Vision Research 161 (2019) 60–62

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Editorial

Visual factors in reading

Reading is essential to everyday participation in modern society. Even if most of us consider it a luxury to find time to read newspapers in the morning or books before going to bed, many daily activities still require us to read, for example, interpreting street signs, reading ingredients in packaged foods, recipes, and captions on television. With the popularity of electronic mobile devices, reading has become even more central to our lives. Many of us use our mobile devices continuously — to catch up with news or social media, to read (electronic) books for leisure, and to check electronic mail and text messages, regardless of where we are, and even if we have only a few minutes to spare.

This Special Issue addresses several important areas of current vision research on reading, namely, models focusing on sensory features in character and word recognition, tools for the measurement and quantification of reading performance, the nature of the interactions between visual and non-visual factors on reading, and the difficulties with reading faced by special populations with visual impairment. There is also an historical essay that traces and defines many of the concepts concerning the role of typography in reading. Findings from several papers are relevant to the ongoing transition from hardcopy print to digital reading on many types of displays in this digital era.

Despite the differences in writing systems across languages, the reading process itself involves decoding the visual input from reading materials and encoding that information into meaningful concepts. The basic constituents of the visual input comprise dots or pixels that are thought to be grouped to form perceptual units referred to as "features"[1]. In alphabetic systems, features are fundamental units that make up letters, and letters are the building blocks of words, which in turn are the building blocks of sentences. Disruptions to any of these components of the visual input can affect the reading process. Such disruptions can occur with reading materials external to the visual system, for example, when there are misspellings or other typographical errors in text. Alternatively, disruptions can be a consequence of the degraded fidelity of the visual input due to front-end visual factors, such as optical blur (Thorn & Thorn, 1989; Chung, Jarvis, & Cheung, 2007), insufficient sampling (Legge, Rubin, Pelli, & Schleske, 1985; Legge, Pelli, Rubin, & Schleske, 1985; Dagnelie, Barnett, Humayun, & Thompson, 2006), unsteady fixation (Crossland, Culham, & Rubin, 2004), the presence of eye disease affecting acuity, contrast sensitivity, or the visual field, and problems associated with higher-level cognitive and oculomotor processes.

The first three papers in this Special Issue focus on theoretical questions related to features (Coates, Bernard, & Chung, 2019), letters (Bernard & Castet, 2019) and the role of attention (Ginestet, Phénix, Diard, & Valdois, 2019).

Coates et al. (2019) used a data-driven approach to identify the common types of letter identification errors when subjects read letter strings in the visual periphery, where crowding (difficulty in recognizing an object in the presence of other nearby objects) is known to be more prominent (e.g. Bouma, 1970; Toet & Levi, 1992). Their findings provide strong evidence that the majority of letter identification errors can be explained by the interaction of letter features between adjacent letters, and that there is a contingent nature of processing letter strings. These authors suggested that future models on reading should take into account crowding and featural decomposition. Bernard and Castet (2019) used an ideal-observer model to study how the visual system combines uncertainty about letter identity and position to recognize words outside the foveal area. It is known that lexical decision times are greater for longer words. Ginestet et al. (2019) used a Bayesian model of visual word recognition to examine the contribution of visual attention to this word-length effect. They showed that a narrowing of the spatial distribution of attention could account for the exaggerated word length effect reported for some reading disorders.

An important question in reading research is how to obtain precise and repeatable measurements of reading performance. Depending on the research question, subjects may be asked to read aloud or silently, and comprehension may or may not be measured. Many studies also measured eye movements simultaneously during reading, so that the eye movement data could be used as surrogate indicators of reading performance or to understand the impact of eye movements on reading. Text materials could be longer prose or stories, or short sentences or even sequences of unrelated words, and they could be presented to subjects as a passage comprising a finite number of paragraphs, or as individual sentences, or maybe even one word at a time using the rapid serial visual presentation paradigm (Masson, 1983; Potter, 1984; Rubin & Turano, 1992; 1994). The performance measurement could be a comprehension score or the accuracy (number or proportion of words read correctly) or speed of reading. The use of these methods in various combinations is demonstrated nicely by many papers in this Special Issue. Even so, a fundamental question is how we could obtain efficient measurement and reliable quantification of reading performance. Attempts at addressing this challenge have led to the development of several near reading tests over the past few decades, including the Bailey-Lovie Near Chart (Bailey & Lovie, 1980), the Minnesota Reading

[1] There are different definitions for "features". Here, features refer to units of pixels or dots that form distinguished structures that are critical to the identity of individual letters. However, features are not restricted to the presence of something, they could also refer to the absence of something, for instance, the gap of a Landolt C target.

https://doi.org/10.1016/j.visres.2019.06.002

Available online 26 June 2019
0042-6989/

Acuity Test (MNREAD; Mansfield, Ahn, Legge, & Luebker, 1993), the Radner Reading Chart (Radner, Willinger, Obermayer, Mudrich, & Eisenwort, 1998) and the IREST (Trauzettel-Klosinski, Dietz, & The IReST Study Group, 2012).

The MNREAD test has been widely used in clinical or applied research but has been limited to only five sets of sentences because of the stringent linguistic and typographic design criteria. In this Special Issue, Mansfield, Atilgan, Lewis, and Legge (2019) describe a computer algorithm that has generated millions MNREAD-compliant sentences. The authors present data showing that the algorithmically generated sentences produce very similar results to the original MNREAD sentence sets.

To date, much has been learned about the impact on reading of the properties of stimulus text. These properties include print size (Legge, Rubin et al., 1985; Legge, Pelli et al., 1985; Legge & Bigelow, 2011), contrast (Legge, Rubin, & Luebker, 1987; Rubin & Legge, 1989), text color (Legge & Rubin, 1986), blur (Chung et al., 2007), and retinal eccentricity (Chung, Mansfield, & Legge, 1998; Latham & Whitaker, 1996; Pelli et al., 2007). Interactions of these properties have also been studied, for example, the interaction of print size and retinal eccentricity (Chung et al., 1998; Latham & Whitaker, 1996), and contrast and retinal eccentricity (Chung & Tjan, 2009). However, not as much is known about how non-visual factors and differences across writing systems interact with text properties to affect reading. In this Special Issue, He, Baek and Legge (2018) extend the investigation of the interaction effects of print size and retinal eccentricity to Korean, a language with a more complex orthography. They found that Korean reading speed is more affected by retinal eccentricity than English, a finding that they attributed to the increased within-character crowding arising from the more complex Korean characters. In relation to crowding, it has been shown that letters can be recognized more accurately when their contrast polarity is opposite to that of their nearby neighbors, for example, a white target letter surrounded by black letters would be more easily recognized than a white letter surrounded by other white letters (Kooi, Toet, Tripathy, & Levi, 1994; Chung & Mansfield, 2009). However, the improved letter recognition performance does not lead to improved reading performance (Chung & Mansfield, 2009). One explanation for the lack of improvements when reading words that comprise mixed contrast-polarity letters could be the disruption of word form. Recognizing this possibility, Rummens and Sayim (2019) tested whether or not applying opposite contrast polarities to syllables, instead of letters, could improve reading performance. Davidenko and Ambard (2018) examined the effects of egocentric and environmental reference frames on reading text with different orientations. They measured response time for lexical decisions while subjects sat upright or lay sideways, and found that the function relating response time to text orientation differed between these two postures. The authors discussed their findings in relation to the use of head-mounted displays. Stoops and Christianson (2019) found that inflectional morphology in Russian (a language with linear concatenative morphology) can be integrated parafoveally.

Since reading is such a pivotal daily activity, there is intense interest in investigating and improving reading in special populations, including children, people with dyslexia, and people with impaired vision. In this Special Issue, we have seven papers that cover a variety of topics on reading in special populations. Latham (2018) used a new metric to evaluate the benefits of low vision devices on reading. She measured reading performance using the MNREAD chart without and with low vision devices. Despite an improvement in reading accessibility (i.e. smaller print could be read) with the use of low vision devices, reading accessibility of her low vision participants was still markedly lower than normal levels. Chung and Bernard (2018) investigated whether or not the clinical wisdom of advising patients with macular disease to read bolder text indeed improved reading speed. They measured reading speed as a function of the thickness or boldness of letterstrokes for participants with macular disease and found that, contrary to expectations, participants did not significantly benefit from reading print with bolder letterstrokes. Stolowy et al. (2019) attempted a different approach to improving reading speed for people with macular disease. Instead of manipulating the low-level characteristics of text such as letter and line spacing (Chung, 2002; Chung, Jarvis, Woo, Hanson, & Jose, 2008; Calabrèse et al., 2010; Yu, Cheung, Legge, & Chung, 2007) and letterstroke thickness (Chung & Bernard, 2018), these authors explored the effect of word frequency on word reading speed. Their results demonstrate a clear effect of frequency on word reading time and suggest that inferential processes are stronger in readers with macular disease than in readers with normal vision. These results suggest that text simplification might be a tool to improve reading speed for this population. Gantz, Sousou, Gavrilov, and Bedell (2019) investigated whether people with infantile nystagmus benefit from reading text with a different orientation than the conventional horizontal orientation because of the potential smearing of text along the horizontal direction due to the incessant eye movements of these individuals. They found that reading speed was fastest for horizontally oriented text and dropped for other text orientations for participants with infantile nystagmus and normal vision alike. Still, the reduction in reading speed for non-horizontally oriented text was greater for participants with infantile nystagmus than for those with normal vision.

Colored overlays have been suggested as a means to reduce visual stress and improve reading speed for children with normal vision and children with reading disability (for a review, see Wilkins, 2002). Veszeli and Shepherd (2019) investigated the effects of the color and size of the colored overlays on reading speed in a group of 106 children aged between four and seven years. They found that different children benefited from different color overlays but the effect did not depend on the size of the overlays. Nevertheless, these authors suggested that color overlays may be effective in helping very young children. A major cause of vision impairment in children is amblyopia. When detected early, there is a good chance that the reduced acuity in the weaker eye, or the strabismus (if present), can be treated (Holmes, Lazar, Melia, & The Pediatric Eye Disease Investigator Group, 2011). However, even with treatment, is there a lingering effect of amblyopia or strabismus on reading ability in these children? Kugathasan, Partanen, Chu, Lyons, and Giaschi (2019) addressed this question by comparing the reading ability of children treated for strabismic or anisometropic amblyopia, and children treated for strabismus without amblyopia, with normal controls. The authors found that the mean performance for all groups was within the average range of the normative sample, but several children treated for amblyopia or for strabismus had below-average scores on the single-word reading task. These authors interpreted their findings as an indication that both strabismus and amblyopia could disrupt reading ability even following successful treatment. Raghuram, Hunter, Gowrisankaran, and Waber (2019) assessed self-reported vision-related symptoms and sensorimotor measures of vergence, accommodation and ocular motor tracking skills for a group of children with developmental dyslexia and a group of children with normal vision. They found that ocular motor tracking was associated with visual symptoms in the developmental dyslexia group.

The concluding paper of this Special Issue is an essay by Bigelow (2019) that provides an extensive historical background on typeface features and explains many aspects of conversions or relationships between traditional type design features (especially those in print) and modern type designs that can be displayed digitally. This account should be highly relevant to future studies of reading and vision at a time of transition from the printed page to digital display.

We hope that you will find this collection of papers on vision and reading both stimulating and informative. In addition to the longstanding questions considered here, future research on vision and reading will need to address the challenge of the increasingly pervasive role of technology, including mobile devices, head-mounted displays, and virtual and augmented reality. This is an exciting and fascinating time for research in reading.

References

Bailey, I. L., & Lovie, J. E. (1980). The design and use of a new near-vision chart. *American Journal of Optometry and Physiological Optics, 57*, 378–387. https://doi.org/10.1097/00006324-198006000-00012.

Bernard, J.-B., & Castet, E. (2019). The optimal use of non-optimal letter information in foveal and parafoveal word recognition. *Vision Research, 155*, 44–61. https://doi.org/10.1016/j.visres.2018.12.006.

Bigelow, C. (2019). Typeface features: From analog to digital. *Vision Research*. https://doi.org/10.1016/j.visres.2019.05.003 in press.

Bouma, H. (1970). Interaction effects in parafoveal letter recognition. *Nature, 226*, 177–178. https://doi.org/10.1038/226177a0.

Calabrèse, A., Bernard, J.-B., Hoffart, L., Faure, G., Barouch, F., Conrath, J., & Castet, E. (2010). Small effect of interline spacing on maximal reading speed in low-vision patients with central field loss irrespective of scotoma size. *Investigative Ophthalmology & Visual Science, 51*, 1247–1254. https://doi.org/10.1167/iovs.09-3682.

Chung, S. T. L. (2002). The effect of letter spacing on reading speed in central and peripheral vision. *Investigative Ophthalmology & Visual Science, 43*, 1270–1276. https://doi.org/10.1097/00006324-200012001-00034.

Chung, S. T. L., & Bernard, J.-B. (2018). Bolder print does not increase reading speed in people with central vision loss. *Vision Research, 153*, 98–104. https://doi.org/10.1016/j.visres.2018.10.012.

Chung, S. T. L., Jarvis, S. H., & Cheung, S. H. (2007). The effect of dioptric blur on reading performance. *Vision Research, 47*, 1584–1594. https://doi.org/10.1016/j.visres.2007.03.007.

Chung, S. T. L., Jarvis, S. H., Woo, S. Y., Hanson, K., & Jose, R. T. (2008). Reading speed does not benefit from increased line spacing in AMD patients. *Optometry and Vision Science, 85*, 827–833. https://doi.org/10.1097/OPX.0b013e31818527ea.

Chung, S. T. L., & Mansfield, J. S. (2009). Contrast polarity differences reduce crowding but do not benefit reading performance in peripheral vision. *Vision Research, 49*, 2782–2789. https://doi.org/10.1016/j.visres.2009.08.013.

Chung, S. T. L., Mansfield, J. S., & Legge, G. E. (1998). Psychophysics of reading. XVIII. The effect of print size on reading speed in normal peripheral vision. *Vision Research, 38*, 2949–2962. https://doi.org/10.1016/S0042-6989(98)00072-8.

Chung, S. T. L., & Tjan, B. S. (2009). Spatial-frequency and contrast properties of reading in central and peripheral vision. *Journal of Vision, 9*(9), 16.11–16.19. https://doi.org/10.1167/9.9.16.

Coates, D. R., Bernard, J.-B., & Chung, S. T. L. (2019). Feature contingencies when reading letter strings. *Vision Research, 156*, 84–95. https://doi.org/10.1016/j.visres.2019.01.005.

Crossland, M. D., Culham, L. E., & Rubin, G. S. (2004). Fixation stability and reading speed in patients with newly developed macular disease. *Ophthalmic and Physiological Optics, 24*, 327–333. https://doi.org/10.1111/j.1475-1313.2004.00213.x.

Dagnelie, G., Barnett, D., Humayun, M. S., & Thompson, R. W., Jr. (2006). Paragraph text reading using a pixelized prosthetic vision simulator: Parameter dependence and task learning in free-viewing conditions. *Investigative Ophthalmology & Visual Science, 47*, 1241–1250. https://doi.org/10.1167/iovs.05-0157.

Davidenko, N., & Ambard, A. (2018). Reading sideways: Effects of egocentric and environmental orientation in a lexical decision task. *Vision Research, 153*, 7–12. https://doi.org/10.1016/j.visres.2018.08.006.

Gantz, L., Sousou, M., Gavrilov, V., & Bedell, H. E. (2019). Reading speed of patients with infantile nystagmus for text in different orientations. *Vision Research, 155*, 17–23. https://doi.org/10.1016/j.visres.2018.12.004.

Ginestet, E., Phénix, T., Diard, J., & Valdois, S. (2019). Modeling the length effect for words in lexical decision: The role of visual attention. *Vision Research, 159*, 10–20. https://doi.org/10.1016/j.visres.2019.03.003.

He, Y., Baek, S., & Legge, G. E. (2018). Korean reading speed: Effects of print size and retinal eccentricity. *Vision Research, 150*, 8–14. https://doi.org/10.1016/j.visres.2018.06.013.

Holmes, J. M., Lazar, E. L., Melia, B. M., & The Pediatric Eye Disease Investigator Group (2011). Effect of age on response to amblyopia treatment in children. *Archives in Ophthalmology, 129*, 1451–1457. https://doi.org/10.1001/archophthalmol.2011.179.

Kooi, F. L., Toet, A., Tripathy, S. P., & Levi, D. M. (1994). The effect of similarity and duration on spatial interaction in peripheral vision. *Spatial Vision, 8*, 255–279. https://doi.org/10.1163/156856894X00350.

Kugathasan, L., Partanen, M., Chu, V., Lyons, C., & Giaschi, D. (2019). Reading ability of children treated for amblyopia. *Vision Research, 156*, 28–38. https://doi.org/10.1016/j.visres.2019.01.001.

Latham, K. (2018). Benefits of low vision aids to reading accessibility. *Vision Research, 153*, 47–52. https://doi.org/10.1016/j.visres.2018.09.009.

Latham, K., & Whitaker, D. (1996). A comparison of word recognition and reading performance in foveal and peripheral vision. *Vision Research, 36*, 2665–2674. https://doi.org/10.1016/0042-6989(96)00022-3.

Legge, G. E., & Bigelow, C. A. (2011). Does print size matter for reading? A review of findings from vision science and typography. *Journal of Vision, 11*(5), 8.1–8.22. https://doi.org/10.1167/11.5.8.

Legge, G. E., Pelli, D. G., Rubin, G. S., & Schleske, M. M. (1985). Psychophysics of reading — I. Normal vision. *Vision Research, 25*, 239–252. https://doi.org/10.1016/0042-6989(85)90117-8.

Legge, G. E., & Rubin, G. S. (1986). Psychophysics of reading. IV. Wavelength effects in normal and low vision. *Journal of the Optical Society of America, A, 3*, 40–51. https://doi.org/10.1364/JOSAA.3.000040.

Legge, G. E., Rubin, G. S., Pelli, D. G., & Schleske, M. M. (1985). Psychophysics of reading — II. Low vision. *Vision Research, 25*, 253–265. https://doi.org/10.1016/0042-6989(85)90118-x.

Legge, G. E., Rubin, G. S., & Luebker, A. (1987). Psychophysics of reading — V. The role of contrast in normal vision. *Vision Research, 27*, 1165–1177. https://doi.org/10.1016/0042-6989(87)90028-9.

Mansfield, J. S., Ahn, S. J., Legge, G. E., Luebker, A. (1993). A new reading-acuity chart for normal and low vision. *Ophthalmic and visual optics/noninvasive assessment of the visual system technical digest. Vol. 3. Ophthalmic and visual optics/noninvasive assessment of the visual system technical digest* (pp. 232–235). Washington, D.C.: OSA.

Mansfield, J. S., Atilgan, N., Lewis, A. M., & Legge, G. E. (2019). Extending the MNREAD sentence corpus: Computer-generated sentences for measuring visual performance in reading. *Vision Research, 158*, 11–18. https://doi.org/10.1016/j.visres.2019.01.010.

Masson, M. E. J. (1983). Conceptual processing of text during skimming and rapid sequential reading. *Memory and Cognition, 11*, 262–274. https://doi.org/10.3758/bf03196973.

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), 20.1–20.36. https://doi.org/10.1167/7.2.20.

Potter, M. C. (1984). Rapid serial visual presentation (RSVP): A method for studying language processing. In D. Kieras, & M. Just (Eds.). *New methods in reading comprehension research* (pp. 91–118). Hillsdale, N. J.: Erlbaum.

Radner, W., Willinger, U., Obermayer, W., Mudrich, C., & Eisenwort, B. (1998). A new reading chart for simultaneous determination of reading vision and reading speed. *Klinische Monatsblätter für Augenheilkunde, 213*, 174–181. https://doi.org/10.1055/s-2008-1034969.

Raghuram, A., Hunter, D. G., Gowrisankaran, S., & Waber, D. P. (2019). Self-reported visual symptoms in children with developmental dyslexia. *Vision Research, 155*, 11–16. https://doi.org/10.1016/j.visres.2018.11.007.

Rubin, G. S., & Legge, G. E. (1989). Psychophysics of reading — VI. The role of contrast in low vision. *Vision Research, 29*, 79–91. https://doi.org/10.1016/0042-6989(89)90175-2.

Rubin, G. S., & Turano, K. (1992). Reading without saccadic eye movements. *Vision Research, 32*, 895–902. https://doi.org/10.1016/0042-6989(92)90032-e.

Rubin, G. S., & Turano, K. (1994). Low vision reading with sequential word presentation. *Vision Research, 34*, 1723–1733. https://doi.org/10.1016/0042-6989(94)90129-5.

Rummens, K., & Sayim, B. (2019). Disruption uniformity: Feature contrasts that reduce crowding interfere with peripheral word recognition. *Vision Research, 161*, 25–35. https://doi.org/10.1016/j.visres.2019.05.006.

Stolowy, N., Calabrèse, A., Sauvan, L., Aguilar, C., François, T., Gala, N., ... Castet, E. (2019). The influence of word frequency on word reading speed when individuals with macular diseases read text. *Vision Research, 155*, 1–10. https://doi.org/10.1016/j.visres.2018.12.002.

Stoops, A., & Christianson, K. (2019). Parafoveal processing of inflectional morphology in Russian: A within-word boundary-change paradigm. *Vision Research, 158*, 1–10. https://doi.org/10.1016/j.visres.2019.01.012.

Thorn, S., & Thorn, F. (1989). Television and vision: Reading captions when vision is blurred. *American Annals of the Deaf, 134*, 35–38. https://doi.org/10.1353/aad.2012.0714.

Toet, A., & Levi, D. M. (1992). The two-dimensional shape of spatial interaction zones in the parafovea. *Vision Research, 32*, 1349–1357. https://doi.org/10.1016/0042-6989(92)90227-a.

Trauzettel-Klosinski, S., Dietz, K., & The IReST Study Group (2012). Standardized assessment of reading performance: The new international reading speed texts IReST. *Investigative Ophthalmology & Visual Science, 53*, 5452–5461. https://doi.org/10.1167/iovs.11-8284.

Veszeli, J., & Shepherd, A. J. (2019). A comparison of the effects of the colour and size of coloured overlays on young children's reading. *Vision Research, 156*, 73–83. https://doi.org/10.1016/j.visres.2019.01.006.

Wilkins, A. (2002). Coloured overlays and their effects on reading speed: A review. *Ophthalmic and Physiological Optics, 22*, 448–454. https://doi.org/10.1046/j.1475-1313.2002.00079.x.

Yu, D., Cheung, S. H., Legge, G. E., & Chung, S. T. L. (2007). Effect of letter spacing on visual span and reading speed. *Journal of Vision, 7*(2), 2.1–2.10. https://doi.org/10.1167/7.2.2.

Susana T.L. Chung
School of Optometry, University of California Berkeley, Berkeley, CA 94720, United States
E-mail address: s.chung@berkeley.edu.

Gordon E. Legge
Department of Psychology, University of Minnesota, Minneapolis, MN 55455, United States
E-mail address: legge@umn.edu.

Denis G. Pelli
Department of Psychology, New York University, New York, NY 10003, United States
E-mail address: denis.pelli@nyu.edu.

Cong Yu
Department of Psychology, Peking University, Beijing, China
E-mail address: yucong@pku.edu.cn.