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THE PERCEPTUAL LIMIT IN THE DEVELOPMENT OF READING SPEED

Roberta Marrucchelli[1], Francesca Agostini[1], Giorgia Botticelli[1], Denis Pelli[2], & Marialuisa Martelli[1]
[1]Department of Psychology, Sapienza University of Rome (Italy)
[2]Department of Psychology and Neural Science, New York University (USA)

Abstract

The acquisition of fluent reading emerges from the interaction of visual-perceptual mechanisms and higher-order cognitive processes. A well-established constraint is visual crowding—the impaired recognition of a target stimulus caused by nearby distractors. Bouma's law (Bouma, 1970) describes this effect as a fundamental limit on letter recognition in peripheral vision: the minimum space needed to recognize the target increases with eccentricity from the fovea. Previous research has shown that crowding is a major bottleneck for reading in both typical and struggling readers (Pelli et al., 2007; Spinelli et al., 2001; Martelli et al., 2009; Pelli et al., 2016), but its developmental trajectory during primary school remains poorly understood. This cross-sectional study aimed to investigate the developmental trajectory of peripheral crowding from first to fifth grade, to trace how crowding range and reading proficiency co-evolve during childhood, and to explore the role of crowding in atypical reading development. To this end, we assessed 159 children across grades 1–5, examining peripheral crowding and its relationship with reading fluency. Reading proficiency was assessed with standardized passage and word list tests, and participants were classified as skilled or low readers (≤ –1.5 SD). Peripheral crowding and reading speed (RSVP paradigm) were measured using a computerized application (EasyEyes; Jiang, Burchell, & Pelli, 2021) under controlled conditions. Results revealed a clear developmental trajectory: peripheral crowding decreased systematically with grade, reflecting an expansion of the visual span, while reading speed increased reliably. Higher grade levels predicted both reduced crowding ($r = –0.66$, $p < .001$) and faster reading rates ($r = 0.64$, $p < .001$). Across the sample, reading performance was inversely associated with crowding ($r = –0.64$, $p < .001$), with stronger effects in low-skilled readers ($r = –0.73$, $p < .001$), suggesting that crowding imposes a particular constraint on children with reading difficulties. These findings indicate that peripheral crowding diminishes with age and plays a central role in the acquisition of fluent reading. From an applied perspective, results underscore the importance of incorporating perceptual constraints into developmental models of literacy, and suggest that interventions targeting crowding and visual span may help support children with reading difficulties.

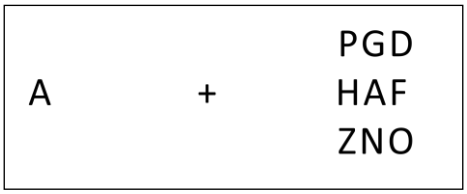
Keywords: *Reading development, perceptual integration.*

1. Introduction

Reading is a multicomponent process that relies on the integration of perceptual and cognitive mechanisms. Among the visual factors that influence fluent reading, *visual crowding* plays a significant role. Crowding refers to the difficulty in identifying a target when it is surrounded by nearby distractors, and numerous studies have shown that it limits reading speed and letter recognition in both typical and dyslexic readers (Pelli et al., 2007; Spinelli et al., 2001; Martelli et al., 2009; Pelli et al., 2016).

Crowding represents a fundamental perceptual bottleneck operating at early stages of sensory processing since it limits the identifiable letters needed for reading (Figure 1).

Figure 1. Demonstration of crowding. Fixate the +. It is easy to identify the A on the left but impossible to identify the A on the right, because of the flankers.



The unit of measurement for crowding is the *critical spacing*, defined as the minimum distance required between stimuli for the target to be correctly recognized. This critical spacing is small in the fovea and increases with eccentricity (distance from the fovea), becoming much larger in peripheral vision.

According to Bouma's law (Bouma, 1970), this spacing corresponds to approximately half the eccentricity at which the target is presented. During reading, when letters are displayed with uniform center-to-center spacing, those falling in peripheral vision may become difficult to discriminate due to interference from adjacent letters. This reveals a bottom-up perceptual limitation that can strongly affect the extraction of information from text.

Evidence also indicates that crowding decreases with development, paralleling improvements in reading fluency (Kwon *et al.*, 2007; Pelli & Tillman, 2008). However, the precise developmental trajectory of this phenomenon remains unclear, as does the relative contribution of intrinsic visual factors and maturational influences to individual differences in crowding.

The present study aims to investigate the developmental course of peripheral crowding from first to fifth grade, to track how crowding range and reading proficiency co-evolve during childhood, and to explore the role of crowding in atypical patterns of reading development.

2. Methods

159 students from 1st to 5th grade were screened for reading, through standardized passage reading (MT Reading Test) and word list tests (One Minute Test), and fluid intelligence (Raven Coloured Progressive Matrices).

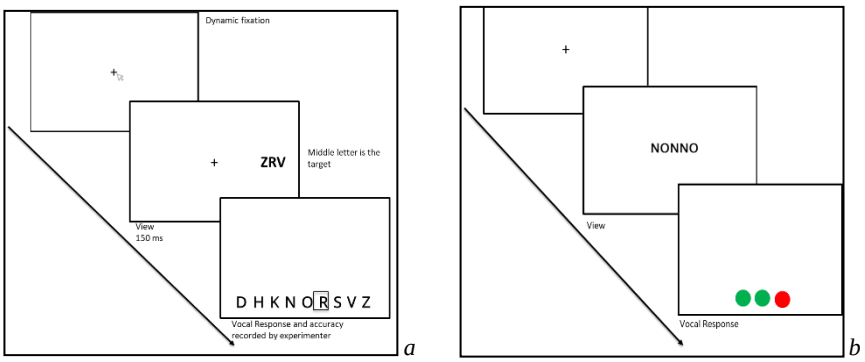
Based on their reading performance, the sample was split into two groups: skilled readers (N=141) and low readers (N=18). Low readers were defined as those scoring more than 1.5 standard deviations below the mean in speed and/or accuracy on a standardized passage-reading aloud task.

Peripheral crowding was measured using a computerized application (EasyEyes; Jiang, Burchell, & Pelli, 2021). Children were required to follow a moving fixation point with the mouse cursor and then identify the central letter of a trigram presented at 8 degrees of eccentricity, either to the right or to the left of the screen.

Reading speed was also measured using Easy Eyes through the Rapid Serial Visual Presentation (RSVP) paradigm, in which three words were displayed sequentially with no interval, and the examiner recorded the accuracy of the child's response. Both tasks employed an adaptive procedure.

The experimental procedure is graphically reported in Figure 2.

Figure 2. Procedure of Peripheral Crowding task (a) and Rapid Serial Visual Presentation (b).



3. Analysis

Pearson correlation coefficients were computed to examine the associations among grade level, peripheral critical spacing (deg), and reading speed (w/min). These analyses assessed both developmental trends and the relationship between crowding and reading performance across the full sample. Simple linear regression models were additionally used to quantify the predictive contribution of grade level to crowding and reading speed, as well as the strength of the association between crowding and reading performance. To explore whether this relationship differed as a function of reading ability, all analyses were repeated separately for skilled and low readers. All analyses were run using Jamovi 2.6.19.

4. Results

Results revealed a clear developmental trajectory: peripheral crowding decreased systematically with grade, reflecting an expansion of the visual span, while reading speed increased reliably. Higher grade levels predicted both reduced crowding ($r = –0.66$, $p < .001$) and faster reading rates ($r = 0.64$, $p < .001$). Across the entire sample, reading performance was inversely associated with crowding ($r = –0.64$, $p < .001$), indicating that children with larger critical spacing tended to read more slowly.

When examined by subgroup, this relationship was even stronger among low-skilled readers ($r = –0.73$, $p < .001$), suggesting that visual crowding imposes a particularly pronounced constraint in children with reading difficulties.

5. Discussion and conclusions

Overall, these findings show that peripheral crowding limitation diminishes with age and plays a central role in the development of fluent reading. From an applied perspective, the results highlight the importance of incorporating perceptual constraints into developmental models of literacy and suggest that interventions targeting perceptual processes may be beneficial for children who struggle with reading.

References

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature*, 226, 177-178.

Jiang, P., Burchell, A., & Pelli, D. G. (2021). EasyEyes aids online testing by emulating a wireless keyboard and tracking viewing distance. *Perception, 50*(1),7-7.

Kwon, M., Legge, G. E., & Dubbels, B. R. (2007). Developmental changes in the visual span for reading**.** *Vision Research, 47*(22), 2889-2900.

Martelli, M., Di Filippo, G., Spinelli, D., & Zoccolotti, P (2009). Crowding, reading, and developmental dyslexia. *Journal of Vision*, *9*(4), 14.1-18.

Pelli, D. G., Tillman, K. A., Freeman, J., Su, M., Berger, T. D., & Majaj, N. J. (2007). Crowding and eccentricity determine reading rate. *Journal of Vision, 7*(2), 20, 1-36.

Pelli, D. G., & Tillman, K. A. (2008). The uncrowded window of object recognition. *Nature Neuroscience, 11*(10), 1129-1135.

Pelli, D. G., Waugh, S. J., Martelli, M. et al. (2016). A clinical test for visual crowding. *F1000Research*, *5*, 81. Retrieved from: https://f1000research.com/articles/5-81/v1

Spinelli, D., De Luca, M., Judica, A., & Zoccolotti, P. (2001). Crowding effects on word identification in developmental dyslexia. *Cortex*, *38*, 179-200.