The Effects of Crowding on Letter Identification

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ABSTRACT

In everyday life, it is rare that one is called upon to identify a letter completely isolated from all other stimuli. Yet much of visual research centers around such experiments. Learning how one identifies a single letter is, of course relevant to understanding how words, sentences, paragraphs, etc. are interpreted. However, little is known about why nearby letters interfere with the recognition of a single letter within the group. The *crowding* effect, is much stronger in peripheral than in foveal vision. It is also marked in the vision of people afflicted with amblyopia, a visual disorder affecting about 2% of the population. Through this study, it was found that the critical spacing of the crowding effect is identical in normal foveal and peripheral, as well as in amblyopic vision. Crowding is often referred to as contour interaction, implying that the crowding effect is due to interference between neighboring features. However, comparisons of the size of letters being identified and the minimum space between letters required to eliminate the effect of crowding and recent research on the scale dependence of letter identification show that crowding is not the result of interference between features. Rather, crowding occurs at the level of pattern recognition.

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INTRODUCTION

Past research in vision has given some hints as to how we recognize objects. Subjects of study have ranged from perception of relatively simple patterns, such as stripes, to more complex objects, such as letters and words. Most of the research dealing with letter recognition concerns identification of single letters. However, in everyday life, recognition of single letters is a task seldom performed. Rather, it is the identification of strands of letters, making up words, that constitutes the vast majority of day to day reading tasks.

LITERATURE RESEARCH

The recognition of a given character has long been known to be strongly degraded by the presence of neighboring characters (Ehlers, 1936). The degree of interference caused by the neighboring characters depends on several factors, including the separation between the characters, their size, and their location in the visual field (Strasburger et al., 1991). This phenomenon, commonly referred to as the crowding effect, is especially pronounced in the vision of amblyopes, as well as in normal peripheral vision (i.e. looking out of the "corner" of one's eye). The very existence of a crowding effect in the normal fovea is often disputed.

Bouma (1970) found a correlation between eccentricity (distance of a target from the fovea in degrees of visual angle) and crowding using single letters of height 1.95 mm as targets flanked on either side by distracter letters. He reported that crowding became apparent when the flanks were at a distance from the target of roughly half the eccentricity. No significant effect from crowding was found in the fovea. This runs counter to many other studies showing not only that there is a crowding effect in the fovea, but that crowding in the periphery and in amblyopes is identical to crowding in the fovea except for a change in scale. Levi, Klein & Aitsebaomo (1985 a,b) measured the effects of crowding on vernier acuity in normal central and peripheral as well as in amblyopic vision. They found that for all three conditions, the extent of spatial interference present due to flanks (distracters) above and below the target was proportional to the unflanked vernier threshold. This scaling was also found in a similar experiment with Landolt C's (Flom et al., 1963). Levi et al. found that the spatial extent of interference could be predicted by estimates of the cortical magnification.

Cortical Magnification

The visual cortex of the brain is arranged in a columnar fashion. Different columns are responsible for different aspects of vision, such as color and orientation. For each small area of the visual field, there is a small module, called a hypercolumn, that is responsible for analyzing all of these aspects. The size of hypercolumns remains relatively constant across the cortex, but the area of the visual field each hypercolumn analyzes increases with eccentricity. Because a disproportionately large area of the cortex is used to analyze the part of the visual field contained in the fovea, the fovea is represented in greater detail than the periphery; thus acuity is best in the fovea and decreases with eccentricity. The "cortical magnification" theory of spatial vision seeks to explain all decreases in visual performance through this fact about the arrangement of hypercolumns in the visual cortex. According to the theory, the difference between foveal and peripheral vision is only a difference in scale.

Amblyopia

Many crowding experiments include at least one amblyopic observer. The reason for this is simple--a large effect of crowding is one of the hallmarks of amblyopic vision. *Amblyopia*, Greek for "blunt" or "dull" "vision", is somewhat of a catch-all phrase describing any loss of visual acuity without observable cause. The two most common causes of amblyopia are anisometropia and strabismus. Anisometropia is an uncorrected difference in the focus of the two eyes, leading to a suppression of one eye. Strabismic amblyopia is a misalignment of the two eyes, which produces a double image unless one eye is suppressed. The crowding effect in strabismics, unlike in anisometropes, is larger than their acuity deficit would predict (Levi & Klein,1985).

Scale Dependence

It is often taken for granted that the visual mechanisms underlying object identification scale with the size of the object. A recent study of the visual "channels" used to identify letters contradicts this assumption of proportional scaling. A channel is a group of neurons in the visual cortex that is sensitive to objects of a certain size. Majaj, Kurshan, Palomares and Pelli (1997) determined the channels used to identify letters of different sizes and complexities. They found that large letters are recognized through finer channels relative to their size, while smaller letters are identified via relatively coarse channels, revealing that identification of single letters is scale dependent.

HYPOTHESIS

Recent work on letter identification indicates that the process through which humans identify letters is divided into two stages that are only loosely coupled. The first stage, feature detection, independently detects components of the letter. The second stage, pattern recognition, groups the isolated features and matches their arrangement to that of a known pattern. The two stages differ not only in function but in method. Pattern matching necessarily scales with letter size, while the features used in identifying letters do not. Whether crowding occurs at the first or second of these stages is not known, but can be inferred by comparing letter size with critical spacing. If crowding is caused by interference at the feature level, then critical spacing should scale with the features used, which do not scale with letter size. On the other hand, if crowding is caused by interference at the level of pattern recognition, then critical spacing should be proportional to letter size.

Additionally, there have been mixed results concerning whether the effects of crowding are similar across the visual field. Analysis of the critical spacings at different target eccentricities should give a suggestion as to how crowding in the fovea relates to crowding in the periphery.

METHOD

Task and Measurements

Observers viewed a gamma corrected grayscale computer monitor (Pelli & Zhang, 1983) and were asked to fixate a point either at the center or 5 or 10 degrees from the center of the screen. A target letter, flanked by four distracter letters (above, below, and to the right and left of the target, as shown in Fig. 1) was presented for 200 ms. (The *spacing*, the distance of the distracters from the target in degrees of visual angle, was varied across runs). After a delay of 200 ms, the screen displayed the ten letters from the Sloan alphabet. The observer was asked to identify the target letter by pointing and clicking on it with the mouse. Correct trials were rewarded with a beep. Letters were from a set of 10 Sloan characters specified by the NAS-NRC Committe on Vision(1980). The Sloan font is available for research purposes. Energy thresholds (the amount of energy required for the observer to correctly identify 82% of the letters) were measured by 40-trial runs of the modified Quest staircase procedure (Watson and Pelli, 1983; King-Smith et al., 1994).

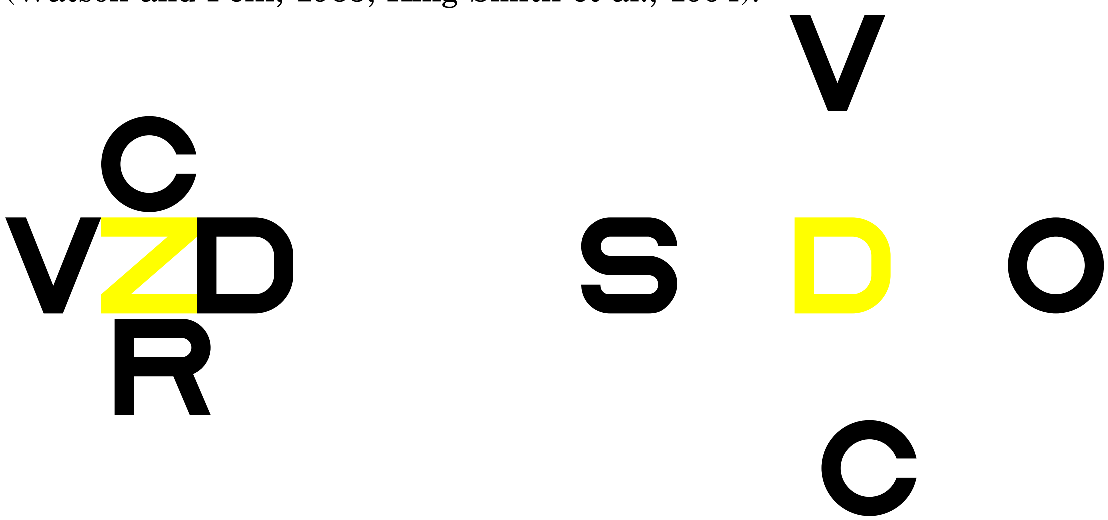

Fig. 1: CROWDED LETTERS. Stimulus used in crowding experiment.

Observers

Three observers with normal or corrected-to-normal vision as well as one observer with strabismic amblyopia performed the task. Results from the three normal observers were similar, so that the data from the first observer are representative, and is the data most often presented. Testing on the normal observers was binocular. Testing on the strabismic subject was monocular, occluding the unaffected eye by a black eye patch. Data collection on the strabismic subject was limited by his extremely low acuity (4/20) in his amblyopic eye.

Stimuli

The stimuli were created using MATLAB software on a Macintosh Power PC 7500/100 using Brainard's (1997) *Psychophysics Toolbox* and Pelli's (1997) *Video Toolbox*. The background luminance was set to the middle of the monitor's range, about 16 cd/m^2.

Data analysis

Energy threshold as a function of letter spacing was measured at several target eccentricities and letter sizes. All graphs displayed a similar pattern. Thresholds were highest at the smallest spacing, that is, when the flanking letters were closest to the target, and decreased as spacing increased, until a critical spacing was reached. Once this critical spacing was surpassed, thresholds remained constant. We fit a template function to each graph of threshold (Fig. 2) to estimate the critical spacing (Fig. 3).

RESULTS AND DISCUSSION

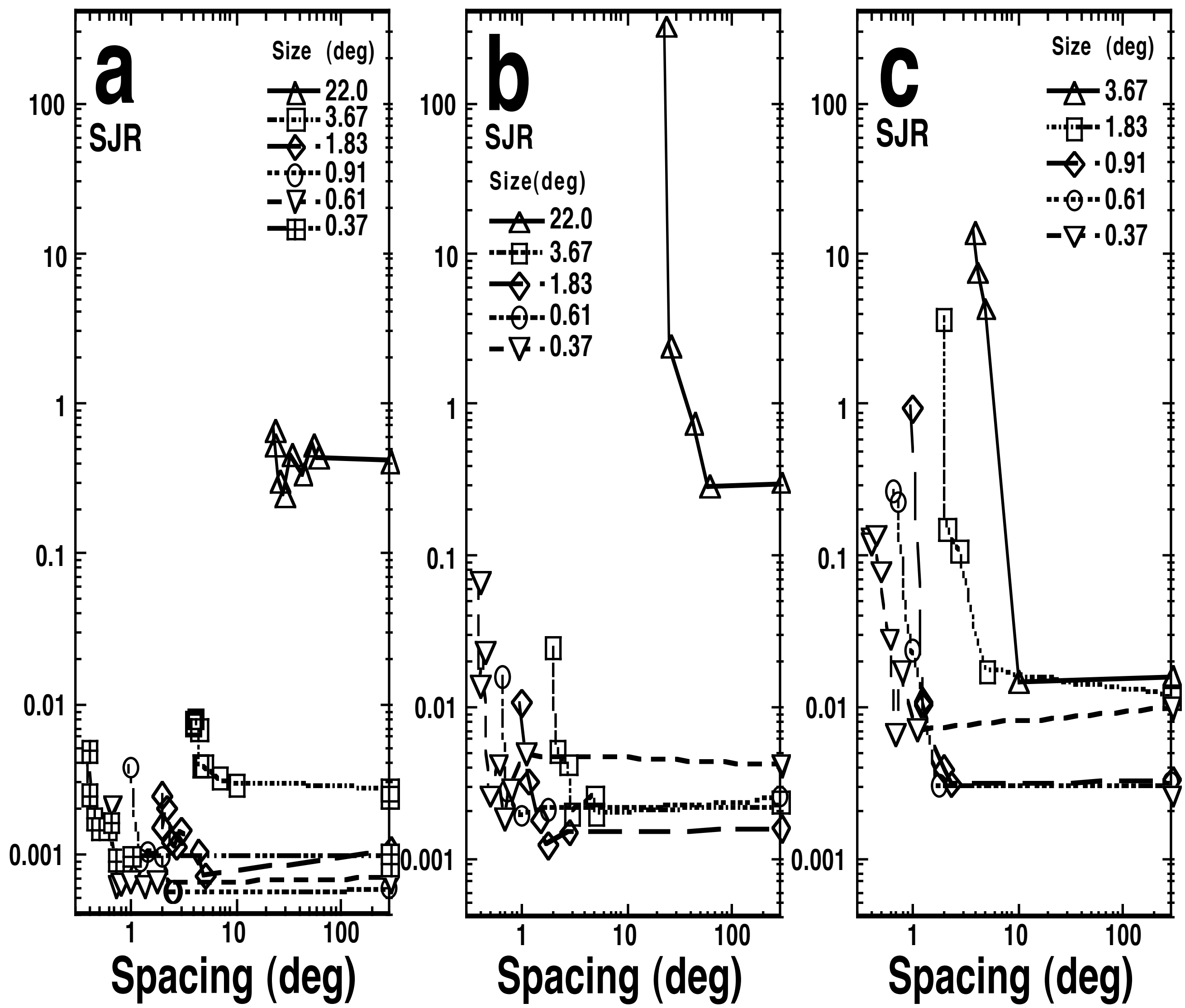

Fig. 2 : ENERGY THRESHOLD VS. DISTANCE BETWEEN LETTERS.
Threshold energy measured as a function of spacing between target and distracter letters at (a) the fovea, (b) 5° eccentricity and (c) 10° eccentricity.

Fig. 2 shows obvious differences between the data collected when the target image fell on the fovea of the observer and that when the image was in the observer's peripheral field of view. The overall energy threshold is much higher at greater target eccentricities, and the threshold elevation due to crowding also increases greatly in the periphery. However, it can also be readily observed that though the graphs differ in magnitude, they all have the same L-like shape. We fit a template function to each graph in

Fig. 2 to provide an estimate of the critical spacing, which is plotted in Fig. 3, for each viewing condition.

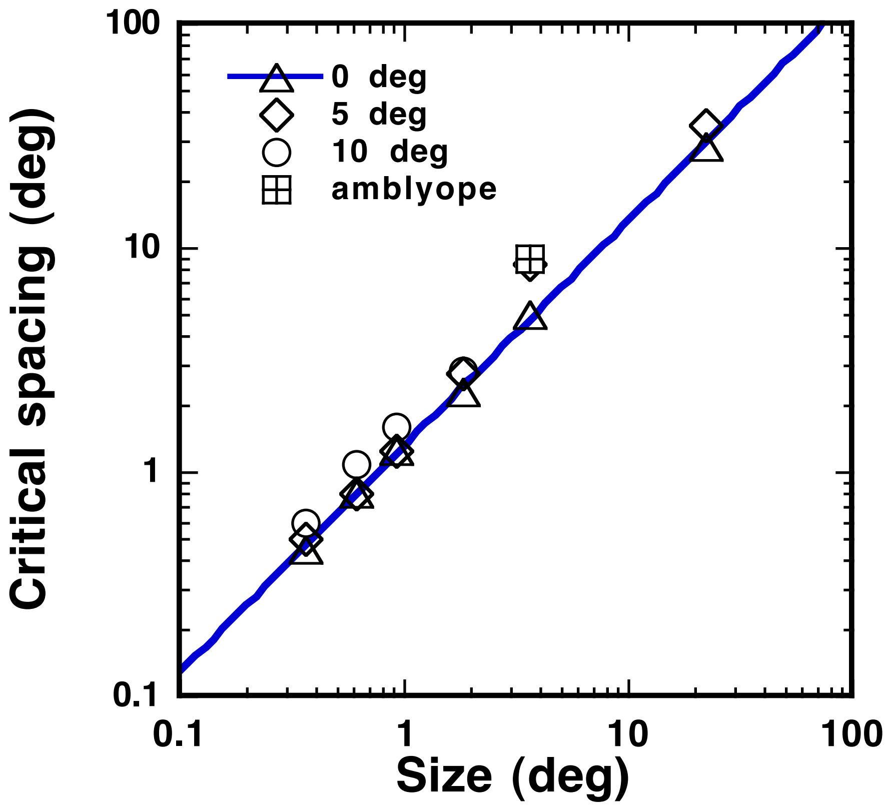

Fig. 3 : CRITICAL SPACING AS A FUNCTION OF LETTER SIZE

The derived graph has all of the data from the three different viewing conditions and a point obtained from testing of an amblyope. The straight line, with a slope of about 1, is a fit to the normal foveal data.

The log-log slope of 1 shows that critical spacing is proportional to letter size. If crowding occurred at the level of a feature, one would expect a log-log slope of about 0.7 (Majaj et al., 1997). The fact that critical spacing is proportional to letter size indicates that crowding occurs later, presumably at the level of pattern recognition. This is consistent with results from Strasburger et al. (1991) suggesting that crowding arises from more than mere contour interaction.

The similar shapes of the graphs in Fig. 2 indicate a similarity between crowding in the periphery and crowding in the fovea. In Fig. 3 it is apparent that critical spacing is virtually the same at all target eccentricities, and varies only with stimulus size. This shows that differences between crowding effects in the center of vision and the periphery are simply differences in intensity, not in spatial scale.

CONCLUSION

Analysis of the functions relating letter size to critical spacing, revealedseveral interesting new facts about the effect of crowding on letter identification. First, it was found that critical spacing is proportional to letter size. Using recent findings on the role of features in letter identification, it was possible to infer that since critical spacing for crowding is proportional to letter size, crowding must occur after feature detection, most likely at the level of pattern recognition. We were also surprised to find that the critical spacing is independent of target eccentricity. The effect is stronger in the periphery, but operated, but operated at the same spatial scale, contrary to suggestions that involved the cortical magnification factor.

FUTURE RESEARCH

The topic of crowding is not limited to measures of spatial offsets or discrimination of Landolt C's, or even to more common tasks, such as letter identification. Rather, crowding is present in all forms of recognition, since few objects exist in complete visual isolation. One often hears about a "face in the crowd", and it would be interesting to test the effects of crowding on face identification, as well as on recognition of common objects.

APPLICATIONS

Amblyopia is a very common visual disorder, affecting roughly one out of every fifty people. Despite its prevalence, relatively little is known of the disease. By furthering our understanding of the normal periphery, which shares many characteristics of amblyopic vision, we can better enable others to identify and treat amblyopia. General knowledge about letter interaction could also prove very useful for helping to accommodate for those with visual disorders, including, but not limited to, amblyopes, where reading tasks are concerned.

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