The object of my recognition:
The role of high-level vision in reading of 4th graders

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Lokaverkefni til MS gráðu í klínískri sálfræði
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Abstract

Impairments in visual recognition have been detected in adult dyslexic readers, and high-level visual regions appear to be hypoactive. Configural processes seem to be intact but featural processes impaired. The focus has mostly been on adults where vast differences in reading experience could influence the results. The object of this study was to establish whether there is a correlation between fourth graders’ performance on configural and featural visual processing tasks and their reading scores. We predicted that there would be a positive correlation between these measures, especially in the case of featural visual processing and reading ability. 20 children in the 4th grade took part in this study (10 girls and 10 boys), out of which four were excluded from analysis as they opted to quit during the visual task, were non-native Icelandic speakers, or had an autism spectrum disorder diagnosis which could be independently associated with face processing problems. Reading ability was estimated by two word lists, IS-FORM (common and uncommon words) and IS-PSEUDO (pseudowords). Visual recognition task was presented in a computer game and ADHD symptoms screened with the SWAN rating scale. The results do not provide strong support for the role of high-level visual processes in reading abilities, but ADHD symptoms explain almost half of its variation. Due to a small sample results must be interpreted with caution.
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Dyslexia is categorised as a developmental disorder with characteristics that include difficulties with accurate and/or fluent reading, as well as writing and spelling. These deficits cannot be explained by lack of education, impaired intelligence, uncorrected vision or auditory senses or other critical neurological problems (Peterson & Pennington, 2015; Schulte-Körne & Bruder, 2010; Shaywitz & Shaywitz, 2005). According to a report made by the Ministry of Education in Iceland (Menntamálaráðuneyti, 2007) based on the result of the OECD Pisa report, the prevalence of severe reading problems among 15-year-olds in Iceland is 4%, and another 10% are at a disadvantage. Dyslexia is therefore a common developmental disorder which can have a large impact on many areas of daily life.

The cause of dyslexia has been debated for a long time. Probably one of the most accepted theories of dyslexia focuses on phonological processing deficit as the central cause (Snowling, 2001; Vellutino, Fletcher, Snowling, & Scanlon, 2004). According to the phonological processing theory of dyslexia, the prerequisite for accurate and fluent word recognition and reading is the ability to attend to and manipulate linguistic sounds, which, in turn, is vital to be able to establish and automatize letter-sound correspondences (Peterson & Pennington, 2015). However, evidence has emerged that partly contradicts this theory. First, many adult dyslexic readers perform adequately on phonological tasks (Ramus & Szenkovits, 2008; Dickie, Ota, & Clark, 2013; Vellutino, Fletcher, Snowling, & Scanlon, 2004) and, second, neuroimaging results point toward phonological representations among some dyslexic readers being intact (Boets, et al., 2013). It is likely, therefore, that dyslexia, like many other developmental disorders, is a multifaceted problem with a variety of causes.

A growing number of researchers have highlighted the role of visual processing in reading difficulties (e.g. Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015). Some of these theories, however, focus mostly on adults, which may be problematic as reading experience often differs between typical readers and dyslexic readers and reading experience
has been shown to affect visual processing (Sigurdardottir & Jozranjbar, 2019; Dundas, Plaut, & Behrmann, 2013; Pinel, et al., 2014). In such cases, therefore, it may be difficult to exclude the confounding effects of reading experience. The current study attempts to address this issue by exploring the relationship between high-level visual processing skills and the reading ability of young readers in the fourth grade. Whether the results will follow the same trends as in research with adults is not known and further possible similarities as well as differences are discussed below.

**Visual theories of Dyslexia**

As outlined above, there has been an increased emphasis on visual theories of dyslexia. These theories have commonly proposed a visual deficit brought about by an impairment in the magnocellular-dorsal visual pathway (see e.g. Gori & Facoetti, 2014; for critical approach, see e.g. Amitay, Ben-Yehudah, Banai, & Ahissar, 2002). This impairment is thought to occur anywhere between the retina and posterior parietal cortex (Boden & Giaschi, 2007). Related hypotheses have focused on the possible problematic nature of visual attention in dyslexic readers. Those problems, originating from deficiencies in the fronto-parietal attention network, encompass, among others, automatic orienting of attention and problems with sustained attention (Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Sigurdardottir, Danielsdottir, Gudmundsdottir, Hjartarson, Thorarinsdottir, & Kristjansson, 2017). Although this line of enquiry is not undisputed (Goswami, 2015), it has highlighted the visual nature of reading and the possibility that a disruption in the human visual system could impact reading.

**The high-level visual dysfunction hypothesis**

According to the high-level visual dysfunction hypothesis (Sigurdardottir et al., 2015, 2017, 2018, 2019), dyslexia may be caused in part by problems with high-level visual
processing. High level vision primarily deals with the interpretation and use of information rather than recovery of physical properties. It involves extraction of shape properties and spatial relations, as well as object recognition and classification (Ullman, 2000). Visual categorisation and recognition are often considered the endpoint of processing within the ventral visual stream (Logothetis & Sheinberg, 1996; Grill-Spector & Weiner, 2014). These processes are essential to reading because they are necessary for object recognition and reading involves recognising letters (objects) and combining them into a word or sentence. The left hemisphere seems to be highly important in the visual processing of letters (Dundas, Plaut & Behrmann, 2013) Dysfunction of the left ventral-visual stream would consequently cause problems with reading (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015; Sigurdardottir, Danielsdottir, Gudmundsdottir, Hjartarson, Thorarinsdottir, & Kristjansson, 2017).

Support for this hypothesis comes from experimental investigations demonstrating brain regions specialised in face and word recognition that are activated during reading and the recognition of faces and/or objects (Behrmann & Plaut, 2012; Behrmann & Plaut, 2013; Cohen, 2000). Furthermore, people with damage to the ventral inferior temporal cortex have difficulty recognising objects or letters. For example, Asperud, Kühn, Gerlach, Delfi and Starrfelt (2019) found that patients with such damage in either left or right hemisphere had difficulties with word and face recognition. This result is in general alignment with the high-level visual dysfunction hypothesis which supposes that problems with visual word recognition would go together with problems with recognising other complex objects by sight. In another study, Dundas, Plaut and Behrmann (2013) presented children, young adolescents and adults with a discrimination task. Adults showed expected pre-eminence regarding hemispheric selectivity; however, young adolescents and children only showed right hemispheric selectivity for words but not in the left for faces. These results indicate that areas
in the right ventral inferior temporal cortex shows greater selectivity for faces, but the left ventral inferior temporal cortex greater selectivity for words. Moreover, the emergence of face lateralisation was correlated with reading competence, after controlling for the influence of other possible variables such as age, quantitative reasoning scores, and face discrimination accuracy (Dundas, Plaut, & Behrmann, 2013). These and other results discussed above are in line with the “many-to-many” hypothesis (Behrmann & Plaut, 2012; Behrmann & Plaut, 2013) which proposes a common network facilitating the recognition of faces and words. All in all, therefore, there seems to be a valid foundation for further venture into the role of brain regions’ involvement in face and object (including words) recognition. For example, reading evokes a strong activation in the left fusiform gyrus, particularly in the “visual word form area” (VWFA) (Dehaene & Cohen, 2011) despite the fact that written language is, in an evolutionary sense, a reasonably recent accomplishment for the human race (roughly 5000 years ago). It is, therefore, unlikely that written language has had an impact on our brain development. This means that reading must rely on pre-existing neural systems for vision and language which may, therefore, be recycled for its current use (Dehaene & Cohen, 2007).

This neuronal recycling hypothesis states that it is possible for neural circuitry to be converted to a different function, in response to new cultural objects. The cortical region in question is then being used for a different purpose than it had evolved to. As the original function is never entirely erased it may constrain those newer functions (Ventura, 2014). Recent fMRI studies have supported this claim. For example, cortical responses to faces in adults decrease in the left fusiform area (FFA) with increased literacy, while increasing in the right FFA (Dehaene, et al., 2010). Conversely, cortical responses to written words in children with normal reading skills seem to be lateralized to the left, while responses to faces show stronger right lateralisation (Monzalvo, Fluss, Billard, Dehaene, & Dehaene-Lambertz, 2012).

Furthermore, importantly for the current study, reading experience hinders the representation
of faces and objects from expanding into the cortex around the VWFA (Dehaene, et al., 2010). It seems that there is ample evidence that stimulus categories, such as faces and words, compete for cortical regions and the hemispheric lateralisation develops at the time of this competition. In other words, lateralisation for faces seems to emerge as reading competence increases (Dundas, Plaut, & Behrmann, 2013; Pinel, et al., 2014; Dehaene, et al., 2010; Cantlon, Pinel, Dehaene, & Pelphrey, 2010) and could be facilitated by the combination of predefined hemispheric biases and visual experience (Sigurdardottir & Jozranjbar, 2019).

**Configural vs featural processing**

In alignment with the high-level visual dysfunction hypothesis, adults with dyslexia show impairment in their recognition of faces and other visually complex objects. However, their holistic processing of faces appears to be intact, suggesting that dyslexics may instead be specifically impaired at feature processing of visual objects (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015). In terms of visual processing, reading has been categorised as a featural process (recognition of individual features e.g. nose) (Pelli & Tillman, 2007; Wong, Bukach, Yuen, Yang, Leung, & Greenspon, 2011) while facial recognition has been categorized primarily as a holistic or configural one (Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Michel, Rossion, Han, Chung, & Caldara, 2006). This separation might be a simplification because it is likely that neither process is solely holistic nor featural (DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012; Collishaw & Hole, 2000; Rhodes, Brake, & Atkinson, 1993; Sergent, 1984). The visual recognition of other object categories is generally thought to rely somewhat on both types of processing. Configural processing can be divided into three types; sensitivity to first-order relations (two eyes above a nose, which is above a mouth), holistic processing (gluing together those features into a gestalt) and sensitivity to second-order relations (perceiving the distance between those features) (Maurer, Le Grand, & Mondloch, 2002).
The general idea is that the right hemisphere is more involved in holistic or configural processing and the left with featural, part-based processing (Rossion, et al., 2000). In dyslexic readers, ventral stream regions have been found to be hypoactive in the left hemisphere (Richlan, Kronbichler, & Wimmer, 2011) which is in alignment with the left hemisphere being more involved with feature-based processing. Problems in the left ventral visual stream would then explain problems with reading in accordance with the apparent high-level visual deficit of dyslexic readers. Furthermore, it could explain why the problem dyslexic readers have with facial recognition is not necessarily apparent in daily life. Many studies have found that holistic or configural processing is vital for facial recognition and this process seems to be intact in dyslexics (Sigurdardottir, Hjartarson, Gudmundsson, & Kristjánsson, 2019). It is essential to note, however, that the term holistic processing has many meanings and is often used interchangeably without proper distinction (for further discussion see (Richler, Palmeri & Gauthier, 2012)). In this study, the focus is on second-order configural processing (i.e. the spacing among features) as well as featural processing (recognition of individual features e.g. eyes, nose, hair) and whether these processes are associated with reading fluency.

**Development of visual processes**

As outlined above, configural and featural processes seem to play a part in facial and object recognition, as well as in reading. In regard to visual recognition, all processes are not created equal. Some are present almost from birth while others take longer to form. A lot of research in this regard has focused on facial recognition and this research is useful to gauge the development of featural and configural processes. Infants show differentiation of some emotional expressions (Barrera & Maurer, 1981; Young-Browne, Rosenfeld, & Horowitz, 1977), discrimination of the direction of eye gaze (Hains & Muir, 1996; Hood, Willen, & Driver, 1998; Vecera, & Johnson, 1995), formation of a mental prototype of a group of faces (de Haan, Johnson, Maurer, & Perrett, 2001) and recognition of a person’s face posing with
different head orientations (Pascalis, De Haan, Nelson, & De Schonen, 1998). Infants are also drawn toward face-like patterns rather than other stimuli (Johnson, Dziurawiec, Ellis, & Morton, 1991; Mondloch, et al., 1999), suggesting that first order configural processing, in some form, is inherent in us. At the age of seven months, children show what is perhaps the earliest sign of configural (holistic) processing, namely they start processing the relationship among the features of the face and combining them into a gestalt (Carey & Diamond, 1994).

Even though early signs of configural processing can be found, it takes quite a long time to fully develop. Between the ages of seven and eleven, face recognition ability increases immensely, but adolescents still make more errors than adults at 14 years of age (Bruce, Campbell, Doherty-Sneddon, Langton, McAuley, & Wright, 2000). When adults observe first-order relations, they tend to treat it as a gestalt which in turn impairs their ability to tend to individual features and ignoring the whole. Their performance improves when the stimuli is manipulated in a way that disrupts the configural processing (Young, Hellawell, & Hay, 1987; Hole, 1994; Carey & Diamond, 1994; Hole, George, & Dunsmore, 1999). This indicates that when upright faces are processed the internal features are highly integrated, so much so that it remains challenging to pry them apart into isolated features (Hole, 1994). Conversely, words are made up of letters which seem to be processed independently or more accurately on a feature basis (Pelli & Tillman, 2007). Another indication of configural processing is that adult participants are about 10% more accurate when asked to recognise facial features when they are presented in the context of a whole face rather than in isolation (Tanaka & Sengco, 1997; Tanaka & Farah, 1993). The same results have been reported for 6-year-olds (Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). This supports earlier findings that configural processing is, to some extent, present by the age of six (Mondloch, Le Grand, & Maurer, 2002) although it seems a lot less developed than in adults and only gradually gets more precise. For example, research indicates that four to seven year old children perform poorly,
although better than chance, when they have to discriminate between faces where the
distractors differ only in the spacing between features (Freire & Lee, 2001), and six-year-olds
perform similarly poorly when matching faces that differ in clothing, point of view or lighting
(Carey, Diamond, & Woods, 1980).

The research reviewed above indicates that, although configural processing seems to
be present at an early age, children place less reliance on configural processing and more on
featural processing than adults. They also rely more on external features (e.g. hair, hats,
lighting) at least up until the age of seven, conversely, adults rely on internal features (e.g.
nose, mouth) (Ellis, 1992). Between the ages of nine and eleven, however, children begin to
show an adult-like pattern of featural processing (Campbell & Tuck, 1995; Campbell, Walker,
& Baron-Cohen, 1995; Mondloch, Le Grand, & Maurer, 2002). Participants in the current
study turn ten at the year of testing and their processes are still developing, according to the
research above, this might affect our results in unforeseen ways.

Dyslexic adults show evidence of problems with face and object recognition, but their
configural processing of faces appears to be intact (Sigurdardottir, Ívarsson, Kristinsdóttir, &
Kristjánsson, 2015). This coincides with the idea that configural processing seems to be
lateralized in the right hemisphere (Rossion, et al., 2000) which is also more active during
facial recognition, compared to words (Dundas, Plaut, & Behrmann, 2013). The left
hemisphere, which is hypoactive in dyslexics (McCrorry, Mechelli, Frith, & Price, 2004),
shows more activation for words than faces (Dundas, Plaut, & Behrmann, 2013) and is also
more active during featural processing (Rossion, et al., 2000). These results suggest that
dyslexic readers might be impaired at the featural processing of words, faces and other objects
(Richlan, Kronbichler, & Wimmer, 2011).
**The current study**

Empirical evidence suggests that dyslexic adults have face and object recognition problems, which in turn could stem from functional abnormalities in the ventral visual stream. Adults with reading difficulties, however, tend to have less experience with reading than adults without reading problems. Therefore, given that reading experience shapes the visual system, it can be difficult to assess whether object and face recognition problems are a cause or an effect of reading difficulties (Sigurdardottir & Jozranjbar, 2019; Dundas, Plaut, & Behrmann, 2013; Pinel, et al., 2014). The aim of the current study was to explore the relation between high-level visual processing and reading ability among young readers in 4th grade, thus minimizing the effect of differences in reading experience. In addition, we will control for the possible mediating effects of ADHD symptoms, as they have a high comorbidity with reading difficulties, namely approximately 18-45% of children with ADHD also fulfill the clinical definition of reading difficulties (Gayán, et al., 2005; Langberg, Vaughn, Brinkman, Froehlich, & Epstein, 2010). The main question was concerned with whether their reading skills could be explained by their performance on a recognition test of faces and houses, at either second order configurational level, or featural level. The following research question guided our study:

Is there a correlation between fourth graders’ performance on the configural and featural visual processing tasks and their reading scores? In light of prior research on dyslexic adults (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015) we predicted that there would be a positive correlation between these measures, especially in the case of featural visual processing and reading ability.
Method

Participants

Participants in this study were 4th graders in one school in Reykjavík. Parents or guardians of all 4th grade children in the school were contacted, with 20 providing their informed written consent for the participation of their child. The children all turn ten in 2019. Four were excluded from analysis as they opted to quit during the visual task, were non-native Icelandic speakers, or had an autism spectrum disorder diagnosis which could be independently associated with face processing problems. Their scores in the visual task were therefore not included in our analyses. One participant did not have Icelandic as a native language and consequently the participant’s reading scores were not included. All in all, 19 participants contributed data in one form or another.

Test materials and procedure

The University of Iceland Science Review Board gave their permission for the project. The Icelandic Data Protection Authority ruled that due to our study being based on a comprehensive informed consent the were not required to address this study specifically, they did however advise us on our wording of said consent. The Department of Education and Youth in Reykjavík also gave its permission for conducting the study in the selected school. The school in question was then contacted and information letters describing the study, along with a written consent form, were sent to the guardians of participating children. To enable us to control for the children’s attention and behavioral control, guardians were asked to answer a rating scale assessing ADHD symptoms of their children (the Strengths and Weaknesses of ADHD Symptoms and Normal Behavior rating scale, or SWAN, see below), as well as to answer background questions. The background questions were as follows;

1. What best describes your child’s gender?
2. Is your child's native language Icelandic?
3. Does your child have a normal or correct vision?
4. How many minutes does your child read on average per day? (This refers to reading outside school hours)

5. How much do you agree or disagree with the following statement: My child is very interested in reading (5 point Likert scale)

6. Has your child been diagnosed with: Dyslexia? Attention deficit and / or hyperactivity disorder (ADD or ADHD)? or Autism disorder (such as autism or Asperger syndrome)?

The participating children were taken out of class for the duration of the tests. The testing was conducted in a quiet, well-lit room in the school with which the students were familiar. The testing procedure was explained to the participants along with their right to withdraw from the session at any time. Each child was taken out of class for the duration of the tests, which took no longer than half an hour. First the children were asked to read the three word lists and then to move in front of a computer for the visual recognition task.

ADHD symptoms: The SWAN rating scale

The SWAN rating scale is intended to measure dimensions of ADHD in the normal population (Swanson et al., 2012). This scale has, therefore, greater variation than most other screening instruments aimed to identify children with ADHD, making it appropriate for control purposes. The SWAN is comprised of 18 assertions based on the diagnostic criteria for the disorder in accordance with Diagnostic and Statistical Manual V (DSMV). Guardians are asked to respond to each of these assertions based on their children’s behaviour for the past six months (Hay, Bennett, Levy, Sergeant & Swanson, 2007; Swanson et. al., 2012). Unlike most other ADHD rating scales, the SWAN rating scale is designed to assess both strength and weaknesses, with assertions being positively framed (e.g. gives close attention to detail and avoids careless mistakes). Prior research has demonstrated good reliability and
The scale was translated into Icelandic by three experts in the field. This will be the first time it is used in Icelandic.

**Reading skills**

The children’s reading skills were assessed by asking them to read two reading tests containing real words (IS-FORM) and pseudowords (IS-PSEUDO) out loud. The children were asked to read out loud as many words as they could in one minute, but still take care to read each word correctly. The IS-FORM consists of two word lists (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015). The first contained 128 common Icelandic word forms and the second 128 uncommon word forms. The IS-PSEUDO is comprised of 128 pseudowords (Sigurdardottir Danielsdottir, Gudmundsdottir, Hjartarson, Thorarinsdottir, & Kristjansson, 2017). This test was included as difficulty with reading phonologically valid pseudowords has been shown to be highly predictive of dyslexia among English speaking children (Shaywitz et al., 1998). Outcome scores were the total number of correctly read words per minute, with a higher score indicating better reading skills. These lists have been used before in research on adult dyslexic readers and they are made to encompass a wide dimension of reading abilities. Because they are word lists the readers cannot use context to guess the word endings and should therefore increase errors for letter-by-letter readers. We also pertained permission to connect these results to a standardized reading exam administered by the Directorate of Education in Iceland.

**Assessments of visual processing**

Participants were asked to sit approximately 57 cm away from a computer screen (although movement while completing the game was not controlled). They were then asked to
participate in a visual recognition test in the form of a video game designed by Heida Maria Sigurdardottir.

The game was designed to engage the children and provide rest between blocks of the visual task. In the game, all participants received the same standardised instructions. The game was simple storytelling where the participants first chose a character and then touched a gemstone. Touching the gemstone caused their avatar to shrink. They then met a witch that explained that she could help them become big again but, in order for that to happen, they needed to chase an insect and recover a key to a chest. To chase the insect the children had to intermittently complete tasks (visual recognition test) to gain mental power in order to catch the insect. Once they had retrieved the key and returned to the witch, they grew big again and the game was completed. While the witch (narrator) is explaining the game and intermittent tasks, practise trials with simple visual forms were built in, to teach participants how to complete the eventual visual recognition tasks. Those tasks were comprised of the visual recognition test in question. There were six blocks of visual tasks, after each the children were asked to press a key when they were ready to continue. The performance, i.e. speed and accuracy, did not affect the progress of the game but the children were encouraged to do their best.
The visual recognition test itself is comprised of visual stimuli in the form of faces or houses. Dr. Jane E. Joseph provided the stimuli (Collins, Zhu, Bhatt, Clark, & Joseph, 2012) but she was responsible for developing them alongside her team. The original test was comprised of pictures of either faces or houses. In each set there were five pictures, one target and four distractors that differed from the target either on a featural level or as a second order configural one (spacing between features). Each distractor was different in its difficulty level where the congruency level 0 had nothing in common with the target; level 1 had one thing in common, level 2 two things and so forth.

We performed a pilot test on two participants at the same age as our sample. From that pilot testing we opted to use only congruency level 1, as other difficulty levels were either too easy or too hard. The number of trials was kept at 192 in total, few enough to hopefully maintain the attention of children in that age. The difference in each set was then either on a featural level or a second order configural level. In this study, we balanced the number of featural stimuli to the second order configural. There were therefore 96 featural trials (half of which showed faces, and half of which showed houses) and 96 configural trials (half faces, half houses).

<table>
<thead>
<tr>
<th>Second order configural</th>
<th>Featural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>Same as target</td>
</tr>
</tbody>
</table>

![Figure 2 Sample of visual stimuli](image)
In the training phase of the computer game, participants were shown a picture of a simple form for a brief moment (300 milliseconds) followed by a random dot visual mask (5 cm in diameter, shown for 200 milliseconds). Participants were then presented with two pictures, shown onscreen until response, one of the aforementioned simple form which was located either to the left or right. It was then explained to participants, by audio in the game, that they were to pick the previously viewed image by pressing one of two marked buttons on the keyboard. This was then repeated three times, once with the previous simple form now on the opposite side and then with a different simple form, once on either side.

In the actual testing phase, the same procedure as in the training phase was used. First a picture of either a house or a face (width and height approximately 2 cm) was shown for 300 milliseconds followed by a random dot visual mask (5 cm diameter) for 200 milliseconds. Then two pictures were shown (1 cm gap between them), one of the stimuli from earlier and the other a distractor. The testing was divided into six blocks separated by the story of the game. Each block contained 32 trials for a total of 192 trials for the test in its entirety. The trial order was randomized once and that order then kept for all participants. On each trial, the target stimulus was presented, then the visual mask, and then two stimuli, one was the target and the other one a distractor, the number of correct answers on each side were counterbalanced. The participants knew from the practice phase to press one of two buttons on the keyboard, either the left one (z) marked with a red dot or the right one (m) marked with a green dot. This was then repeated for the remainder of the set. No feedback was given to whether each answer was correct or incorrect.

**Statistical analysis**

*Statistical Package for Social Sciences* (SPSS, version 21) was used to statistically analyse the data. As the SWAN rating scale has not been used previously in Icelandic, some of its psychometric properties were looked at. A principal component factor analysis was
performed on the 18 item SWAN rating scale to see which questions were loading on which factors (ADHD combined, ADHD hyperactivity and ADHD inattentive, respectively) and a reliability analysis was performed. A correlation was calculated between; number of correct words read per minute (IS-FORM common and uncommon and IS-PSEUDO), SWAN rating scale, accuracy of second order configural houses and faces, accuracy of featural houses and faces, reading per day in minutes and interest in reading. The variance of second order configural (houses and faces) and featural accuracy (houses and faces) was shown in graphs and a paired sample T-test between the two was performed to estimate the difference of their respective means. A multiple regression was performed with number of correct words read per minute as the dependent variable and second order configural (houses and faces) and featural (houses and faces) as two independent variables. A hierarchical multiple regression was additionally performed, again with number of correct words per minute as the dependent variable. The SWAN rating scale was inserted at block 1 and second order configural (houses and faces) and featural (houses and faces) were both inserted at block 2.
Results

Psychometric properties and descriptive analyses

Measures of reading: IS-FORM and IS-PSEUDO

In Table 1, mean scores for all three reading tests along with their total mean score can be seen. Results from each list were counted both in total words read per minute and then total correct words read per minute. As expected, participants scored highest in the IS-FORM common word test and made fewest errors on average (56 total words read per minute and 54 correct words read per minute). IS-FORM uncommon words were second best (36 total and 34 correct) and IS-PSEUDO was most difficult (27 total and 24 correct).

Table 1 Average score on word lists

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS-FORM common words read per minute</td>
<td>55.89</td>
<td>25.43</td>
<td>19</td>
</tr>
<tr>
<td>IS-FORM common words correct per minute</td>
<td>54.11</td>
<td>25.49</td>
<td>19</td>
</tr>
<tr>
<td>IS-FORM uncommon words read per minute</td>
<td>36.37</td>
<td>13.86</td>
<td>19</td>
</tr>
<tr>
<td>IS-FORM uncommon words correct per minute</td>
<td>33.63</td>
<td>13.66</td>
<td>19</td>
</tr>
<tr>
<td>IS-PSEUDO pseudo-word read per minute</td>
<td>26.63</td>
<td>9.89</td>
<td>19</td>
</tr>
<tr>
<td>IS-PSEUDO pseudo-word correct per minute</td>
<td>23.53</td>
<td>9.07</td>
<td>19</td>
</tr>
<tr>
<td>IS-FORM + IS-PSEUDO read per minute</td>
<td>39.63</td>
<td>15.84</td>
<td>19</td>
</tr>
<tr>
<td>IS-FORM + IS-PSEUDO correct per minute</td>
<td>37.09</td>
<td>15.60</td>
<td>19</td>
</tr>
</tbody>
</table>

The three IS-reading lists were highly positively correlated \((r = .937, p = 0.00; r = .845, p = 0.00; r = .921, p < 0.001)\). A principal component analysis showed that all three measures loaded on a single component that explained 93.4% of the total variance in the three variables, confirming that they are capturing the same underlying construct, namely reading ability. The measure used in statistical analysis was the IS-FORM + IS-PSEUDO correct per
minute (mean number of (pseudo)words read correctly across all three categories). The 19 participants who took part in the reading task read an average of 37 correct (pseudo)words per minute (SD of 15.6).

**Behavioural measures and ADHD**

The Strengths and Weaknesses of ADHD symptoms and Normal behaviour rating scale (SWAN) contains 18 questions based on DSM-V criteria (American Psychiatric Association, 2013). Those questions are designed to measure inattentive, hyperactive, and impulsive behaviours. A principal component analyses was performed where the questions loaded on three components explaining 82.97% of the total variance of the rating scale (see Table 2). Although some studies (see e.g. (Arnett, et al., 2013) report two components the three-component structure could nevertheless be in accordance with the categorisation of ADHD by the DSM-V, where the diagnosis is now threefold (ADHD hyperactive, ADHD inattentive and ADHD combined, respectively) (American Psychiatric Association, 2013). The scale has a very high level of internal consistency as determined by a Cronbach’s alpha of 0.965. The removal of independent items did not significantly affect the scale (removal of item 10 lowered alpha to 0.959 the lowest, removal of items 6 and 18 increased the alpha to 0.967 the highest).
<table>
<thead>
<tr>
<th>Components</th>
<th>1: ADHD combined</th>
<th>2: ADHD hyperactivity</th>
<th>3: ADHD inattentive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sit still (control movement of hands/ feet or control squirming)</td>
<td>.819</td>
<td>.433</td>
<td>268</td>
</tr>
<tr>
<td>Modulate motor activity (inhibit inappropriate running/climbing)</td>
<td>.795</td>
<td>.498</td>
<td>.181</td>
</tr>
<tr>
<td>Keep track of things necessary for activities</td>
<td>.773</td>
<td></td>
<td>.259</td>
</tr>
<tr>
<td>Follow through on instructions &amp; finish school work/chores</td>
<td>.771</td>
<td>.209</td>
<td>.366</td>
</tr>
<tr>
<td>Sit still (control movement of hands/ feet or control squirming)</td>
<td>.754</td>
<td>.459</td>
<td>.426</td>
</tr>
<tr>
<td>Listen when spoken to directly</td>
<td>.736</td>
<td>.347</td>
<td>.363</td>
</tr>
<tr>
<td>Settle down and rest (control constant activity)</td>
<td>.733</td>
<td>.515</td>
<td>.250</td>
</tr>
<tr>
<td>Play quietly (keep noise level reasonable)</td>
<td>.715</td>
<td>.531</td>
<td>.126</td>
</tr>
<tr>
<td>Enter into conversations &amp; games (control interrupting/intruding)</td>
<td></td>
<td></td>
<td>.908</td>
</tr>
<tr>
<td>Reflect on questions (control blurting out answers)</td>
<td>.401</td>
<td>.793</td>
<td>.157</td>
</tr>
<tr>
<td>Await turn (stand in line and take turns)</td>
<td>.489</td>
<td>.760</td>
<td>.203</td>
</tr>
<tr>
<td>Modulate verbal activity (control excess talking)</td>
<td>.587</td>
<td>.687</td>
<td>.279</td>
</tr>
<tr>
<td>Engage in tasks that require sustained mental effort</td>
<td>-.113</td>
<td>.375</td>
<td>.862</td>
</tr>
<tr>
<td>Ignore extraneous stimuli</td>
<td>.343</td>
<td>.132</td>
<td>.808</td>
</tr>
<tr>
<td>Organize tasks and activities</td>
<td>.538</td>
<td></td>
<td>.787</td>
</tr>
<tr>
<td>Sustain attention on tasks or play activities</td>
<td>.648</td>
<td>.219</td>
<td>.649</td>
</tr>
<tr>
<td>Remember daily activities</td>
<td>.546</td>
<td>-.100</td>
<td>.637</td>
</tr>
<tr>
<td>Give close attention to detail and avoid careless mistakes</td>
<td>.468</td>
<td>.267</td>
<td>.586</td>
</tr>
</tbody>
</table>
The SWAN rating scale was answered on a seven-point Likert scale (ranging from; far below average, below average, slightly below average, average, slightly above average, above average, far above average). The scores ranged from -3 to 3, the negative numbers representing stronger ADHD symptoms. The lowest mean response to the SWAN rating scale was -1.89 while the highest was 2.44. Overall the mean was 0.48 (SD 1.28).

**Visual recognition accuracy**

In this study the focus is on visual recognition accuracy on stimuli manipulated either on a second order configural processing level or featural processing level. On the whole, the children averaged 74.02% accuracy when choosing between stimuli manipulated on a featural level compared to 71.29% on second order configural stimuli. The variance of accuracy was good as can be seen in table 4.

*Table 3* Average scores and response times

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second-order face stimuli accuracy</td>
<td>76.95%</td>
<td>8.76%</td>
</tr>
<tr>
<td>Second-order house stimuli accuracy</td>
<td>64.19%</td>
<td>11.54%</td>
</tr>
<tr>
<td>Featural face stimuli accuracy</td>
<td>77.21%</td>
<td>7.43%</td>
</tr>
<tr>
<td>Featural house stimuli accuracy</td>
<td>72.27%</td>
<td>6.17%</td>
</tr>
<tr>
<td>Second-order (house + face)</td>
<td>71.29%</td>
<td>8.33%</td>
</tr>
<tr>
<td>Featural (house + face)</td>
<td>74.02%</td>
<td>6.68%</td>
</tr>
<tr>
<td>Second-order face stimuli average response time</td>
<td>1.41 seconds</td>
<td>370 ms</td>
</tr>
<tr>
<td>Second-order house average response time in sec</td>
<td>1.61 seconds</td>
<td>480 ms</td>
</tr>
<tr>
<td>Featural face stimuli average response time in sec</td>
<td>1.35 seconds</td>
<td>320 ms</td>
</tr>
<tr>
<td>Featural house stimuli average response time in sec</td>
<td>1.54 seconds</td>
<td>470 ms</td>
</tr>
<tr>
<td>Second-order processing (face + house) mean response time</td>
<td>1.51 seconds</td>
<td>400 ms</td>
</tr>
<tr>
<td>Featural processing (face + house) mean response time</td>
<td>1.44 seconds</td>
<td>390 ms</td>
</tr>
</tbody>
</table>
A paired sample T-test was performed in order to ascertain whether a statistically significant difference was between the “configural processing” and “featural processing”. There was no statistically significant difference \((p = .199)\) nor was the correlation between the two \((r = .430, p = .097)\).

![Box plots showing variance of accuracy for second order configural houses and faces (left) and featural houses and faces (right).](image)

**Figure 3** Variance of accuracy for second order configural houses and faces (left) and featural houses and faces (right).

**Influence of visual recognition processes on reading**

As can be seen in Table 3. There was a statistically significant, high positive correlation between “reading ability”, the “SWAN rating scale”, “interest in reading” and “reading per day in minutes”. The moderate correlation of reading ability with the scores from the visual recognition test, however, was not statistically significant. The “SWAN rating scale” does have a statistically significant, high positive correlation with “interest in reading”, “reading per day in minutes” and “configural processing” but not “featural processing” \((p = .052)\). The p-value is just above the criterion and could be a result of the small sample.
To explore the influences of visual recognition processes on reading a linear multiple regression was performed with “reading skills” (IS-FORM and IS-PSEUDO number of correct words read) as the dependent variable and “Configural processing” and “featural processing” entered as independent variables. The model was not statistically significant in whole ($F(2, 13) = 1.755, p = 0.212$), suggesting that there was not a linear relationship between the predictors and the outcome variables. It seems, therefore, that “configural processing” and “featural processing” do not uniquely explain any significant variation in children’s ability to read words and pseudo-words.

Secondly, to explore the contribution of configural and featural processing in reading, once the effect of attention and behaviour control was accounted for, a two-stage hierarchical multiple regression was performed with scores on the “SWAN rating scale” entered at stage 1, and “configural processing” and “featural processing” entered together at stage 2. Again, “reading skills” was the dependent variable. See table 5 for full details on each regression model. The full model of “SWAN rating scale”, “configural processing” and “featural processing was statistically significant, $R^2 = .499, F(3, 12) = 3.982, p < 0.05$; adjusted $R^2 =$
However, the addition of “configural processing” and “featural processing” to the prediction of “reading skills” (Model 2) did not lead to a statistically significant increase in $R^2$ ($R^2$ change = .005, $F(2, 12) = .065, p = 0.938$).

**Table 5 Hierarchical multiple regression**

<table>
<thead>
<tr>
<th>Variable</th>
<th>B</th>
<th>$\beta$</th>
<th>P</th>
<th>$R^2$</th>
<th>$R^2$ change</th>
<th>F</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td></td>
<td></td>
<td>0.493</td>
<td>0.493</td>
<td>13.639</td>
<td>0.002</td>
</tr>
<tr>
<td>SWAN rating scale</td>
<td>8.110</td>
<td>0.702</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td></td>
<td></td>
<td>0.499</td>
<td>0.005</td>
<td>0.065</td>
<td>0.938</td>
</tr>
<tr>
<td>Swan rating scale</td>
<td>8.068</td>
<td>0.699</td>
<td>0.022</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Configural processing</td>
<td>-10.376</td>
<td>-0.699</td>
<td>0.825</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Featural processing</td>
<td>16.999</td>
<td>-0.077</td>
<td>0.755</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The $R^2$ for model 1, including only “SWAN rating scale”, was 49.3% with adjusted $R$ of 45.7%. “SWAN rating scale” then explains just under half of the variation of “reading skills” compared to the mean model. The coefficient (unstandardised b) for “SWAN rating scale” is 8.110. Other coefficients were not statistically significant. This means that an increase in “SWAN rating scale” of one unit change would predict an increase in “reading skills” of 8.110 correct words read per minute. The addition of the variables in model 2 did not add to the predictive value nor any significant explanatory factor.

**Discussion**

This study aimed to evaluate whether the reading ability of fourth graders could be explained by visual recognition aptitude. The results indicated that visual processes do not influence the reading ability of fourth graders although there was some correlation and the lack of effect might be explained by a small sample. The predictive value of the vision processes in reading
were not statistically significant, irrespectively of whether the influence of ADHD symptoms was controlled for or not. However, the parent’s assessments of their children’s attentional and behavioural control, as indicated by SWAN rating scale, explained just under half of the variation in reading ability.

The results above are somewhat different from with results of former studies exploring the role of configural and featural object recognition among dyslexic adults. There is some correlation between visual processes and reading ability although not significant perhaps due to the small sample, but attention seems to explain a lot more in this age group. Based on their results, Sigurdardottir et al. (2015, 2017, 2018, 2019) posited a high-level visual dysfunction hypothesis suggesting a dysfunction in high-level vision for adults with dyslexia. As configural (holistic) processes seemed to be intact among their participants, Sigurdardottir et al. theorized that people with dyslexia are impaired at feature-based object recognition, rather than in configurally-based recognition (Sigurdardottir, Ívarsson, Kristinsdóttir, & Kristjánsson, 2015). In the current study there was not a statistically significant difference between configural and featural visual processing. Thus, in this age group, reading ability seems to be primarily explained by attention, which in itself gives vital information on further testing at this developmental level. The IS-FORM reading lists have not been utilised before on this age group, but the psychometric properties seem to be good. There is reliability and good construct validity. The SWAN rating scale has not been used before in Icelandic, so it is pleasant to see how high its reliability turned out to be. It also, based on its predictive value, seems to capture relevant information regarding factors influencing reading ability among fourth graders.

It is important to note, however, that the current study was based on a small size, which could contribute to the lack of statistical significance. In fact, only 16 participants finished the visual recognition test. Therefore, the findings should be interpreted with caution.
There is some evidence that featural and configural processes develop at a different rate and it could be that in nine-year olds neither of those processes have reached full maturity (Mondloch, Le Grand, & Maurer, 2002) and it could be that they rely more on different processes than their adult counterparts.

The visual recognition test was pretested in order to ascertain the appropriate difficulty level and length of the test. There is a chance, however, that the visual recognition task was too long for nine-year olds. It would be interesting to statistically evaluate whether that was the case for example by looking into whether the participants performance dropped in the latter half of the task. However, as shorter tasks can lower reliability, a rigorous pilot testing would always be advisable. The difficulty level of the visual recognition test could have been wrong, in the pilot study this level was appropriate, but we only tested on two participants and it would be advisable to establish a difficulty level based on a larger sample.

Comparing the two visual processes directly is difficult without having a different age group and we would have benefitted from having longitudinal data. There is an ongoing study at Icelandic Vision Lab where that is the case since its participants are adults of various ages. Further examination of the current study’s data in context with the data from the ongoing study will be of interest in the future. An important novelty of the current study is the employment of the visual recognition task in a form of a computer game. Visual recognition tasks tend to be both long and tedious, putting attentional strain on participants, especially on young children. The children in this study, however, reported that they enjoyed the game, making it more likely that they stayed focused for the whole session. It should be interesting for future studies to make use of this protocol and evaluate to what extent it enhances the interest and focus of participants.
Conclusion

The effect of visual recognition processes (second order configural and featural processes) on reading ability was nonconclusive. They did not statistically significantly explain the variation of reading ability and neither did they have statistically significant predictive value on their own nor did they add such value over and above what the SWAN rating scale predicted. The SWAN rating scale, however, not only had a high positive statistically significant correlation to reading ability but also explains almost half of its variation. SWAN rating scale in addition has a statistically significant predictive value on reading ability. Results from the current study show that reading ability of fourth graders is best explained by ADHD symptoms.
Bibliography


