The reciprocal relationship between letter size and luminance contrast when reading.

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Abstract

Reading is one of the most important activities in daily life. This makes legibility a highly important area of concern. However, different letters have various levels of contrast, and there is still scholarly debate on how legibility should be defined. This paper discusses the literature on contrast and reading, with a particular focus on human contrast sensitivity. More specifically, this includes a review of previous studies on retinal spatial frequency, contrast sensitivity, object frequency bands that contribute to character recognition, and the effects of both character size and contrast on reading efficiency. Results show that the critical band of a letter and contrast sensitivity at the retinal spatial frequency at which the critical band is processed may help to predict reading efficiency. There are also several prospects for examining reading performance in individuals with low vision.

Keywords: Letter size, Luminance contrast, Reading, Contrast sensitivity function, MNREAD.

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Introduction

Reading is one of the most crucial activities in the context of daily life. The widespread nature of this need is also known to substantially impact quality-of-life factors for people with low vision [1], particularly from the perspective of legibility. This makes it necessary to consider the luminance contrast of individual letters as well as the observer's contrast sensitivity. This review summarizes the current body of literature on contrast sensitivity, human visual characteristics, letter size, luminance contrast as a design factor, and the impacts of all such issues on reading performance.

Retinal spatial frequency and contrast sensitivity

Spatial frequency is the measure of periodic changes in luminance with spatial location. It is represented as a two-dimensional grating stimulus in which a pair of dark and light areas is set to one cycle. The spatial frequency indicates the number of times the cycle is repeated per unit of space; the spatial frequency of a stripe repeating three cycles per one degree of visual angle is represented as 3 cycles/degree (cpd). There are various waveforms of the grating, the simplest of which is the sine wave. Regardless of complexity, any spatial pattern can be represented by a combination of sine wave gratings of various frequencies. A spatial frequency analysis decomposes a complex spatial pattern into sine wave gratings of various frequencies and then analyzes the amplitude at each frequency.

Spatial patterns that are not simple sine waves are referred to as broadband stimuli. In this sense, they "contain various frequencies". Letters are also considered a type of broadband stimulus, as they contain information across a wide range of frequency bands. Some studies have suggested the existence of a spatial analysis phase during the human visual perception process [2-4]. In this context, early visual processing (e.g., LGN or V1) is thought to play a role in determining which frequency components are present and in what amounts, with the results being used for object recognition.

Not all gratings within each spatial frequency are equally visible to humans. Individual sensitivity to the grating of each retinal spatial frequency is described as the Contrast Sensitivity Function (CSF), which is the envelope of the contrast sensitivity of some channels that respond to a relatively narrow frequency band [4,5]. A well-known example of this is the band-pass function, which peaks at 3–4 cpd. CSF would be regarded as a filter for predicting how humans perceive an object image that is comprised of sine wave gratings with various retinal spatial frequencies.

Pelli and Bex (2013) previously conducted a detailed review of the methods used to measure contrast sensitivity [6]. From a practical standpoint, some methods use letters to assess contrast sensitivity reduction, including the Pelli-Robson Chart [7]. While full CSF is not measured very often due to the substantial amount of time required, reports have indicated that low vision CSF can be predicted based on normal vision CSF [8].

Object spatial frequency and letters

Other than sine waves, most objects and images are broadband stimuli that contain wide ranges of spatial frequency elements. Reports have shown that the object spatial frequency information of objects contributes to their recognition. For example, Van Meeteren and Barlow (1981) examined the pattern recognition process using visual stimuli that modulated random dot patterns according to the sine wave. Regardless of stimulus size, they found that four or five stripes (2 to 2.5 cycles/object) were detected most easily and effectively while also having the lowest contrast sensitivity [9].

Research has also shown that very limited information in the object spatial frequency significantly contributes to letter recognition. In this regard, Parish and Sperling conducted a letter identification task with a two-octave wide bandpass filtered alphabetic character between 0.74 and 20.25 cycles/letter (cpl) [10]. Their results suggested that the most efficient recognition was for letters with central frequencies of 1.49 cpl. In this experiment, comparisons were made at different viewing distances and under different retinal spatial frequencies, but scale invariance remained in the 32:1 range of viewing distances which meant the effect of letter size was limited.

Some researchers have reported that letter recognition efficiency significantly decreases when information in the specific frequency band is disturbed. One study used noise masking methods to estimate the object spatial frequencies used for letter identification, thus suggesting that 2–3 cpl was particularly important for roman letter identification [11]. Another study used the Bubbles method to show that a band of 2–4 cpl contributed to character recognition [12]. Several studies have also suggested that certain bands of spatial frequencies are relevant to character recognition [13-16]. Taken together, the critical band of roman letters presumed to be approximately 1-3 cycles/letter, although this number varies slightly between studies.

The critical band is not constant in all situations. In fact, research has indicated that it may vary depending on the complexity of the letter [17,18]. Some studies have also shown that the critical band is size-dependent. For example, Alexander, Xie, and Derlacki (1994) measured contrast thresholds for multiple letter sizes using bandpass-filtered letters [19], thus finding that letter sizes of 0 logMAR and 0.3 logMAR were most efficiently identified with a 1.25 cpl filter, while those of 0.7 logMAR were most effectively identified with a 2.50 cpl filter. Majaj, Pelli, Kurshan, and Palomares (2002) also reported that larger letters demanded higher-frequency outline information for identification [17].

Letter size and reading efficiency

Reading efficiency is defined as the accuracy and speed of character recognition in this article. In this context, reading speed is usually calculated based on the time and number of the error taken to reading aloud a text. Reading speed is therefore a good measure of reading efficiency. It is affected by many factors, particularly including letter size. As such, Legge and Bigelow (2011) conducted an in-depth review of how letter size affects the reading process [20].

Letter size and reading speed have been described as a two-limbed function [21]. That is, reading speed is quick and constant with sufficient letter size, but rapidly slows down with decreased letter size, especially below a certain point. Since reading speed also decreases when letters are too large, there is an inverse U-shaped relationship between letter size and reading speed when including extremely big sizes at ends [22].

The Minnesota low vision reading chart (MNREAD) is widely to measure reading efficiency [23]. While the original version is presented in English, there are also versions for use in other language contexts, including Japanese [24], Portuguese [25], Turkish [26], Greek [27], and Persian [28]. The MNREAD chart consists of a set of sentences that become progressively smaller at 0.1 log size intervals. The observer is asked to read aloud beginning with the largest size while an experimenter measures reading time and records the number of correct answers. Here, three representative values that define reading efficiency are obtained based on the reading speed function for letter size, including reading acuity (RA), maximum reading speed (MRS), and the smallest letter size that can be read at MRS (i.e., critical print size; CPS). CPS is particularly important because it is used to prescribe magnifiers or eyeglasses.

Luminance contrast and reading efficiency

Luminance contrast is a spatial characteristic that represents the lightness of objects such as letters. It is calculated based on the brightness of both the letters and their background. Along with human contrast sensitivity, several studies have examined how luminance contrast works as a physical dimension to affect letter legibility. Fosse and Valberg (2001) compared several related measures between individuals with normal vision and those with age-related macular degeneration (AMD), including the contrast sensitivity of gratings, visual acuity, and reading speed [29]. In patients with AMD, peak contrast sensitivity was shifted toward lower frequencies, while sensitivity at peak frequency varied greatly between individuals, which affected reading. The researchers thus suggested that the integrated sensitivity of each frequency band affected reading, not the contrast sensitivity of any specific band.

While Fosse and Valberg (2001) reported that overall contrast sensitivity affected reading [29], both Leat and Woodhouse (1993) and Rubin & Legge (1989) suggested that specific retinal frequency bands affected reading [30,31]. The evidence shows a linear relationship between contrast sensitivity and reading speed in the retinal spatial frequency band of 0.5 cpd [29]. This prompted the researchers to conclude that the limited retinal spatial frequency band affected reading speed, as the combined sensitivity of the other frequency bands did not increase the explanatory rate of the reading speed estimation. In Rubin and Legge's (1989) experiments, the contrast threshold measured at 0.3 cpd characters accurately estimated the critical contrast, which indicates a contrast whose reading speed took 50% of the maximum [31].

Other studies have measured contrast sensitivity between children with and without reading disabilities, thus reporting a reduction in sensitivity with 2 to 4 cpd in children with reading difficulties [32]. Experiments have also been conducted to compare eye movements between younger and older adults based on their readings of frequency-filtered sentences, thus showing that fixation time was longer and associated with increased difficulty when participants were presented with sentences that were filtered to a higher central frequency of 11.1 cpd, especially among the older adults [33].

Based on the results described above, it is difficult to determine which retinal spatial frequency bands are critical for reading with respect to various contrasts. Legge, Pelli, Rubin, and Schleske (1985) had participants read a sentence that had been subjected to a low-pass filter, finding that reading speed decreased as the cutoff frequency fell below 2 cpl [22]. It is consistent with the critical band mentioned in the previous section. Reading efficiency may be predicted by considering both the critical band of a letter and the contrast sensitivity of the retinal spatial frequency at which it is processed.

Joint considerations of letter size and luminance contrast

Studies on reading performance have produced interesting results when jointly considering luminance contrast and letter size. Legge et al. (1987) examined whether the inverse U-shaped relationship between letter size and reading speed was affected by luminance contrast [34], thus finding that peak reading speed values were not significantly different across the 99–10% settings. Fujita, Oda, Watanabe, and Yuzawa (2008) conducted an experiment with the MNREAD chart in which they implemented varied luminance contrast settings ranging between 10-100% [35]. They reported that decreased luminance contrast resulted in increased CPS, although there were no effects on MRS. This indicates that the function itself shifted to a larger font size without changing the shape of the function. Ohnishi et al. (2020) reported different reading speed measurements for variously sized phrases with contrasts ranging from 3.1% to 99.3% [36], thus supporting Fujita et al. (2008) [35].

The result in Ohnishi et al. (2020) suggested a reciprocal relationship between letter size and contrast [36]; that is, CPS increases as luminance contrast decreases. However, experiments conducted by Legge et al. (1987) showed that MRS drops significantly at 3% luminance contrast [34]. In sum, there is still room for scholarly debate on the relationship between luminance contrast and letter size, meaning that continued research is needed.

Discussion

When assessing the relationship between luminance contrast and reading efficiency, it is first crucial to consider the object spatial frequency and its intensity of letters as a physical factor in addition to the retinal spatial frequency and its contrast sensitivity as a human visual characteristic. Assuming the existence of a critical band, both its amplitude and the contrast sensitivity of the corresponding retinal spatial frequency can affect reading. For small letters, the critical band is processed at a higher retinal spatial frequency, and may not be processed with low-contrast letters due to low contrast sensitivity. For larger letters, the critical band is processed at a lower retinal spatial frequency and it might be patient with contrast reduction. These hypotheses may explain the results obtained by both Fujita et al. (2008) and Ohnishi et al. (2020) [35,36].

The finding that MRS is stable with decreasing contrast may constitute an important practical solution for people with low vision [35,36]. A variety of documents seen in daily life contain low contrast letters. As such, there may be cases in which CPS (as measured by high-contrast text) is insufficient for persons with low vision. However, MRS can be achieved by increasing the text size to compensate for reduced contrast and/or contrast sensitivity.

Ohnishi et al. (2020) showed a linear relationship between the logarithms for contrast and CPS [36]. However, the slope of this relationship was not zero for all observers, but varied according to the individual. This indicates individual differences in how large the font size must be to compensate for the contrast reduction.

It should be noted that both Fujita et al. (2008) and Ohnishi et al. (2020) were conducted among participants with normal vision [35,36]. On the other hand, Rubin and Legge (1989) investigated how contrast affected reading speed among individuals with low vision [31]. Results showed that the shape of the reading function itself did not greatly differ from that seen among individuals with normal vision, instead suggesting influences from other factors depending on the condition of the eyes (e.g., polarity).

It is also necessary to consider that the critical band of letter identification may vary depending on letter size and the visual field. In this regard, reports have shown that the critical band shifts to higher frequencies with larger letter [17,19]. It has also been suggested that lower object frequency bands may be important for peripheral vision [15,37]. These findings may be more important when considering reading issues for persons with low vision, who may require larger print sizes when viewing letters in their peripheral vision.

It is important to determine the appropriate level of magnification when the contrast of the stimulus is reduced. In this regard, it may be useful to implement a predicted sensitivity function, as done by Chung and Legge (2016) [8]. If multiple reading functions with different contrasts are obtained in advance, then it may be possible to predict the influence of contrast at the individual level. Alternatively, if future studies determine the factors affecting the coefficients, then it may be possible to predict the magnification required to read low-contrast texts based on MNREAD results for high-contrast texts.

Conclusion

Based on a literature review, this paper discusses how both luminance contrast and letter size affects reading efficiency. There are three main points:

- Both luminance contrast and letter size have significant impacts on reading efficiency.
- There is a reciprocal relationship between luminance contrast and letter size.
- Individual contrast sensitivity is an important factor for determining reading performance across a variety of contrasts and sizes.

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References

1. Mangione CM, Berry S, Spritzer K, et al. Identifying the content area for the 51-item National Eye Institute Visual Function Questionnaire: results from focus groups with visually impaired persons. Arch Ophthalmol 1998;116:227-33.
2. De Valois RLD, Albrecht DG, Thonrell LG. Spatial Frequency Selectivity of Cells in Macaque Visual Cortex. Vision Res 1982;22:545–59.
3. Daugman JG. Two-dimensional spectral analysis of cortical receptive field profiles. Vision Res 1980;20:847-56.
4. Maffei L, Fiorentini A. The visual cortex as a spatial frequency analyser. Vision Res. 1973;13:1255-67.
5. Campbell BYFW, Robson JG. Application of Fourier analysis to the visibility of gratings. J. Physiol 1968;197:551-66.
6. Pelli DG, Bex P. Measuring contrast sensitivity. Vision Res 2013;90:10-4.
7. Pelli DG, Robson JG, Wilkins AJ. The design of a new letter chart for measuring contrast sensitivity. Clin Vision Sci. 1988;2:187-99.
8. Chung ST, Legge GE. Comparing the shape of contrast sensitivity functions for normal and low vision. Investig. Ophthalmol. Vis. Sci. 2016;57:198-207.
9. Van Meeteren A, Barlow HB. The statistical efficiency for detecting sinusoidal modulation of average dot density in random figures. Vision Res. 1981;21:765-77.
10. Parish DH, Sperling G. Object spatial frequencies, retinal spatial frequencies, noise, and the efficiency of letter discrimination. Vision Res. 1991;31:1399–415.
11. Solomon J, Pelli D. The visual filter mediating letter identification. Nature. 1994;369:395-7.
12. Fiset D, Blais C, Ethier-Majcher C, et al. Features for identification of uppercase and lowercase letters. Psychol Sci. 2008;19:1161–8.
13. Braje WL, Tjan BS, Legge GE. Human efficiency for recognizing and detecting low-pass filtered objects. Vision Res. 1995;35:2955–66.
14. Chung STL, Legge GE, Tjan BS. Spatial-frequency characteristics of letter identification in central and peripheral vision. Vision Res. 2002;42:2137-52.
15. Kwon M, Legge GE. Spatial-frequency cutoff requirements for pattern recognition in central and peripheral vision. Vision Res. 2011;51:1995-2007.
16. Kwon M, Legge GE. Spatial-frequency requirements for reading revisited. Vision Res. 2012;62:139-47.
17. Majaj NJ, Pelli DG, Kurshan P, et al. The role of spatial frequency channels in letter identification. Vision Res. 2002;42:1165-84.
18. Zhang JY, Zhang T, Xue F, et al. Legibility variations of Chinese characters and implications for visual acuity measurement in Chinese reading population. Investig. Ophthalmol. Vis. Sci. 2007;48:2383-90.
19. Alexander KR, Xie W, Derlacki DJ. Spatial-frequency characteristics of letter identification. J Opt Soc Am A Opt Image Sci Vis. 1994;11:2375-82.
20. Legge GE, Bigelow CA. Does print size matter for reading? A review of findings from vision science and typography. J. Vis 2011;11:8.
21. Mansfield JS, Legge GE, Bane MC. Psychophysics of reading. XV: font effects in normal and low vision. Invest Ophthalmol Vis Sci, 1996;37:1492-501.
22. Legge GE, Pelli DG, Rubin GS, et al. Psychophysics of reading--I. Normal vision. Vision Res. 1985;25:239–52.
23. Legge GE, Ross JA, Luebker A, et al. Psychophysics of reading. VIII. The Minnesota low-vision reading test. Optom Vis Sci. 1989;66:843-53.
24. Oda K, Mansfield JS, Legge GE. MNREAD-J: new reading evaluation chart to prescribe the aids for people with low-vision. 1998. 7th Annual Meeting of Japanese Association for Rehabilitation of the Visually Impaired, 101-104.
25. Castro CT, Kallie CS, Salomão SR. Development and validation of the MNREAD reading acuity chart in Portuguese. Arquivos brasileiros de oftalmologia. 2005;68:777-83.
26. İdil ŞA, Çalişkan D, İdil NB. Development and validation of the Turkish version of the MNREAD visual acuity charts. Turk J Med Sci. 2011;41:565-70.
27. Mataftsi A, Bourtoulamaiou A, Haidich AB, et al. Development and validation of the Greek version of the MNREAD acuity chart. Clin Exp Optom. 2013;96:25-31.
28. Elham R, Jafarzadepur E. Development and validation of the persian version of the MNREAD acuity chart. J Curr Ophthalmol. 2020;32:274.
29. Fosse P, Valberg A. Contrast sensitivity and reading in subjects with age-related macular degeneration. Vis Impair Res. 2001;3:111-24.
30. Leat SJ, Woodhouse JM. Reading performance with low vision aids: relationship with contrast sensitivity. Ophthalmic Physiol Opt 1993;13:9-16.
31. Rubin GS, Legge GE. Psychophysics of reading. VI--The role of contrast in low vision. Vision Res. 1989;29:79-91.
32. Lovegrove W, Martin F, Bowling A, Blackwood M, Badcock D, Paxton S. Contrast sensitivity functions and specific reading disability. Neuropsychologia 1982;20:309-15.
33. Paterson KB, McGowan VA, Jordan TR. Filtered text reveals adult age differences in reading: evidence from eye movements. Psychol Aging. 2013;28:352–64.
34. Legge GE, Rubin GS, Luebker A. Psychophysics of reading--V. The role of contrast in normal vision. Vision Res. 1987;27:1165-77.
35. Fujita K, Oda K, Watanabe J, Yuzawa M. How normal eyes perform in reading low-contrast texts. Jpn J Ophthalmol. 2008;52:44-7.
36. Ohnishi M, Otsukuni T, Takahashi A, Sugiyama M, Hirakimoto M, Ogawa S, Suzuki A, Oshima Y, Sheu C-F, Oda K. Effects of luminance contrast and character size on reading speed. Vision Res. 2020;166:52-9.

37. Anderson RS, Thibos LN. The filtered Fourier difference spectrum predicts psychophysical letter discrimination in the peripheral retina. Spatial Vision. 2004;17:515.

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