from two numerals up to nine in the Digits Forward (16 items) and eight in the Digits Backward (14 items) tasks. Each number of digits is repeated twice. Standard stop criteria were used. Scores range from 0-30, with each correct item counting as one point.

ADHD Symptoms

Two self-report questionnaires evaluated the DSM-IV behavioral criteria for ADHD on a 4-point Likert scale. The first questionnaire evaluates symptoms in adulthood where the frame of reference is participants' behavior in the past six months. The second questionnaire measures childhood symptoms and concerns behaviors in the age period 5 to 12 years (Magnússon et al., 2006; Mehringer et al., 2002). The scores range from 0 to 54. A score above 25.8 on the childhood symptoms scale and a score above 32.5 for current symptoms are considered indicative of ADHD. Both questionnaires have been shown to be reliable and valid methods of screening for ADHD (Magnússon et al., 2006).

Race Contact Questionnaire

Participants´ experience with own- and other-race faces was assessed with an own- and other-race contact questionnaire inspired by those previously used by Hancock & Rhodes (2008) and Walker & Hewstone (2006). Participants were instructed to define their own race as white (of European descent), Asian (of Asian descent), or other, and to select the statements best describing themselves on self-report questions regarding contact with people of Asian (10 questions) and European (10 questions) descent. Each question was answered on a 1-5 Likert scale with answers ranging from "Applies very poorly" (1) to "Applies very well" (5). Total scores ranged from 10-50 for each of the two races, with greater scores indicating greater contact.

The questions were (in Icelandic): 1) 'I know a lot of people of Asian/European origin', 2) 'I have many friends of Asian/Caucasian origin, 3) 'I socialize a lot with people of Asian/Caucasian origin, 4) 'I often see people of Asian/Caucasian origin', 5) 'I am often a guest at the homes of people of Asian/European origin', 6) 'People of Asian/Caucasian origin often come around to my house', 7) 'I have lived in a country where the population was to a large extent of Asian/Caucasian origin, 8) 'I interact with people of Asian/European origin at school or at work', 9) 'I generally only interact with people of Asian/Caucasian origin, 10) 'I interact with people of Asian/Caucasian origin on a daily basis'.

Visual Tests of Own- and Other-Race Face Recognition

To assess the effect of experience on recognition ability, we used two tests of the other-race effect in face recognition: CFMT-CA and ORCA. Two tests were used to decrease the likelihood that results would idiosyncratically reflect the specific stimuli used or the method chosen to assess face recognition abilities. In both tests, participants listened through headphones to pre-recorded audio instructions. Participants sat without head restraints approximately 57 cm from the computer monitor. The stimuli were presented on a 21.5-inch Dell LCD monitor (60 Hz refresh rate; 1280x720 pixels) using PsychoPy (Peirce, 2007). The outcome measure was the percentage of trials on which learned own- and other-race faces were correctly identified.

CFMT-CA. CFMT-CA was an adapted and combined version of CFMT-Australian (McKone et al., 2011) and CFMT-Chinese (McKone et al., 2012), which themselves were based on the original Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006).

CFMT-CA Stimuli. We used faces from the Australian version over faces in the original CFMT as the former look more typically Northern European (McKone et al., 2011) and would therefore better match the typical appearance of the Icelandic population. McKone et al. (2011) demonstrated the validity of CFMT-Australian, and

McKone et al. (2012) found an other-race effect using the CFMT format (CFMT-original, CFMT-Chinese, CFMT-Australian). Horry, Cheong, & Brewer (2015) specifically compared the performance of people of Australian and Malaysian descent on the CFMT-Australian and CFMT-Chinese and found a robust other-race effect in both study populations.

The standard CFMT paradigm has four phases: practice, learning, novel and noise. The CFMT-CA included all but the noise stage due to unequal levels of Gaussian noise in test items across the Australian and Chinese versions, and because adding noise to the images was deemed likely to diminish the usefulness of feature-based processing of faces more than holistic or configural processing (McKone, Martini, & Nakayama, 2001), the former of which may mainly contribute to impaired face recognition in dyslexia (Sigurdardottir et al., 2015). Recent work has also indicated that a shortened CFMT without the noise stage may be equally effective for detecting face processing impairments (Corrow, Albonico, & Barton, 2018).

During practice and learning, study faces subtended roughly 5.0° in height and appeared on a 5.5° x 6.0° (w, h) black background on a white screen. During test trials, each face subtended 4.5° in height, presented on a 12.8° x 6.4° black background superimposed on a white screen. In the review part at the start of the novel phase, where all 12 target faces were shown together, each face subtended 4.5° in height and appeared on an 18.0° x 16.0° black background superimposed on a white screen.

CFMT-CA Procedure.

Practice phase. In the practice phase, participants could practice the task on cartoon faces. The practice phase was repeated until the participant got all trials correct.

Learning phase. Participants were told to learn and identify faces as during the practice phase. Twelve faces were presented, six Caucasian from CFMT-Australian and six Asian from CFMT-Chinese. The order of the faces was randomized before the experiment, and this order was then kept fixed across participants (fixed-random order) to minimize individual differences due to order, with the constraint that neither Caucasian nor Asian faces could appear more than twice in succession. Each of the 12 faces was presented three times (left profile, frontal view, right profile) for three seconds at a time (ISI 0.5 s). After the presentation from all three viewpoints, three faces were shown side by side. One was identical to one of the 12 studied faces, hereafter referred to as the target face. The other two faces were unfamiliar foils of the same race as the target face. Participants were asked to select the target face amongst the foils (3AFC) by pressing the number key (1, 2, or 3) corresponding to the number under the face they wished to choose. Faces stayed onscreen until response. The participant had to identify the target face in this way two more times, from different viewpoints, before the next target face was presented from the three viewpoints and the process repeated. The learning phase had a total of 36 (3x12) trials.

Novel phase. Participants reviewed all 12 previously learned faces, which were presented simultaneously in three rows with four columns. The review image was onscreen for 40 s, after which 60 3AFC trials followed presented in a fixed-random order. In each of these trials (5 trials for each target face), a novel image of a target face was presented among two new distractor faces, where the pose and/or lighting of the target face differed from the studied face images. As participants had never seen these images of the target faces, they had to identify the target faces across identity-preserving transformations and presumably rely on high-level visual mechanisms rather than image-specific memory.

ORCA. A second measure of the other-race effect in dyslexia, the Other Race Caucasian Asian test (ORCA) was developed for this study.

ORCA Stimuli. 240 grayscale images of Caucasian and Chinese male faces were used as stimuli (courtesy of James Tanaka, VizCogLab, University of Victoria). Male faces were chosen to avoid general gender differences in face recognition abilities, as females tend to outperform males when recognizing female faces but no gender differences are found in the ability to recognize male faces (Lewin & Herlitz, 2002). Stimuli were originally developed from photographs from the Department of Corrections' face databases from Florida, Arkansas, Georgia, and Kansas. Face images from this database have previously been used in studies on own- and other-race face processing (e.g. Roos, Lebrecht, Tanaka, & Tarr, 2013; Tanaka & Pierce, 2009). The faces were seen in frontal view through an oval window with blurred edges which restricted the view of each face from the upper forehead to the lower chin, removing all extraneous information like clothing or hair. The images were processed with the SHINE toolbox in MATLAB (Willenbockel et al., 2010) to make overall luminance similar across all images. The stimuli appeared on a black background. For a flow chart representation of the steps of the ORCA, see figure 1.

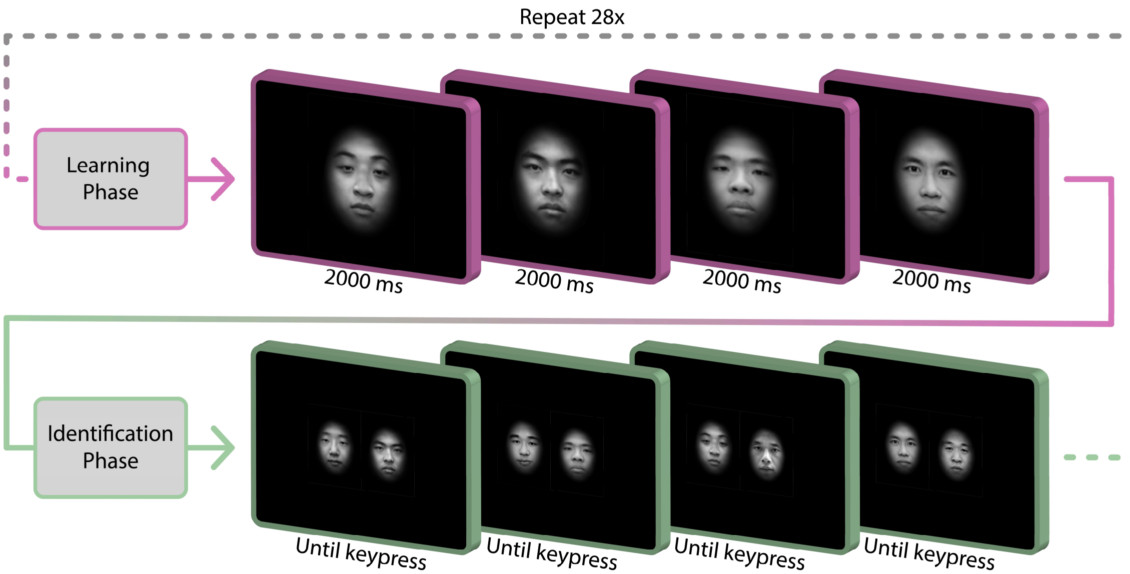

Figure 1. Other Race Caucasian Asian test (ORCA). Each block of the ORCA had a learning phase and an identification phase. In the learning phase, participants had to learn either four Caucasian faces or four Asian faces. In each of four trials of the identification phase, two faces were presented side by side, one of which was one of the four faces previously learned in that block and the other was a novel face. Participants were instructed to select the face that they had previously learned (two alternative forced choice, 2AFC). The ORCA had a total of 112 (4x28) experimental trials, of which half were for Caucasian faces and half were for Asian faces.

ORCA Procedure. The ORCA consisted of repeated cycles of learning and identification phases (figure 1). There were two such practice cycles or blocks (not analyzed), one with Caucasian and the other with Asian faces, and 28 experimental blocks, again half with Caucasian and half with Asian faces. In the learning phase, participants were instructed to learn four sequentially presented target faces (height approximately 9.0°). Each face was preceded by a 0.25 s fixation cross, presented for 2 s, followed by a 1 s blank period. This was followed by an identification phase which consisted of four two-alternative forced choice (2AFC) trials. On each trial, participants saw two faces side by side (approximately centered 3° to the left and right of center), where one was from the set of the four learned target faces (match), as well as a novel distractor face (foil). Foils were never reused as target faces. Participants were instructed to choose the match. Faces in the identification phase were half the height (approximately 4.5°) of those in the learning phase, intended to make participants rely on size-invariant identity-preserving information instead of low-level cues. Faces stayed onscreen until either the left or right arrow key was pressed to choose the corresponding face. The order of experimental blocks, the order of stimuli within blocks, and left-right locations of stimuli were randomized before testing and then kept constant across participants (fixed-random) with the constraint that neither Caucasian nor Asian face blocks could appear more than twice in succession. After every seven blocks there was a one-minute rest break. Participants completed a total of 112 2AFC experimental trials, 56 trials with Caucasian faces and 56 trials with Asian faces.

Data Exclusion and Analysis

To assess group assignment, we ran a binary logistic regression with ARHQ-Ice scores, reading speed, and reading accuracy as predictors of group membership (dyslexic reader or typical reader). The logistic regression model correctly predicted group membership in 95.7% of instances, $\chi^2(3) = 47.724$, $p < 0.001$. Two participants were incorrectly classified. One person in the typical reader group was classified as dyslexic based on slow reading speed and a history of reading problems as assessed by the ARHQ-Ice, and one person in the dyslexic reader group was classified as typical because of fast reading speed and a very low score on the ARHQ-Ice. These participants and their matched counterparts were therefore excluded from all further analyses. In addition, one dyslexic participant responded correctly on only 35% of trials on the ORCA test, well over three standard deviations below the group average and significantly below chance (one-sample binomial test, $p < 0.001$), and was excluded from all further analyses along with the matched typical reader. This left 42 people in the sample (21 dyslexic readers and 21 matched typical readers).

As dyslexic and typical readers were paired on several variables, their scores were expected to covary; thus, group will from here on be treated as a repeated factor and paired-samples t-tests and repeated measures ANOVAs will be used unless otherwise stated. Cohen's *d* (mean difference/standard deviation of difference), Pearson's *r*, and partial eta squared (η_p^2) were used to estimate effect sizes.

Results and Discussion

Reading Abilities

As ARHQ-Ice and reading tests were used to validate group membership, only descriptive statistics are reported for group differences on these reading ability measures. Dyslexic readers reported a greater history of reading problems than typical readers on the ARHQ-Ice ($d = 2.34$). On the IS-FORM, dyslexic participants read fewer common word forms per minute (*d* = 0.98) than typical readers and read fewer common word forms correctly (*d* = 0.66). The same was true for uncommon word forms (uncommon words/minute: *d* = 1.10; uncommon words accuracy: *d* = 1.00) and for pseudowords (IS-PSEUDO; pseudowords/minute: *d* = 0.85; pseudowords accuracy: *d* = 0.74). These large differences in both history of reading problems and actual reading performance strongly validate the group distinction (table 1).

Table 1.

*Descriptive statistics for measures of reading abilities, verbal short-term memory, ADHD symptoms, and own and other-race contact of typical and dyslexic readers. The symbol × indicates that statistical tests were not performed. The symbol * indicates a significant difference in group means. No symbol indicates a non-significant group difference.*

	Typical Readers		Dyslexic Readers		Cohen's d
	Mean	(S.D.)	Mean	(S.D.)	
Reading Abilities					
×ARHQ-Ice	0.27	(0.116)	0.66	(0.111)	2.34
×IS-FORM common words/minute	105	(18.0)	79	(22.8)	0.98
×IS-FORM common word accuracy (%)	99	(1.1)	95	(5.7)	0.66
×IS-FORM uncommon words/minute	77	(13.0)	53	(18.2)	1.10
×IS-FORM uncommon word accuracy (%)	98	(1.8)	87	(11.1)	1.00
×IS-PSEUDO pseudo-words/minute	56	(12.2)	39	(18.7)	0.85
×IS-PSEUDO pseudo-word accuracy (%)	93	(5.6)	80	(15.9)	0.74
Verbal Short-Term Memory					
*Digit Span Score	16.5	(3.98)	14.0	(3.40)	0.47
ADHD Symptoms					
*Childhood ADHD symptoms	11	(6.3)	27	(15.0)	1.02
Current ADHD symptoms	11	(6.6)	16	(7.8)	0.39
Race Contact Questionnaire					
Caucasian contact	49	(2.1)	49	(2.7)	0.12
Asian contact	16	(6.3)	18	(7.4)	0.11

Verbal Short-Term Memory

Dyslexic readers performed worse on the verbal short-term memory task (digit span), repeating significantly fewer digits (forwards or backwards) than typical readers ($t(20)$ = 2.429, p = 0.044, d = 0.47; table 1), consistent with other literature (e.g. Helland & Asbjørnsen, 2004; Rugel, 1974; Spring, 1976).

ADHD Symptoms

Six dyslexic participants and two typical readers reported a previous ADHD/ADD diagnosis. Dyslexic readers reported significantly greater childhood ADHD symptoms than typical readers ($t(20)$ = 4.678, p < 0.001, d = 1.02; table 1). This is generally consistent with the high reported co-morbidity of dyslexia and ADHD/ADD (from 18-42%, Germanò, Gagliano, & Curatolo, 2010). Our sample of dyslexic readers was therefore representative in this regard. The difference between the groups on current symptoms did not reach significance ($t(20)$ = 1.805, p = 0.086, d = 0.39; table 1).

Race Contact Questionnaire

All participants reported being white (of European descent), and all reported greater own-race (Caucasian) contact than other-race (Asian) contact (table 1). Both typical and dyslexic readers reported extensive own-race contact. All own-race contact scores were 40 or higher (on a scale of 10 to 50), and did not differ between the groups ($t(20)$ = 0.550, p = 0.589, d = 0.12). Both groups reported very limited other-race contact. All but one participant in each group had a score of 26 or lower for other-race contact, indicating that a large majority reported that other-race contact items applied rather poorly or very poorly to their experiences. Other-race contact scores did not differ between the groups ($t(20)$ = 0.506 , p = 0.619, d = 0.11). The difference in own- and other-race contact was very large in both groups (d > 3.78) and did not differ between the groups ($t(20)$ = 0.666, p = 0.513, d = 0.15).

Visual Tests of Own- and Other-Race Face Recognition

The performance of dyslexic and typical readers for own- and other-race faces can be seen in figure 2. Dyslexic readers tended to be worse than typical readers at recognizing both own-race (Caucasian) and other-race (Asian) faces. Furthermore, both groups did more poorly in the latter case, thus showing an other-race effect. The effect size for the other-race effect, collapsing across both face recognition tests, was very large and almost identical in both groups (typical readers: $t(20) = 6.969$, $p < 0.001$, $d = 1.52$; dyslexic readers: $t(20) = 6.935$, $p < 0.001$, $d = 1.51$). The degree of other-race experience was negatively yet not significantly correlated with the size of the other-race effect in either group (typical readers: $r(19) = -0.345$, $p = 0.125$; dyslexic readers: $r(19) = -0.254$, $p = 0.267$) or when collapsed across groups ($r(40) = -0.285$, $p = 0.067$).

We ran a three-factor repeated-measures ANOVA with the factors group (dyslexic and typical readers), test-type (CFMT-CA and ORCA) and face-race (Caucasian and Asian). There was a significant main effect of group on performance, where dyslexic readers correctly identified significantly fewer faces ($F(1,20) = 7.155$, $p = 0.015$, $\eta_p^2 = 0.263$), and a significant main effect for face-race, demonstrating a robust other-race effect ($F(1,20) = 62.912$, $p < 0.001$, $\eta_p^2 = 0.759$). There was also a significant main effect of test-type where test scores were generally higher on the CFMT-CA than on ORCA, $F(1, 20) = 12{,}680$, $p = 0.002$, $\eta_p^2 = 0.388$). There was a significant interaction between test-type and race, where the other-race effect was on average somewhat greater on the CFMT-CA than the ORCA ($F(1,20) = 6.256$, $p =0.021$, $\eta_p^2 = 0.238$). No other interactions were significant (all Fs < 0.84, all ps > 0.37). Importantly, the interaction between group and race was not significant, $F(1, 20) = 0.462$, $p = 0.504$, $\eta_p^2 = 0.023$, showing no demonstrable differences in the other-race effect between the groups. We additionally performed a standardization correction to each participant's other-race effect where his or her baseline performance was taken into account. We performed the following correction to standardize the other-race effect: [(own-race performance – other-race performance) / own-race performance]. Results were comparable to our main analysis, where no significant group differences were found in the standardized other-race effect.

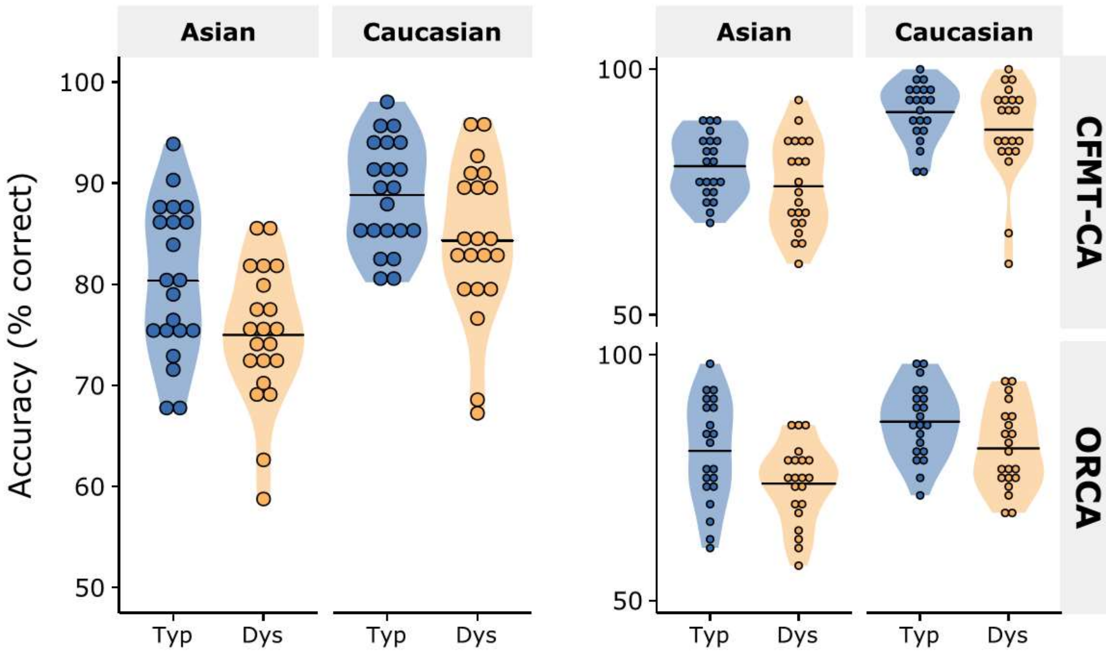

Figure 2. Recognition performance of typical (Typ, blue) and dyslexic (Dys, yellow) readers for Asian and Caucasian faces. Horizontal lines show mean accuracy levels. Violins show density estimates for face recognition accuracy. Each dot represents one observation. They are stacked in bins to form a dot plot, *Left panel:* Accuracy levels across face recognition tests. *Right panels:* Accuracy levels for the CFMT-CA (*top*) and ORCA test (*bottom*).

We had hypothesized that if visual expertise is compromised in dyslexia then the strength of the other-race effect should be diminished in dyslexic readers compared to typical readers. This was not the case, however. Both groups reported similar degrees of experience with own- vs. other-race faces and showed a very robust other-race effect, where 93% remembered more own-race than other-race faces. The strength of this effect however did not significantly differ by group on either test alone or combined. For ORCA, the average other-race effect in the two groups differed by a single percentage point, and for CFMT-CA by only half a percentage point. Across tests, the average other-race effect (accuracy for own-race minus other-race faces) was 9.3 percentage points for dyslexic readers and 8.5 percentage points for typical readers. 95% confidence intervals for group differences in the other-race effect crossed zero, spanning from 3.4 percentage points in the wrong direction (increased other-race effect for dyslexic readers) to 1.7 percentage points in the hypothesized direction (diminished other-race effect for dyslexic readers).

We conclude that it is highly unlikely that dyslexic readers have a diminished other-race effect.

Possible Mediation of General Memory Abilities and Attention. As revealed above, dyslexic and typical readers differed on measures of face recognition, verbal short-term memory, and ADHD symptoms. As general memory abilities and attention might arguably affect face recognition performance, we assessed any effects of these variables on our main results. We again ran a three-way repeated measures ANOVA on face recognition performance, with the factors group (dyslexic and typical readers), test-type (CFMT-CA and ORCA) and face-race (Caucasian and Asian). Differences between paired dyslexic and typical readers on the Digit Span subtest and the two ADHD measures were added as covariates to the model. Group was still a significant contributor to test performance, $F(1,17) = 4.721$, $p = 0.044$, $\eta_p^2 = 0.217$, where dyslexic readers tended to be worse than typical readers at recognizing faces, even when accounting for their differences in verbal short-term memory and ADHD symptoms. As before, face-race also had a significant effect on test performance, $F(1,17) = 31.485$, $p < 0.001$, $\eta_p^2 = 0.649$, demonstrating the other-race effect. No other main effects or interactions between the three factors were significant (all *F*s < 2.50, all *p*s > 0.13).

Educational Background. Over half of both dyslexic and typically reading participants held a university degree. Dyslexia can be a major hindrance for attaining higher education, and highly educated dyslexic readers might thus not be representative of dyslexic readers in general. We therefore looked at the face recognition deficits of two subsamples, those with (N = 22, 73% females; mean age 31 years) and without (N = 20, 50% females; mean age 27 years) a university degree (figure 3). These comparisons were exploratory analyses on small subgroups, and statistical tests should therefore be interpreted with great caution.

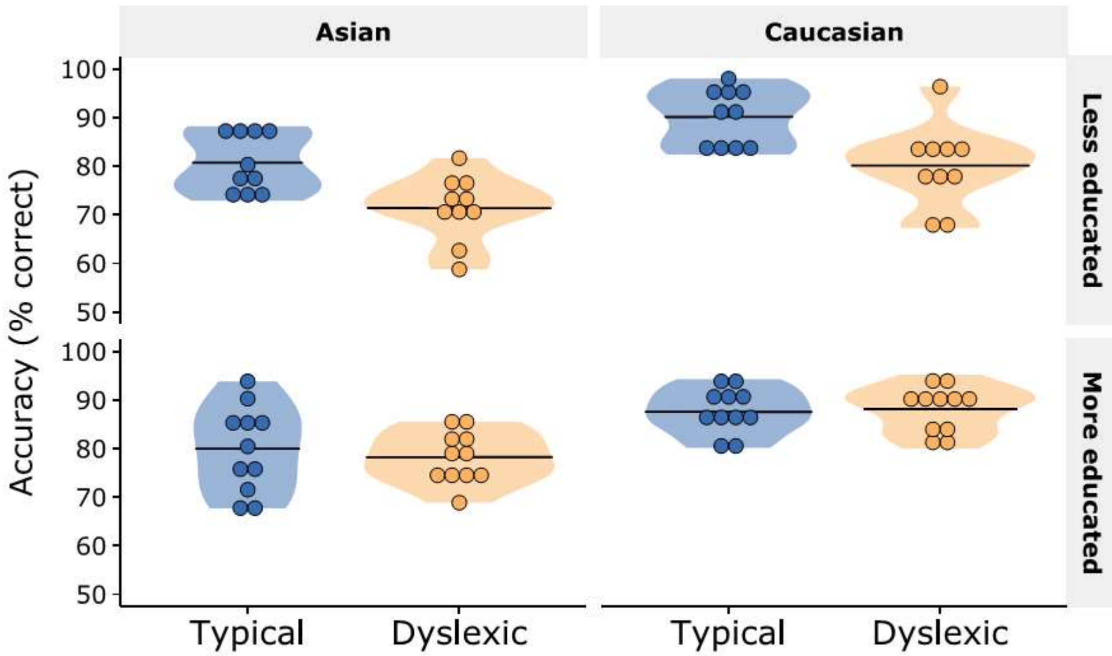

Figure 3. Recognition performance across face recognition tests of less (without a university degree) and more educated (completed a university degree) typical (blue) and dyslexic (yellow) readers for Asian and Caucasian faces. Horizontal lines show mean accuracy levels. Violins show density estimates for face recognition accuracy. Each dot represents one observation. They are stacked in bins to form a dot plot,

As shown in figure 3, less and more educated dyslexic and typical readers all showed a very similar other-race effect. However, our group effect on face recognition abilities (across tests) was solely driven by the less educated dyslexic readers. Dyslexic readers with an undergraduate or graduate degree (M = 83.2% correct) scored on average only 0.6 percentage points lower than typical readers with the same educational background (M = 83.8% correct; $t(10)$ = 0.270, p = 0.793, d = 0.08). In comparison, dyslexic readers with a high-school or gymnasium degree (M = 75.8% correct) scored on average 9.7 percentage points lower than typical readers with the same educational background (M = 85.5% correct; $t(9)$ = 4.408, p = 0.002, d = 1.39). All dyslexic participants in this less-educated group were less accurate on the face recognition tests than their matched typical readers.

Participants with a university degree were on average a bit older than those without such a degree, and the proportion of females was also higher in the former case. The mean age of the dyslexic/typical reader pair was however not significantly correlated with the typical reader advantage in face recognition ($r(19)$ = -0.348, p = 0.122), and the typical reader advantage was also not significantly different for female and male dyslexic/typical reader pairs (independent samples t-test, $t(19)$ = 0.528, p =

0.603, d = 0.25). The apparent modulation by educational level could not easily be explained by differences in age or gender proportions of the two subgroups.

While the average reading difficulties of dyslexic readers with low and high educational background were not noticeably different (mean ARHQ: 0.66 vs. 0.67; mean reading speed 58 vs. 56 words/min; mean reading accuracy: 87% vs. 87%), less educated dyslexic readers are arguably likely to be the most impaired by their reading disability. Face recognition problems were much more pronounced for this group of dyslexic readers.

To increase our sample size, we standardized (z-scored) face processing ability measures from three studies (data from upright CFMT from Sigurdardottir et al., 2015, N = 38; data from face matching experiment 2 from Sigurdardottir et al., 2018, N = 58; data from current study across tests, N = 42) and analyzed together (total N = 138) using hierarchical linear regression. Standardized scores on face processing tasks were treated as a dependent variable. Age (years), gender (0: female, 1: male), and education (1: compulsory education, 2: gymnasium, 3: college/university) were entered at stage 1 of the model. Group (0: typical reader, 1: dyslexic reader) was entered at stage 2. An interaction variable (education x group) was entered at stage 3 of the model. The model as a whole was significant at stage 1 ($F(3, 134) = 2.994$, $p = 0.033$). At this stage, gender ($b = -0.383$, $p = 0.029$) and age ($b = 0.034$, $p = 0.019$) but not education ($b = -0.138$, $p = 0.271$) were significant independent predictors of face processing, where women and older people on average performed somewhat better. Adding group at the second stage significantly improved the model (model change: $F(1,133) = 27.464$, $p < 0.001$). Adding the education x group interaction further improved the model at stage 3 (model change: $F(1,132) = 5.837$, $p = 0.017$). The full model at the final stage was: z-score = 0.313 - 0.388*gender + 0.037*age - 0.378*education - 1.723*group + 0.455*education*group. As an added caveat, however, excluding all data from the current study from the analysis gave a similar yet non-significant education x group interaction term (including current study data: $b = 0.455$, $p = 0.017$; excluding current study data: $b = 0.292$, $p = 0.218$).

Judging from the analyses above, we cautiously conclude that face processing impairments are probably more apparent in dyslexic readers of lower educational levels.

Reading Abilities vs. Face Processing Abilities

Overall face recognition accuracy (collapsed across race and test) was not significantly correlated with average reading speed ($r(40) = 0.244$, $p = 0.119$) but became significantly positively correlated when partialling out age, gender, and educational level ($r(37) = 0.325$, $p = 0.043$). Face recognition was positively yet not significantly correlated with average reading accuracy (zero-order correlation: $r(40) = 0.205$, $p = 0.193$; partial correlation: $r(37) = 0.225$, $p = 0.168$). Finally, face recognition abilities were significantly and negatively correlated with people's history of reading problems as assessed by ARHQ-Ice ($r(40) = -0.383$, $p = 0.012$), and this correlation was also significant when partialling out age, gender, and educational level ($r(37) = -0.402$, $p = 0.011$). Overall, poorer face recognition skills were associated with poorer reading abilities in our sample.

General Discussion

The aim of this study was to look for evidence for a face recognition deficit in people with developmental dyslexia and to explore whether this deficit could be due to faulty visual expertise, as evidenced by a diminished other-race effect. Face recognition problems were seen, but – contrary to our expectations – no apparent visual expertise problems were found.

We found that dyslexic readers performed more poorly than typical readers on two tests of face recognition, the CFMT-CA and ORCA. On both tests, dyslexic readers correctly identified fewer Caucasian ('own race') and Asian ('other race') faces than typical readers. We conclude that despite mixed evidence for face recognition problems in developmental dyslexia, dyslexic readers as a group have such face recognition deficits.

Facial recognition problems could not be fully explained by factors such as lapses in attention (assessed by symptoms of ADHD) or more general memory problems (assessed by verbal short-term memory) even though dyslexic readers in the current study and other previous studies also had these other problems (e.g. Germanò, Gagliano, & Curatolo, 2010; Rugel, 1974; Spring, 1976). It has been argued that verbal memory problems of dyslexic readers are due to degraded phonological representations, and digit span tests as used here are often thought to tap into phonological processing skills (e.g. Tijms, 2004; Snowling, 2001). It is therefore of some interest that digit span could not account for face recognition deficits in dyslexia. The relationship between phonological representations and visual processing in dyslexia is however not well understood at this point and needs further study.

Face recognition was impaired in dyslexic readers on a group level, but not all dyslexic readers had detectable problems with faces. The strength of the group difference in face recognition varied with educational background. Here, the difference in face processing between dyslexic and typical readers seemed to be primarily driven by those with lower educational background, whereas dyslexic readers with a university degree showed performance comparable with matched typical readers. This was an unforeseen result based on post hoc comparisons of small subgroups and should thus be interpreted with caution. Taken at face value, it does indicate that sampling dyslexic readers with a higher educational background could underestimate high-level visual deficits in dyslexia. It is tempting to speculate that those with lower education have more severe forms of dyslexia and accordingly more severe face recognition problems.

It is however also a possibility that this apparent moderation of educational level stems from differences in reading experience. Assuming that dyslexic readers with a university degree have had to do extensive reading during their studies, this experience might itself have an effect on high-level visual processing. Seen in this light, high-level visual problems might not be a causal factor in dyslexia but a secondary effect of limited reading experience. The fact that abnormalities in the ventral visual stream of dyslexic readers might be seen even before reading instruction (see e.g. review by Kronbichler & Kronbichler, 2018) does speak against this possibility, but the direction of causality should still be treated as an open question.

Both dyslexic and typical readers showed a robust other-race effect with a very large effect size. According to Meissner & Brigham (2001), the other-race effect has a weak-to-moderate effect size. However, a large majority of studies on the other-race effect are conducted in multiracial societies where the effect might on average be smaller than when measured in homogeneous racial societies such as those of Western Europe (Rossion & Michel, 2011). The population of Iceland is predominantly Caucasian, and even more homogeneous than most other European populations

(Helgason, Nicholson, Stefansson, & Donnelly, 2003), and accordingly both dyslexic and typical readers reported extensive Caucasian contact and very limited Asian contact.

The degree of other-race experience was nonetheless not significantly correlated with the size of the other-race effect in either group. While seemingly counterintuitive, this does not go against the role of experience in the other-race effect. A relative lack of items on our race contact questionnaire that specifically tap into individuating experience could partly explain the lack of association (Walker & Hewstone, 2006), but a more likely explanation is that low correlations between other-race experience and the other-race effect are due to a restricted range of both variables. The uniformly limited experience with other-race compared to own-race faces should lead to a uniformly large other-race effect without much true individual variability – unless this large difference in experience with faces of different races would not be able to effectively shape the visual system of some people. As previously stated, this appears not to be the case.

Contrary to expectations, our results did not show a reduced or absent other-race effect in dyslexic readers. This does not fit well with the idea that visual expertise is compromised in dyslexia or that visual experience, generally thought to underlie the other-race effect, is inefficient in shaping the visual system of dyslexic readers. What mechanism, then, might underlie the apparent ventral visual stream dysfunction and the face processing problems seen in dyslexia? The fact that dyslexic readers have some problems with recognizing faces regardless of race, yet show a normal other-race effect, might provide some clues. While feature- or part-based, configural, and holistic processing might all be better for own compared to other-race faces (Rhodes et al., 2006), the other-race effect – and visual expertise in general – has often been claimed to be primarily driven by differences in configural or holistic processing (Hancock & Rhodes, 2008; Michel, Caldara, & Rossion, 2006; Michel, Rossion, Han, Chung, & Caldara, 2006; Rhodes, Brake, Taylor, & Tan, 1989; Tanaka, Kiefer, & Bukach, 2004). Holistic processing appears to be intact in dyslexia (Sigurdardottir et al., 2015), as is the other-race effect. If the other-race effect is indeed driven by holistic processing, then dyslexic readers' intact holistic processing of faces might be the reason for their typical other-race effect. Their recognition problems of both own- and other-race faces might instead lie in a process more common to both, namely part-based processing.

Part-based and holistic processing could provide differentiable routes to recognition, and although the different routes might contribute to normal reading to a degree, recognition by parts appears to be of great importance (Farah, 2004; Pelli & Tillman, 2007; Peterson & Rhodes, 2003; Wong et al., 2011). Ventral stream regions most consistently found to be hypoactive in dyslexic readers are in the left hemisphere (Richlan, Kronbichler, & Wimmer, 2011), and these left hemispheric regions might be relatively more involved in the part- or feature-based processing of faces while the corresponding right hemisphere regions are more involved in processing whole faces (Rossion, 2000). Based on the currently available data, we suggest that a problem with part-based processing is the most viable explanation for the apparent high-level visual deficit of dyslexic readers.

If this is true, then problems with face recognition found for dyslexic readers in controlled laboratory conditions – while theoretically important – might not necessarily generalize to real-life situations. As countless studies have shown that holistic processing plays a crucial role in face recognition, this supposedly intact route might for the most part suffice for dyslexic readers to recognize other people in everyday situations without noticeable problems. Future studies might want to investigate this by asking people with dyslexia about their general face recognition abilities with the aid of validated questionnaires such as the 20-item prosopagnosia index (PI20; Shah, Gaule, Sowden, Bird, & Cook, 2015).

We have focused on pinning down the causes of dyslexia, a topic debated for decades (Vellutino, Fletcher, Snowling, & Scanlon, 2004). There is however an orthogonal ongoing debate on the domain specificity or generality of word and face processing (e.g. Behrmann & Plaut, 2013; Burns et al., 2017; Farah, 2004; Gabay et al., 2017; Hills, Pancaroglu, Duchaine, & Barton, 2015; Plaut & Behrmann, 2013; Roberts et al., 2015; Rubino, Corrow, Corrow, Duchaine, & Barton, 2016; Susilo & Duchaine, 2013; Susilo, Wright, Tree, & Duchaine, 2015; Robotham & Starrfelt, 2017). The traditional view is that visual word and face processing are supported by independent and separable mechanisms and brain regions; word and face processing are thought to dissociate, where one can be selectively impaired while the other is intact (Robotham & Starrfelt, 2017). According to the many-to-many view, in contrast, the same distributed neural networks, with differential hemispheric weighting, may be engaged in both face and word processing (Behrmann & Plaut, 2013; Plaut & Behrmann, 2013).

Plaut and Behrmann (2013) explicitly clarify their view where they claim not to imply that word and face processing deficits always co-occur, but instead that "patients with severe face or word impairments will, as a population, tend to be more moderately impaired in the other domain, as well." In general agreement, the current results show that on a group level, people with severe word impairments tend to have moderate face impairments. However, Plaut and Behrmann (2011) emphasize the importance of expertise in shaping the function and cortical organization of word and face processing. In alignment with our initial hypothesis, they (Gabay et al., 2017) explicitly suggest that word and face processing problems in dyslexic readers can be accounted for by difficulties in learning or gaining perceptual expertise, making the apparent lack of a modulatory role of visual expertise in the current study surprising. What complicates the picture even further is that word and face processing sometimes do seem to dissociate, as there are dyslexic readers whose face recognition appears to be perfectly fine. This however does not by necessity contradict the many-to-many view, as this view only concerns the interdependence of *visual* word and face processing mechanisms. While definitions vary, dyslexia is in essence just a label for severe reading problems that cannot be traced back to obvious causes such as poor eyesight, intellectual disability, or a lack of instruction. There is nothing in the description that implies that dyslexia has anything to do with the *visual* processing of words, and indeed the prevailing view is that it does not (Vellutino, Fletcher, Snowling, & Scanlon, 2004). At least some dyslexic readers in our sample might therefore have reading problems caused by non-visual factors, and neither the many-to-many view nor the more traditional view would predict that such dyslexic readers would have any face processing problems. There might be cases of "pure" visual dyslexia, without any face processing deficits, but we cannot claim to have found such cases based on the current results alone.

We should note, however, that two of our previous results might be hard to reconcile with either view. While the computational model of Plaut and Behrmann (2011) would seemingly predict a special link between word and face processing in dyslexic readers, over and above that of other objects such as houses, we have found evidence for recognition deficits in dyslexic readers for faces and non-face objects, including houses (Sigurdardottir et al., 2015). However, we have also found evidence supporting that face discrimination deficits predict dyslexia over and above problems with the discrimination of novel objects (Sigurdardottir et al., 2018). The fact that severe reading problems appear to be more associated with face perception problems than with the perception of a non-face object class is contrary to the strong position that faces are special. The results of Sigurdardottir et al. (2018) also appear to be inconsistent with an important meta-analysis by Farah (1991) where she found no clear cases of patients with prosopagnosia and alexia without object agnosia. We certainly think that these seeming contradictions are interesting, but some apparent contradictory results might nonetheless turn out to be compatible. For example, Farah (1991) interprets her results in favor of two recognition systems, one based on the representation of complex parts and another based on the representation of numerous parts, while the novel objects used in Sigurdardottir et al. (2018) are arguably neither particularly complex not contain numerous parts so they might not tap into either of these supposed systems. We also in general encourage readers to interpret all results – including our own – with some caution until successfully replicated.

The current results, however, have convinced us (and perhaps the reader) that face and word recognition deficits do sometimes go together, and they do not appear to be completely independent. We explicitly want to make the point that problems with high-level visual functioning likely do play a role in some cases of dyslexia, and that their problems, while often thought to be word-specific, can generalize to the processing of other visual objects such as faces. We predict that a group of dyslexic readers tends to consist of a) people with no object perception problems (e.g. phonological impairments, attentional impairments), b) people whose visual problems are mostly noticeable for word recognition due to milder impairments in a visual process crucially important for words and somewhat useful for other objects, and c) people with more severe problems with this same process, leading to reading problems as well as problems with other object recognition tasks where this process is useful. While other options are possible, part-based processing is a likely candidate. We therefore predict a dissociation between word and face processing in cases where the face task can be effectively solved with holistic processing alone, but we expect them to be associated when this strategy is suboptimal, and the task can most effectively be solved by additionally relying on the part-based processing of faces.

Conclusions

According to the high-level visual dysfunction hypothesis, dyslexia may in part stem from problems with high-level visual processing. Studies demonstrating consistent hypoactivity in dyslexia in the left ventral visual stream and problems on behavioral tasks thought to depend on these brain regions support this. The current results show that, on a group level, dyslexic readers are impaired in tests of face recognition, consistent with the high-level visual dysfunction hypothesis. Recognition problems were not accounted for by general problems with attention or verbal short-term memory but could be modulated by educational level as the group effect was driven by impairments in participants with lower education. Contrary to a visual expertise account of dyslexia, face recognition problems were not demonstrably experience-dependent, as they were found to an equal degree for both own-race faces (great experience) and other-race faces (little experience). The current study sets important boundary conditions for any hypothesized high-level visual deficit and prompts investigation of the role of a specific part-based processing deficit in dyslexia.

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