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Size or spacing: Which limits letter recognition in people with age-related macular degeneration?

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ABSTRACT

Recent evidence suggests a double dissociation of size and spacing limit on letter recognition—it is limited by size in the fovea and critical spacing in the normal periphery. Here, we evaluated whether size or spacing limits letter recognition in people with age-related macular degeneration (AMD) who must use their peripheral vision. We measured the size threshold for recognizing lowercase letters presented alone, or flanked by two letters at various center-to-center nominal letter spacings (multiples of letter size) for 11 observers with AMD. For comparison, similar measurements were obtained at 5° and 10° eccentricity in the nasal and lower visual fields in three older adults with normal vision. Single-letter size thresholds were worse for observers with AMD than at comparable retinal locations in the normal periphery. For flanked letters, size threshold improved with larger nominal spacing up to the critical spacing, beyond which size threshold was unaffected by the flankers. Seven AMD observers had a nominal critical spacing between 1.25× and 1.80×, values close to those in the normal fovea, suggesting that their letter recognition is size-limited; two had a nominal critical spacing of 3–4×, values close to those in the normal periphery, implying that their letter recognition is limited by spacing; and another two had a nominal critical spacing of ~2.3×, implying that their letter recognition is limited by both size and spacing. The wide range of nominal critical spacings observed in our AMD observers may reflect the degree of completeness of their adaptation process to vision loss.

1. Introduction

To see an object clearly, the object needs to be large enough such that it exceeds the resolution limit of the eye. However, even when an object is large enough to be recognizable on its own, its recognition may still be hampered if it is closely surrounded by other objects. This is the crowding phenomenon (Flom, 1991; Flom, Heath, & Takahashi, 1963; Flom, Weymouth, & Kahneman, 1963; Levi, 2008; Pelli, Palomares, & Majaj, 2004) and is more pronounced in peripheral vision (Jacobs, 1979; Toet & Levi, 1992). Crowding has been suggested as the bottleneck for object recognition (Levi, 2008; Pelli, 2008; Pelli & Tillman, 2008) and the major limiting factor on reading (Levi, Song, & Pelli, 2007; Pelli et al., 2007).

The pronounced effect of crowding in the periphery naturally leads to the hypothesis that it is a bottleneck on vision for people who lose their central (foveal) vision and must rely on their peripheral vision. The leading cause of central vision loss is age-related macular degeneration (AMD), which is a leading cause of visual impairment in developed countries, especially for people over the age of 65 (e.g. Congdon et al., 2004; Friedman et al., 2004). The relevance of crowding in limiting vision for people with AMD not only relates to the fact that people with AMD have to rely upon their residual peripheral vision to function, but also because reading is the primary goal of most people with AMD seeking visual rehabilitation (Bullimore & Bailey, 1995; Kleen & Levoy, 1981; Leat & Rumney, 1990) and that crowding has been suggested as the major limiting factor on reading (Levi, Song, & Pelli, 2007; Pelli et al., 2007).

If crowding limits reading for people with AMD, then a simple way to minimize crowding and thus improve reading is to increase the separation between adjacent letters in text. A previous attempt in improving reading in AMD through increasing letter spacing in text shows that for all 14 participants in that study, 12 of whom had AMD, the letter spacing that yielded the maximum reading speed, the *critical spacing*, was essentially the same as the conventional standard spacing used in most printed text (Chung, 2012). This result suggests that there is no need to increase the letter spacing beyond the standard for people with AMD, as long as the print size is large enough for them to achieve their maximum reading speed. In other words, people with AMD do not seem to suffer from as much crowding as would be expected based on the normal

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periphery. A caveat of this previous study is that the critical spacing was determined for a reading task. Because people can often read a word correctly without having to recognize individual letters correctly (Mansfield & Legge, 1999; Rawlinson, 1976), the critical spacing for reading may differ from that for letter recognition, which represents a more genuine limitation on how object spacing limits our vision (but see Levi, Song, and Pelli (2007) and Pelli et al. (2007) in which these authors showed that the critical spacing for reading is the same as the critical spacing for letter recognition, a topic that we will discuss in Section 4). Therefore in this study, we used a letter recognition task to determine the critical spacing. Pelli (2008) proposed that for unimpaired recognition of objects, the minimal separation between each pair of objects must exceed a critical spacing that depends solely on the physical location of the objects in the visual field, but is invariant to the object types or categories. Thus the critical spacing determined in this study would help us understand how object spacing limits object recognition in general, instead of the more specific question of how letter spacing limits letter recognition.

Pelli's notion suggests that in addition to object size, there is another limitation on object recognition—object spacing. What then, is the primary limiting factor on object recognition—size or spacing, or does that depend on different situations?

By measuring the threshold letter size (the smallest letter size required to reach a given level of recognition accuracy) required for observers to recognize a letter flanked by other letters for a range of letter spacings, Coates, Chin, and Chung (2013) and Song et al. (2014) independently showed that the threshold letter size depends on letter spacing, but only when the letter spacing is within the critical spacing. Within this regime, letter recognition is limited by letter spacing but not letter size. When the letter spacing exceeds the critical spacing, threshold letter size is independent on letter spacing, and it is size that limits letter recognition in this regime (see Figs. 3 and 4, which will be explained in greater details in Section 3). These results showed that for any given condition, the primary limiting factor on letter recognition is the greater of the two—size limitation or the critical spacing. At the fovea, these authors found that the critical spacing is very small, consistent with the well-known effect that there is very little crowding at the fovea (Chung, Levi, & Legge, 2001; Levi, Klein, & Hariharan, 2002; Toet & Levi, 1992). Song et al. further showed that when observers were asked to recognize blurry letters at the fovea, the critical spacing increases at the same rate as the threshold letter size. These findings imply that the primary limitation on letter recognition for foveal vision is size (resolution). As long as the size of a letter exceeds the resolution limitation, then observers would be able to recognize the letters well, even in the presence of closely flanked letters. In the normal periphery, the story is different. Although the letter size required for correct recognition of single letters increases with eccentricity (Jacobs, 1979; Wertheim, 1980), the critical spacing increases at a faster rate than that for resolution (Coates, Chin, & Chung, 2013; Jacobs, 1979; Levi, Song, & Pelli, 2007), with the effect that letters that can be recognized on their own would not be recognizable if other letters are present within a distance that is smaller than the critical spacing at the retinal location of the target letter.

In this study, we applied a similar methodology and analysis as those of Coates, Chin, and Chung (2013) and Song et al. (2014) to determine whether size or spacing is the more important limiting factor on letter recognition for people with AMD. On one hand, if size was the primary limiting factor on letter recognition, then as long as the letter size is large enough such that single letters could be recognized, patients with AMD would be able to recognize letters at this size even when they are presented in groups, as in text. The result would also suggest that these patients show the characteristics of the normal fovea, in which size is the primary limiting factor on letter recognition. On the other hand, if spacing was the primary limiting factor on letter recognition, then it means that patients with AMD would benefit more from enlarging the spacing, not the letter size. Considering that the currently available optical and electronic magnifiers enlarge object and the space around an object equally, practically it means that patients would still have troubles recognizing letters that are presented in groups, as in text, even if the letters are made large enough to be recognizable when presented alone. The result would also suggest that these patients exhibit the properties of the normal periphery, in which spacing is the primary factor limiting letter recognition. Clearly, not all patients with AMD would show the same limitation. In Section 4, we will propose a simple test, based on only two measurements of letter size thresholds, to predict whether letter size or spacing is the more important factor limiting letter recognition for a given patient.

2. Methods

Eleven observers with AMD, with age ranging from 66 to 89 years, participated in this study. All had confirmed diagnosis by an ophthalmologist or optometrist. The duration for which they had been diagnosed with the disorder ranged from 0.5 to 15 years (see Table 1). Table 1 lists the characteristics, visual acuity as measured using the Bailey–Lovie Acuity Chart and the number of years since the onset of the disorder of these observers. The location of the preferred retinal locus[1] for fixation (PRL, a retinal location outside the dysfunctional macular area adopted as the locus for fixation) as measured using a Rodenstock scanning laser ophthalmoscope (SLO) is included for 10 of the 11 observers. Two of these observers showed residual foveal sparing (see footnote b of Table 1). All observers gave written informed consent before the commencement of data collection. This research followed the tenets of the Declaration of Helsinki and was approved by the Committee for Protection of Human Subjects at the University of Houston and the University of California, Berkeley.

To evaluate whether letter size or spacing is the principal factor limiting letter recognition for people with AMD, we determined the threshold letter size for recognizing the middle letter of sequences of three random lowercase letters (trigrams) for a range of horizontal letter spacings. Threshold letter size was defined as the letter size that yielded a performance accuracy of 52%-correct (50%-correct, after correction for guessing (guessing rate = 1/26)) based on a psychometric function that summarized an observer's performance (see later). We used lowercase letters instead of the more conventional letter symbols for measuring acuity such as Sloan letters (Song et al., 2014) or Tumbling-E stimuli (Coates, Chin, & Chung, 2013) because of our interest in relating the critical spacing for letter recognition with the critical spacing for reading as reported previously (Chung, 2012). Each letter was randomly chosen from the 26 letters of the Times-Roman alphabet, with no repeat allowed within the trigram. We defined letter size according to the *x*-height in degrees of visual angle, and letter spacing as the center-to-center separation between two adjacent letters, specified as multiples of letter size, or, *nominal* letter spacing. Nominal letter spacing is a relative measurement and relates to the absolute spacing by multiplying by the letter size. For example, a nominal letter

[1] Following the onset of the central vision loss, patients often adopt a retinal location outside the dysfunctional macular area as the reference locus for seeing. This location is usually referred to as the preferred retinal locus (PRL). There are reports that the PRL may differ for different tasks, here, our definition of PRL was for a fixation task. However, most of the observers in this study have participated in other studies in our lab in which SLO measurements were obtained. Informal observation showed that in most cases, their PRLs did not change for a fixation, letter recognition and saccadic task.