Processing speed in perceptual visual crowding

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In this study, a perceptual visual crowding paradigm was designed to quantitatively assess the detection speed of (un)crowded meaningful visual targets using eye-movement responses. This paradigm was tested in individuals with dyslexia and age-matched controls. Trials were shown on a monitor with an integrated eye tracker to 25 control and 11 dyslexic subjects without any known ocular problems. Each trial started with fixation of a central target. Next, four peripheral targets were shown (left, right, top, bottom), one being a duplicate of the central target. The duplicate was either surrounded by flankers (crowding trials) or shown in isolation (reference trials). The timing of the primary saccades were obtained as a measure for detection speed. The performance of the reference trials was significantly higher compared to the crowding trials ($p < 0.05$) and a 54% increase in saccadic reaction time (SRT) was found for the crowding trials. The linear mixed model revealed a significant effect of critical spacing and chart type. For the reference trials, no significant differences in SRT were found between dyslexic and control subjects. However, for the crowding trials, a significant increase of ~13% in SRT was found in the dyslexic subjects. A first application of this paradigm showed that dyslexic subjects perform equally well in identifying visual targets in crowded as well as uncrowded scenes compared to controls. However, they seem to need more time to identify targets in crowded scenes, which might be related to the reading difficulties that they experience in general.

Introduction

Visually crowded targets are targets that can be recognized when presented in singular although they cannot be recognized when flanked by other stimuli (Pelli & Tillman, 2008). Thus, a crowded target is still visible but blends with its neighboring stimuli (Louie, Bressler, & Whitney, 2007). Despite the fact that crowding has been studied extensively in recent years, there is no full understanding of the process (Whitney & Levi, 2011). A current idea is that crowding represents a "filter" that is used for object perception, eye–hand movements, visual search, and reading (Levi, 2008). It is caused by the presence of internal representations as well as surrounding objects interfering with the identification of a target (Bulakowski, Post, & Whitney, 2009). The process of crowding depends on the center-to-center distance between the target and flankers (critical spacing; Toet & Levi, 1992) and the locus of the target relative to the fixation point (eccentricity). As a result, recognition of crowded targets, such as letters or words during reading, becomes more difficult (Whitney & Levi, 2011). It has been suggested that crowding can be explained in terms of the erroneous inclusion of features to be integrated within a spatial window (Pelli, Palomares, & Majaj, 2004). These spatial windows, also known as integration fields, are small in the fovea and relatively large in the periphery. In the periphery, the critical distance between target and flanker scales with eccentricity and is independent of target and flanker size. For crowding to occur, the critical spacing needs to be roughly half the eccentricity (Bouma, 1970). Thus, crowding seems most pronounced in peripheral vision (Pelli et al., 2004). In central vision, giving the small sizes of the integration fields, crowding may be more difficult to detect. Little to no crowding was reported at the fovea for low-contrast targets (Simmers, Gray, McGraw, & Winn, 1999), and absence of foveal crowding was

shown for opposite-contrast stimuli (Hess, Dakin, & Kapoor, 2000). Others have reported that foveal crowding occurs over very small distances but that sophisticated techniques are required to overcome the optical limitations (Siderov, Waugh, & Bedell, 2013; Coates, Levi, Touch, & Sabesan, 2018).

Effects of peripheral crowding are distinct from the well-known declined visual acuity in peripheral vision. Crowding is reported in patients with ocular visual impairments, such as strabismic amblyopia (Levi, 2007), and patients with macular degeneration (Wallace et al., 2017) and also in patients with visual perception problems, e.g., in patients with cerebral visual impairment (van Genderen, Dekker, Pilon, Bals, 2012) and developmental dyslexia (Gori & Facoetti, 2015). Individuals with dyslexia have been shown to exhibit difficulties identifying letters within sentences (Geiger & Lettvin, 1987), especially in the extreme periphery (Lorusso et al., 2004). This latter finding supports the notion of a different distribution of lateral masking (Lorusso et al., 2004). Behavioral evidence was provided showing that dyslexics are abnormally affected by crowding (Bouma & Legein, 1977; Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009), whereas others have reported that dyslexic and control subjects have similar crowding degrees (Shovman & Ahissar, 2006). Part of these differences may result from a difference in methodological approach. Performance in crowding tests is mostly assessed by means of correct identification of targets (performance: yes or no). Some studies present data on a continuous scale, such as vocal reaction times (Shovman & Ahissar, 2006). In individuals with dyslexia, however, vocal responses may be affected by phonological problems, potentially causing increased vocal reaction times (Shovman & Ahissar, 2006). To date, no visual crowding paradigm exists that incorporates both visual processing properties and processing speed.

It was recently shown that focusing of attention modulates central crowding, whereas orienting spatial attention can modulate peripheral crowding (Albonico, Martelli, Bricolo, Frasson, & Daini, 2018). Different types of cues were used in a task in which subjects had to discriminate the orientation of a target letter close to acuity threshold when presented in combination with left and right flankers. The cues were a red dot and a small and a big square to alter the focus of attention. In the present study, we propose the central target to be the same as the peripheral target. In addition, previous studies have shown that timing of eye movements can be used as an objective measure to assess the quality and efficiency of perceptual visual functions in terms of processing speed (Mele & Federici, 2012; Kooiker, van der Steen, & Pel, 2016). In the present study, we designed a behavioral decision paradigm to test peripheral crowding using the timing of eye movements

as an outcome measure. Subjects were asked to fixate a centrally placed target. Next, four peripheral targets appeared (left, right, above, and below), one being the duplicate of the target shown in the middle. These peripheral targets were either flanked by other targets (crowding trials) or shown in isolation (reference trials). Subjects were asked to detect and fixate the duplicate target without visual search. Thus, each subject had to detect the duplicate target using peripheral vision only. The outcome measures of this paradigm were (a) performance, i.e., the percentage of correctly detected targets, and (b) the saccadic reaction time (SRT) of the primary saccade in the correctly performed trials.

In the present study, we tested the visual crowing paradigm in normally developed subjects and subjects with dyslexia. Five different visual crowding charts were developed. The charts represented basic visual features, such as colors, contrasts, and forms, and also spatial patterns and letters. The first aim of this study was to confirm that visual crowding resulted in decreased performance and prolonged SRTs in crowding trials compared to reference trials. The second aim was to validate this paradigm in a group of dyslexic subjects. We expected in this group an overall decrease in performance and prolonged SRTs in crowding as well as in reference trials compared with age-matched controls.

Materials and methods

Subjects

Twenty-five subjects were recruited in the age range of 19–26 years old and who were naïve to the purpose of the study. Fourteen subjects were randomly selected for the pilot study and 11 subjects for the validation study. For this latter study, another 11 subjects within the same age range who had an official declaration of dyslexia were recruited. All subjects were recruited at the Erasmus Medical Center Rotterdam (medical students) and had normal or corrected-to-normal vision and color vision. Exclusion criteria were ocular or cerebral pathologies. The experimental procedures were approved by the medical ethical committee of Erasmus University Medical Centre, Rotterdam, the Netherlands (METC-2012-199). The study adhered to the Declaration of Helsinki for research involving human subjects.

Measurement setup

The setup consisted of a 24-in. monitor with an integrated infrared eye-tracking system (Tobii T60XL
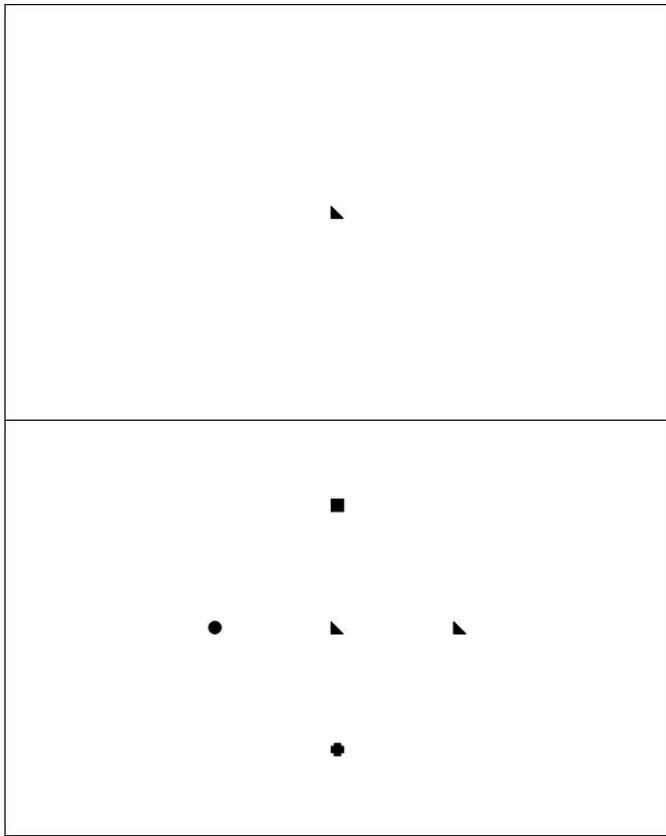
Figure 1. An example of a reference trial. The subject is asked to fixate the central target. When detected with peripheral vision, he or she makes an eye movement to the selected target. The fixation stimulus is shown for 3 s, and then the peripheral targets are shown for 5 s.
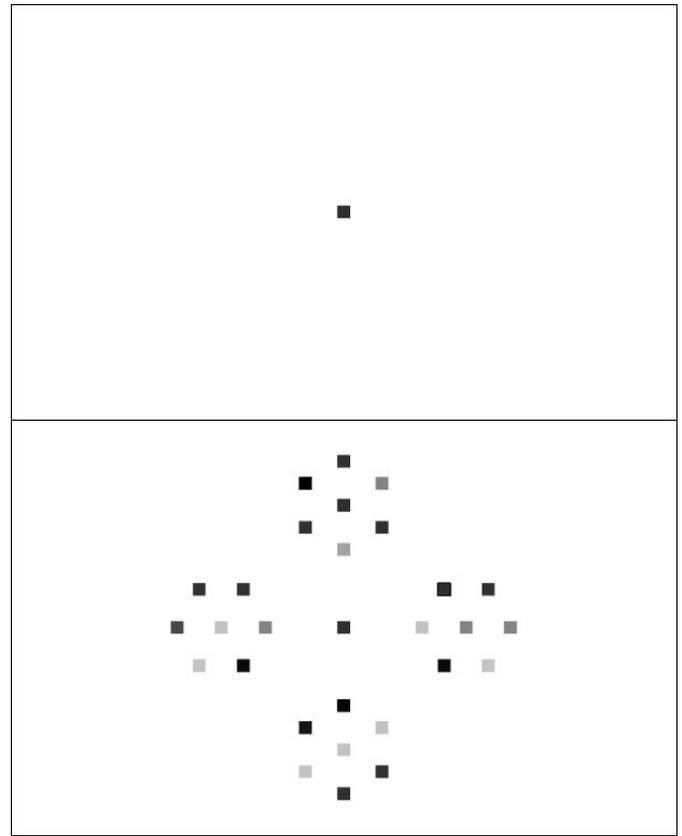

Figure 2. An example of a crowding trial. The subject fixates the central target. When the crowding chart is presented, the subject needs to identify the same target in the periphery that is flanked by similar stimuli.

eye tracker, Tobii Corporation, Sweden). Binocular eye movements were measured at 60 Hz using cornea reflection (binocular accuracy of less than 0.5° and a system's latency of ~30 ms as specified by the manufacturer's accuracy and precision test report dated April, 20, 2011). The experiment was conducted in a quiet room. Each subject placed her or his head in a chin rest to minimize head movements and to keep a fixed distance of 57 cm to the screen. Prior to the experiments, a standardized five-point calibration procedure was performed for both eyes.

Visual crowding paradigm

Five charts were developed, each containing a different fixation stimulus, i.e., color, letter (Bouma, 1973), contrast (Chung, 2007; Kennedy & Whitaker, 2010), spatial frequency (Chung, Levi, & Legge, 2001), and shape; see Supplementary Figure S1. Each target had an average visual angle of about 0.7° and was projected on a white background. The contrast elements varied from 0% (black) to gray scales of 20%,

40%, 60%, and 80% brightness. Each trial started with a chart with a single target that was presented in the middle of the monitor. In the reference trials, peripheral targets were added to the left, right, above, and below this central target using an overlap paradigm; see Figure 1. The distance between the peripheral targets and the central target was 10°. Only one target was a duplicate of the central target. In the crowding trials, again, the peripheral targets were placed at an eccentricity of 10° from the central target. Here, a total of six flankers surrounded each peripheral target; see Figure 2. Flankers had a critical spacing to the center varying from 3.6° (most crowded) to 4.8° (least crowded) in four steps of 0.4°; see Figure 3. Thus, the reference trials were identical to the crowding trials except that no flankers were present.

Procedure

All subjects were introduced with standard instructions, and five test trials were shown. The instruction was to find the duplicate of the central target plotted in the periphery using peripheral vision only. As soon as
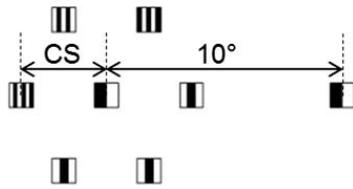
Figure 3. The eccentricity (distance between central and peripheral targets) is set to 10° in each crowding chart, and the degree of crowding altered by the critical spacing varies from 3.6° (most crowding) to 4.8° (least crowding).

the duplicate target was detected while fixating the central target, the subject had to look at this target. Each trial started with the presentation of a centrally placed target that the subject was instructed to fixate for a duration of 3 s. Next, a reference (see Figure 1) or a crowding trial (see Figure 2) was shown for a duration of 5 s. The instruction was the same for the reference and the crowding trials. A total of 260 trials were constructed: crowding trials: five visual charts, four locations, four critical spacings, three repetitions; reference trials: five visual charts, four locations.

Pilot study

Two blocks of 130 trials were presented to a group of 14 control subjects with the aim to test whether visual crowding resulted in decreased performance and prolonged SRTs in crowding trials compared to reference trials. The trials were shown in a random order. Each block lasted ∼20 min, and in between, a 5-min break was allowed.

Validation study

The same two blocks of 130 trials were presented to a new group of 11 control subjects and 11 individuals with dyslexia with the aim to validate the present paradigm. These subjects were also allowed a 5-min break after the first block of trials.

Data analysis

Gaze data were analyzed using a custom Matlab program (Mathworks, Natick, MA). An example is shown in Supplementary Figure S2. Panels A and B show gaze x- and gaze y-traces, respectively, and panel E represents the gaze pattern of one trial. Upon presentation of the central target, gaze fixation had to remain within a 2° visual angle to warrant central target fixation. After detecting the duplicate target in the periphery, an eye-movement response was required by looking at the target of choice. A trial was performed accurately when the primary saccade was made in the

correct direction. The performance of each subject was defined as the percentage of correct responses. The timing of the primary saccade was then determined by transforming gaze data into gaze angle (see panel D). SRT was defined as the time between presentation of the peripheral reference or crowding trial until the moment that eye velocity exceeded 25°/s (see panel D). Eye movements outside the 2° central fixation area were labeled as "invalid" and excluded from the analysis. Sometimes gaps existed in the gaze data due to blinking or eye-tracking errors. Trials with gap durations of less than 100 ms were used for analysis. Trials with gap durations between 100 ms and 250 ms were used for analyzing the performance, but corresponding SRT values were not included. This only occurred in less than 0.2% of the total number of tested trials. The average SRT value of the three repetitions in each test was calculated. The repetitions ensured an SRT value for this tested condition if data of one or two stimuli were missing (e.g., due to eye-tracking failure, a first incorrect primary saccade, or searching for stimuli). When none of the three repetitions led to the registration of an SRT, the outcome was labeled as "missing." Finally, trials with gap durations of more than 250 ms were labeled as invalid and excluded from the analysis.

Statistics
Pilot study

A linear mixed model was applied to assess SRT dependence on crowding conditions, e.g., critical spacing, target location, and chart type, as fixed effects. Levene's test for equality of variances was applied to test the effect of critical spacing on SRT variance. Differences between performances and conditions were tested for significance using the Mann-Whitney U test.

Validation study

A Wilcoxon signed rank test was used to compare SRTs between measurement series. A Mann-Whitney U test was applied to compare performance and SRTs between dyslexic and control subjects. A Bonferroni correction was applied when adjusting for the type I error. All statistical tests were performed in SPSS 21 (SPSS, Chicago, IL). Significance level was set at $p < 0.05$.

Results

A total of 36 subjects were successfully included in the study. Table 1 represents the characteristics of the

Characteristics	Pilot study Controls (n = 14)	Validation study Controls (n = 11)	Dyslexics (n = 11)
Age, years	23 ± 2	23 ± 1	23 ± 2
Gender			
Male	3	3	2
Female	11	8	9
Reference trials			
Gaze data, %	89 ± 5	87 ± 6	90 ± 5
Tracking distance, mm	571 ± 0	570 ± 2	570 ± 5
Crowding trials			
Gaze data, %	89 ± 1	90 ± 1	92 ± 1
Tracking distance, mm	571 ± 0	570 ± 0	570 ± 0

Table 1. Characteristics of the subjects of each group and their overall eye-tracking performance in mean ± 1 SD.

subjects. No significant differences were found between the three groups (two control groups and one dyslexic group) with respect to age and eye-tracking performances (percentage of gaze data and tracking distance). Around three to four times as many females as males participated in this study. Overall, no eye-tracking problems or technical problems were reported, and on average, 90% of eye-tracking data were available for data analysis.

Pilot study

Performance

Table 2 shows the performance of the controls in the pilot study. The performance of the reference trials was significantly higher compared to the crowding trials ($p < 0.05$). The performance depended on the type of stimulus and was independent of critical spacing and target location. The performance was for the contrast charts the highest (96%) and for the spatial frequency charts the lowest (91%).

Reaction times

In Table 3, an overview is presented of the SRTs. A significant difference was found in SRT between the reference trials (on average, 490 ms) and the crowding trials (on average, 754 ms). Within the crowding trials, the linear mixed model revealed a significant effect of critical spacing, $F(4, 1,290,181) = 14.0$, $p < 0.001$; target location, $F(3, 1,629,519) = 17.7$, $p < 0.001$; and chart type, $F(4, 2,746,008) = 29.84$, $p < 0.001$. With decreasing critical spacing, SRTs became faster, identifying the crowding effect expressed in SRT. Location-wise, SRTs were significantly faster on the horizontal meridian compared to the vertical meridian. The fastest SRTs were to the color and shape charts and the slowest SRTs to the contrast and spatial frequency charts. Levene's test for equality of variances revealed that SRT variance was independent of critical spacing.

Validation study

Performance

Table 2 shows the performance of the control and the dyslexic subjects in the validation study. The performance of the reference trials was significantly higher compared to the crowding trials ($p < 0.05$). When comparing the performance between the control and the dyslexic subjects, no significant differences were found for the reference and crowding trials. Within the crowding trials, their performance did not depend on chart type. The errors made during the crowding trials were labeled as missing or invalid. The between-groups comparison showed no significant differences for these two error types.

Reaction times

As in the pilot study, a significant difference was found in SRT between the reference trials and the crowding trials in the control as well as the dyslexic

Performance	Pilot study Controls (n = 14)	Validation study Controls (n = 11)	Dyslexics (n = 11)	p value
Reference trials, %	98 ± 2	97 ± 2	96 ± 2	0.280
Crowding trials, %	93 ± 3	86 ± 3	84 ± 4	0.248
Stimulus				
Contrast, %	96 ± 2	80 ± 4	86 ± 3	0.949
Color, %	93 ± 3	96 ± 2	91 ± 3	1.000
Letter, %	91 ± 3	89 ± 3	84 ± 4	1.000
Spatial frequency, %	88 ± 3	89 ± 3	77 ± 4	0.423
Shape, %	91 ± 3	86 ± 3	80 ± 4	1.000
Missed, %	-	12.3 ± 1.0	15.0 ± 1.8	0.538
Invalid, %	-	1.4 ± 0.2	1.4 ± 0.3	1.000

Table 2. The performance scores of the subjects in percentages (mean ± 1 SD).

Saccadic reaction time	Pilot study	Validation study		
	Controls ($n = 14$), ms	Controls ($n = 11$), ms	Dyslexics ($n = 11$), ms	p value
Reference trails	490 (499–729)	588 (452–737)	592 (501–731)	0.277
Crowding trials	754 (620–934)	725 (561–972)	819 (627–1,087)	0.000
Critical spacing				
3.6°	822 (642–1,018)	778 (607–1,100)	908 (638–1,173)	0.022
4.0°	751 (621–914)	723 (555–977)	839 (615–1,085)	0.006
4.4°	729 (626–900)	699 (548–918)	772 (619–969)	0.017
4.8°	729 (595–913)	695 (544–922)	799 (626–1,066)	0.001
Target location				
Left	687 (578–863)	682 (552–871)	718 (589–910)	0.110
Right	690 (573–859)	656 (490–851)	756 (594–1,010)	0.004
Upper	846 (694–1,040)	853 (5,928–1,143)	968 (675–1,270)	0.000
Lower	790 (662–930)	812 (646–981)	887 (692–1,101)	0.006
Chart type				
Contrast	841 (677–1,092)	821 (619–1,143)	887 (652–1,143)	0.325
Color	681 (563–853)	662 (490–862)	745 (580–965)	0.005
Letter	705 (600–837)	699 (560–898)	799 (649–1,014)	0.001
Spatial frequency	891 (749–1,110)	902 (607–1,278)	968 (735–1,239)	0.131
Shape	694 (568–835)	674 (548–835)	746 (584–982)	0.001

Table 3. The processing speeds expressed as SRT in medians (25%–75% percentile) of the subjects.

groups. The between-groups comparison revealed no significant difference in SRT for the reference trials. However, for the crowding trials, a significant delay of ~13% was found in the dyslexic subjects compared to the control subjects. These delays were found significant for two critical spacings (4.0 and 4.8), three target locations (right, top, and bottom), and three chart types (color, letter, and shape).

Discussion

The aim of this study was to investigate detection speed as a new outcome measure in peripheral crowding research. A perceptual visual crowding paradigm was designed to quantitatively assess the detection speed, expressed as SRT, of (un)crowded visual targets using eye-movement responses. In the pilot study, a significant increase of 54% in SRT was found in the crowding trials compared to reference trials. The linear mixed model revealed a significant effect of critical spacing and chart type, indicating that peripheral crowding indeed affects processing speed. The fastest SRTs were to the color and shape charts and the slowest SRTs to the contrast, letter, and spatial frequency charts. In the validation study, the dyslexic subjects performed equally well on the reference and crowding trials compared to the age-matched controls. When taking detection speed into account, the dyslexic subjects were as fast as controls in detecting the targets of the reference trials. However, during the crowding

trials, they were significantly prolonged (~13%) in detecting the targets. Thus, detection speed was the only functional outcome measure that showed differences between both groups.

Dyslexia is characterized by trouble with reading despite normal intelligence. Individuals with dyslexia can be affected to varying degrees. Problems include difficulties in spelling words, reading quickly, writing words, pronouncing words when reading aloud, and understanding what is read. Recent studies have shown a variety of visual deficits, crowding being one of them. The studies of Geiger and Lettvin (1987) and Lorusso et al. (2004) have reported higher correct identification of letters in the periphery compared to this study. Their approach was to present a crowded stimulus longer to dyslexic subjects than to control subjects. The presentation time was determined based on the time in which 100% correct identification of a target at 2.5° of eccentricity was established. Such an approach makes it difficult to judge the objectivity of that study. Shovman and Ahissar (2006) concluded that crowding was similar in dyslexic and control subjects. The crowding measurements they reported, however, seemed to be based on near fixations, indicating that Bouma's law was partially taken into account. They further reported crowding-like effects at the fovea, either resulting purely from crowding or from lateral masking. Fixation was checked by correct identification of a central fixation letter. Nowadays, eye trackers are more and more used to ensure proper fixation of a centrally placed cross or dot during a crowding experiment. This resembles the approach taken in conventional perim-

etry tests when assessing the extent of the visual field. Here, subjects are also required to sustain a steady central fixation throughout the course of testing. This might result in Ganzfeld blank-out or Troxler's fading effect due to neural adaptation (Martinez-Conde, Macknik, Troncoso, & Dyar, 2006). It often leads to complaints, such as blurred vision, diplopia, inattention, discomfort, hallucination, and fatigue. In addition, the fixation requirement contradicts the natural urge of the subject to look at new peripheral stimuli, thus complicating the task. Overall, the approach leads to an unnatural environment for the measurement of human perceptual performance. Here, we take a different approach by altering the "classic" crowding task from a gaze-fixation task into a "new" gaze-response task. In our paradigm, subjects were allowed to make an eye movement when the peripheral target was detected, thereby reducing the aforementioned complaints. Another advantage is that eye movements are not affected by phonological problems, potentially causing increased vocal reaction times in dyslexic subjects (Shovman & Ahissar, 2006). In the reference trials, no differences in reaction times were found. The results of the validation study suggest that the dyslexic subjects need more time to identify targets in crowded scenes, which might be related to the reading difficulties that they experience in general. It was previously shown that manipulation of letter spacing substantially improved text-reading performance in children with dyslexia. Extra-large letter spacing may help to break the vicious circle by rendering the reading material more easily accessible (Zorzi et al., 2012).

Crowding is proposed to be the primary limiting factor in reading performance (Pelli et al., 2007). It is suggested that crowding slows the speed of saccades. In addition, the visual span, i.e., the field that is covered by a saccade, is directly related to the size of the crowded region (Chung, Mansfield, & Legge, 1998; Vlaskamp & Hooge, 2006). Crowding in individuals with dyslexia is mostly tested using letter-crowding paradigms (Hawelka & Wimmer, 2005). Here, in addition to letters, we also tested other visual processing features, such as contrast, color, spatial patterns, and shapes. We previously showed, in typically developing children, that the processing speed of different types of visual features depends, among others, on saliency of the stimulus and age (Kooiker et al., 2016). High salient stimuli, including colorful and high-contrast features, were seen fastest (~250 ms) and reached stable reaction times in children aged 3–4 years. Low salient stimuli, on the other hand, resulted in reaction times between 500 ms and 900 ms, and these became stable in children aged 8–9 years. An advantage of the proposed paradigm is that the targets are not restricted to letters. In the present study, we included different visual charts. Fastest responses were found for color and shape charts. Presumably, color and form stimuli were still salient in peripheral vision compared to letters, contrast, and spatial frequency. It remains, however, the question if the relative saliency of each of the different target conditions influences the processing speed. An additional study could be to level the visibility across the different chart types by adjusting their visibility thresholds. Then, by altering the relative visibility of some charts, it could be tested if visual processing speed can be improved in dyslexic subjects. Finally, the results suggest that not only letters, but also other visual features might affect visual processing in individuals with dyslexia. In a recently published paper, the brain mechanisms involved in visual and orthographic deficits in individuals with dyslexia were compared to age- and reading-matched controls. In the dyslexic subjects, less activation was found in the left precuneus and greater activation in the right pre/postcentral gyrus compared to age- and reading-matched controls. These data suggest a shared mechanism of visual and orthographic deficits in dyslexia and shed new light on understanding visual processing problems in individuals with dyslexia (Cao, Yan, Spray, Liu, & Deng, 2018).

This study has some limitations that need to be addressed. We performed the validation study in a sufficient but small sample of dyslexic and control subjects. We were not able to study the effect of type and/or severity of dyslexia on detection speed. Still, on a group level, we were able to show that detection speed was significantly altered in this group. The subjects reported that the test was demanding, and some even reported the task to be difficult. In our paradigm, at first, a central target was presented that they had to detect in their peripheral field. The straining part was to focus the attention on the central as well as on the peripheral targets. Although a break was presented in between the two blocks, the subjects suggested allowing more short breaks. In the pilot group, we investigated if test duration had an effect on SRT. No differences were found between average SRTs assessed in blocks 1 and 2, but we cannot rule out the possibility that fatigue may have influenced the performance. Finally, the proposed paradigm tests peripheral crowding, not central crowding. A first step in introducing detection speed to test central crowding could be to flank the central target in combination with unflanked peripheral targets. Most challenging would still be to assess the limits of crowding on an arcminute scale due to optical limitation, such as irregularities in the cornea and lens blurring foveal vision (Coates et al., 2018). Such an approach would require a far more accurate eye-tracking system because the resolution of the presently used remote infrared eye-tracker system would be too low.

The proposed perceptual visual crowding paradigm can be used to investigate perceptual crowding on a behavioral level, not only including performance, but also processing speed as an outcome measure. Here we showed that individuals with dyslexia perform equally well in identifying visual targets in crowded as well as uncrowded scenes compared to controls. However, they seem to need more time to identify targets in crowded scenes, which might be related to the reading difficulties that they experience in general.

Keywords: crowding, perception, eye movements

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