Readers Beware!

Effects of Visual Noise on the Channel for Reading

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Summary

The words that you are reading right now are composed of many different frequencies. These frequencies are interpreted by a mechanism in the brain called a visual channel. Channels are dependent solely on the frequency of the stimulus. However, text is made up of many different frequencies. Therefore, we would expect multiple channels to be used during reading. Instead, we found that we only used a channel that was centered around 2.8 cycles per letter.

Abstract

We perceive visual stimuli as a result of processing mechanisms in our brain called channels, which are tuned to spatial frequencies emitted by a signal. Supposing that we have an infinite number of channels at our disposal and that we use the most sensitive channel(s) for the task at hand, it was once assumed that we would use an assortment of channels for objects containing many frequencies. Contrary to this conjecture, Solomon and Pelli (1994) found that for some broadband objects, such as letters, we confine ourselves to only one channel. If this channel is masked by visual noise, identification is impeded. Although the identification of letters is essential, it is not a daily task that we have to master. Instead, we assimilate many letters into words that we must interpret to read. Now, more than ever, text appears on a variety of textured backgrounds containing many spatial frequencies. Our experiments identified which frequencies most disrupt reading, characterizing the frequency-dependent channel that we use to read. We measured reading rates for subjects who were asked to read texts on a background of visual noise bandpass filtered to restrict it to a band of frequencies, with various center frequencies. We found that reading rate as a function of center frequency produced a parabolic curve—indicating that we use only one channel while reading—with a bottom at 2.8 cycles per letter. At this frequency, the noise reduces reading rate by a factor of ten!

Introduction

Reading fascinates scientists of visual perception because it is an important skill that may soon be explainable by existing basic theories of vision. Vision is based on the use of multiple channels. Each channel is selective for a band of spatial frequency.

For an auditory stimuli, pitch is determined by its temporal frequency. Similarly, the coarseness or fineness of a visual pattern is determined by its *spatial frequency*. Visual detection and identification of an object depends on the spatial frequencies contained in the stimulus. Researchers can restrict visual noise to a band of frequency. Auditory noise impairs hearing. Visual noise impairs vision. “White” noise, with equal energy at all frequencies, looks like the static on a television screen (Figure 1).

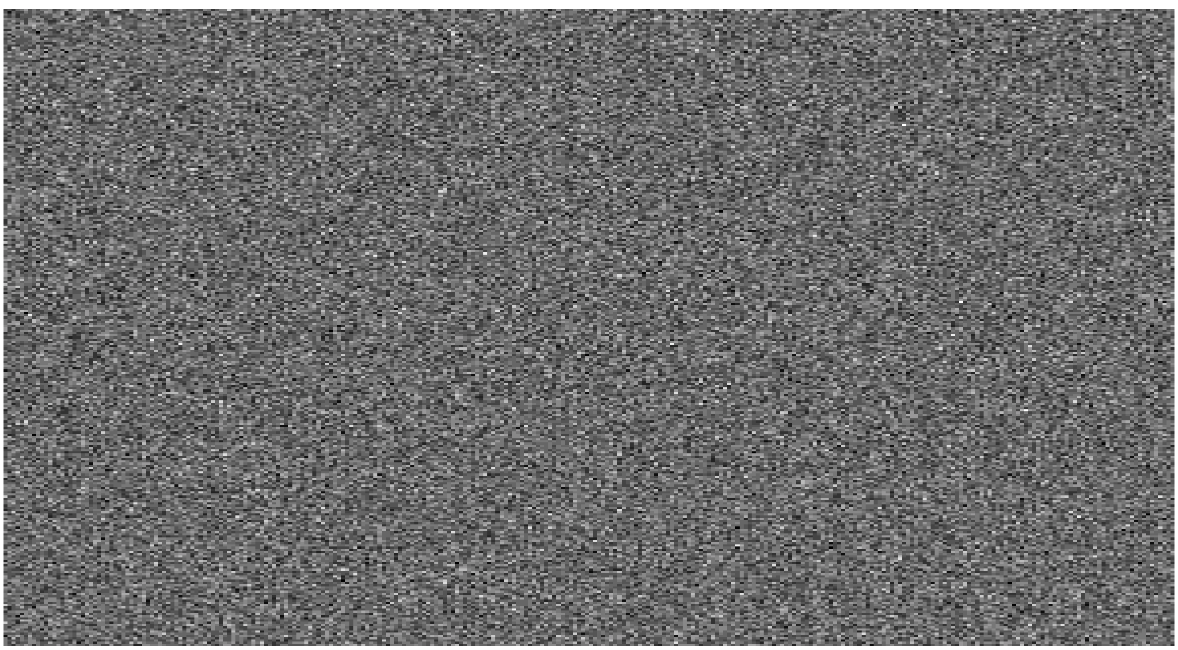

Figure 1. “White” noise, containing equal energy at all frequencies.

Previous research found that our ability to perceive the signal depends on the proximity of the frequencies of the signal and the noise. The detection threshold for the signal is higher when the noise is closer. In hearing, it is harder for us to recognize a signal of a particular frequency when it is intercepted by another signal of a similar frequency. For example, it is harder to discriminate between two high-pitched women than between a low-pitched man and a high-pitched woman. Similarly, in vision, researchers have found that a signal is masked (disrupted) by noise less than an octave away from the frequency of the signal. In other words, noise that is spectrally adjacent to the signal is most effective in suppressing recognition (Stromeyer and Julesz, 1973). But if no part of the mask spectrum falls within two octaves of the signal, detection is not hindered at all.

The idea is the humans identify an object by means of a spatial-frequency-selective visual channel, with a bandwidth of about 1.5 octaves (Campbell and Robson, 1968) (Figure 2).

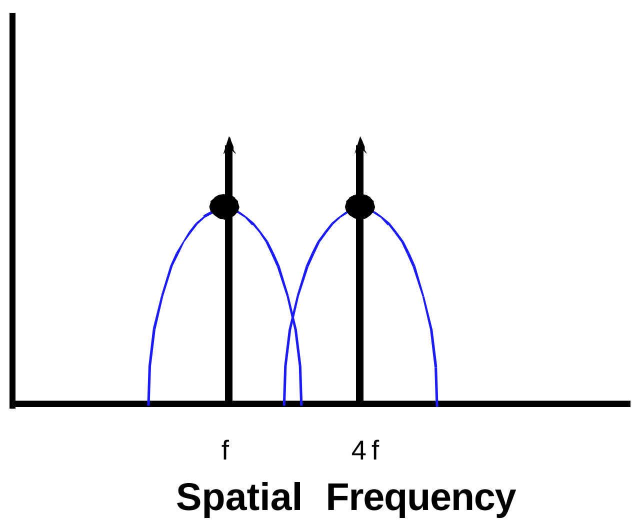

Figure 2. Demonstrates the shape of a frequency-tuned channel. The first channel is tuned to spatial frequency of f. While the other channel is centered around a spatial frequency of 4f.

Since stimuli can be made up of an infinite number of frequencies, we have access to an infinite number of channels to view an object with. Given that most objects are broad band (having a broad spatial frequency spectrum), we would expect many channels to be involved in identifying an object. However, this assumption does not hold for certain objects.

In the case of letters, which are broad band, Solomon and Pelli (1994) found that even though we have an infinite number of channels at our disposal, we identify a letter by means of a single visual channel with a center frequency of 3 cycles/ degree. (1 degree of visual angle is the angle subtended by one cm at a distance of 57 cm; it is roughly the width of your index finger at arm's length.) In order to identify the channel, Solomon and Pelli used critical band masking. White noise contains all the frequencies of the visual spectrum. By filtering, we can limit the noise by letting pass from the visual spectrum only the frequencies that we would like to pass. Limiting the spectrum allows us to see which frequencies impair our ability to see. These measurements characterize the visual channel that is used. White noise masks signals the most because every signal frequency is masked, and Scharff, Hill, and Ahumada (2000) found this in their word-search task.

Measuring reading rate, Legge, Pelli, Rubin, and Schleske (1985) determined that a critical cutoff frequency for reading low pass filtered text was about 2 cycles per letter. (Low pass refers to anything that has been stripped of all its higher frequencies down to the cutoff frequency. Or conversely, text that has all its lower frequencies up to the cutoff.) At 2 cycles per degree, they found that the observer reached an asymptotic reading rate of 247 words per minute. (Asymptotic reading rate is the rate at which the observer is no longer limited by the noise cutoff frequency.)

Moreover, Legge, Pelli, Rubin, Schleske (1985) found that asymptotic reading rate versus character width produced a downward curving parabola. Thus, reading rates for character widths smaller than 0.3 deg declined, possibly due to the acuity limit. For character widths greater than

2 deg, reading rates also dropped, though much less steeply. This might also be due to a visual field limitation. The peak asymptotic reading rate is at a character width of 0.3 deg. This indicates that we read fastest at this character size. Nonetheless, the curve is shallow, and reading rate did not change much over a 60:1 range suggesting that visual processing is nearly size invariant.

Other research has shown that performance for letter identification is also unaffected by size. Parish and Sperling (1981) found that in their letter identification tasks, efficiency for identifying filtered letters in filtered noise was unchanged over a 32:1 range, again indicating size invariance.

Majaj, Pelli, Kurshan, and Palomares (2001) discovered that for letters of different sizes, we use different parts of the letter in order to identify it. Bigger letters are identified by their edges; smaller letters by their gross strokes. The center frequency of the channel rises less than proportionally with the stroke frequency of the letter. This indicates that visual processing *does* depend on letter size.

Methods

Stimuli

The stimuli were created on a Macintosh Power PC. The bandwidths of the spatial frequency were manipulated using the MATLAB Psychophysics Toolbox (Brainard 1997; Pelli 1997). The stimuli consisted of a signal added to a background of noise (Figure 3).

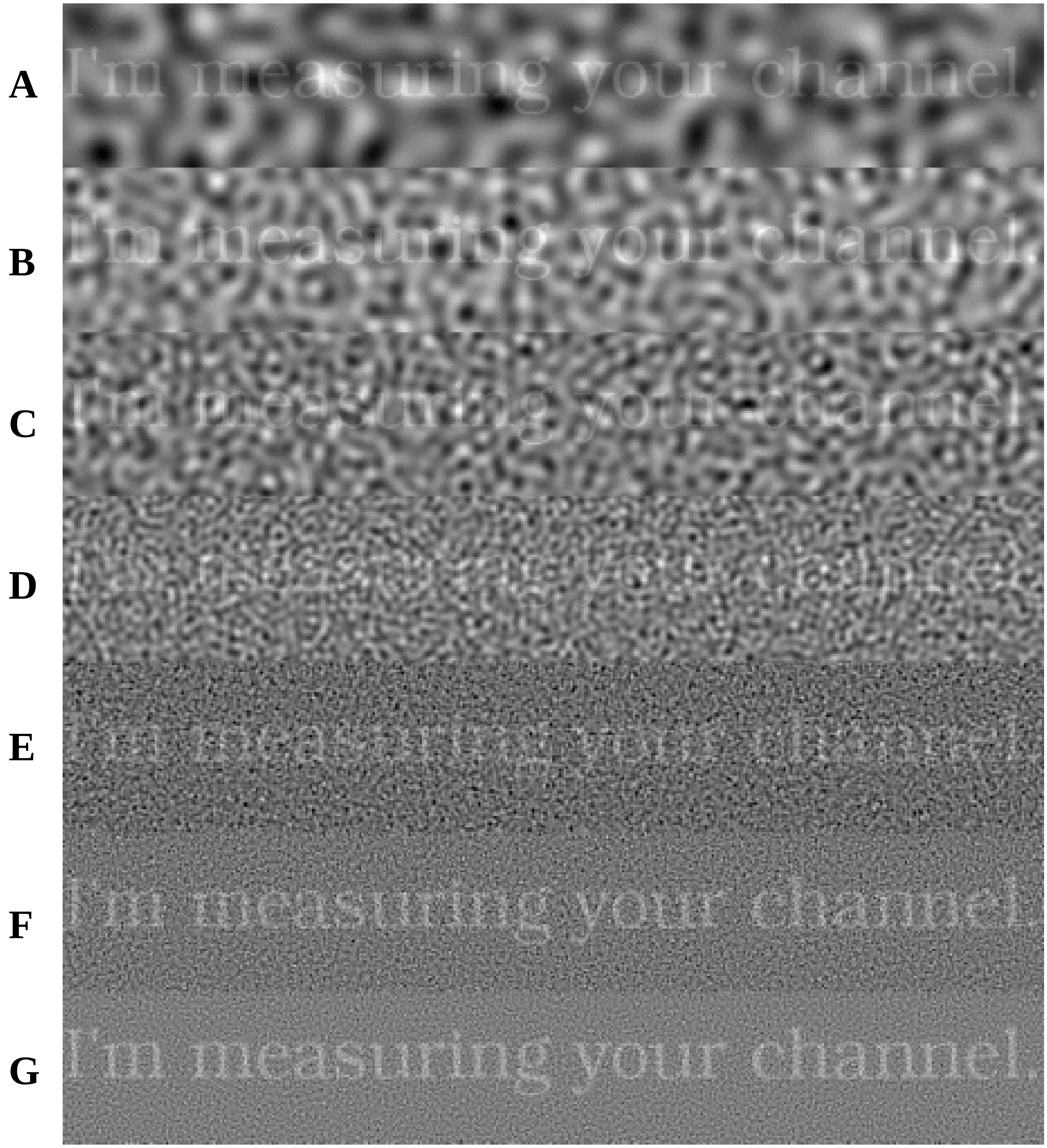

Figure 3. A line of text in noise filtered to various bands. The central frequencies for each of the bands are the following: Band A=.5, B=0.8, C=1.6, D=2.2, E=3.7, F=5.6, G=7.4 c/letter. Not all the bands used for the experiment are shown. As you will probably notice, your reading capacity is most impaired by bands D and E. This corresponds to our result of 2.8, which lies between these two bands.

Signal

Each signal was a passage from the book *The Watership Down* by Richard Adams. Each passage of text was initially rendered as white (1) pixels on a black (0) background in a 922x922 pixel area. The passages contained an average of 57 words. We used size 56 Bookman (1.25 strokes per deg) for comparison with the letter-identification results of Solomon and Pelli (1994).

Contrast

We wanted the contrast for the noise and the text to be such that at the maximum contrasts the text was barely perceptible but not impossible to see. We set the noise contrast to 60% and the text contrast to 18 % (Figure 4 shows a contrast chart).

Figure 4. Eye chart with ever fainter letters, all of the same size, to measure threshold contrast (Pelli, Robson, and Wilkins, 1988).

Noise

MATLAB was used to filter the white noise, using the fast Fourier transform, removing all unwanted frequencies by setting them to zero, and inverting the fast Fourier transform. This generated a visual representation of the frequencies in a window of 922 by 922 pixels. We filtered our noise to a two-octave wide band. However, we also used two narrower bandwidths (Figure 5). We created a no-noise condition as well, to obtain the base reading rate.

Band	Low Cutoff (cycles per image)	High Cutoff (cycles per image)	Center Frequency (cycles per image)	Center Frequency (cycles per letter)
1	6.5	26	13	0.48
2	11	44	22	0.82
3	15	60	30	1.1
4	30	60	42	1.6
5	25	100	50	1.9
6	30	120	60	2.2
7	38	150	75	2.8
8	60	120	85	3.1
9	50	200	100	3.7
10	60	240	120	4.4
11	75	300	150	5.6
12	100	400	200	7.4

Figure 5. The bandwidths of the spatially filtered noise ranging from the low to the high cutoff and defined in our results by the center frequency.

Cycles per letter

Our original frequency was in terms of cycles per image or the whole window containing our noise and our text. We converted the cycles per image into cycles per degree by taking image size and viewing distance into account. Using average center-to-center letter spacing as our measure of letter size, we converted cycles per degree to cycles per letter.

Reading rate

We measured the time it took the observer to read the text, and calculated the reading rate in words per minute. As in Legge et al. (1985), reading rate only counted words read correctly; skipped and mistaken words did not contribute to reading rate.

Procedure

Four observers completed the experiment. All the observers were fluent in English and could read at the level of the text. They also had normal or corrected 20/20 vision. The observers were all between the ages of 17 and 23.

The participants were instructed to sit at a viewing distance of 45 cm (from their eyes to the screen). For each bandwidth of noise, they were asked to read three different paragraphs of text as quickly and accurately as possible. Upon finishing a paragraph, they pressed a key to go to the next paragraph. The participants were given a break halfway through the experiment. Total time to complete the experiment ranged from 30 minutes to one hour.

Results

Figure 6 shows the mean reading rate (for three passages) as a function of the central frequency of the noise (and the no noise condition). The vertical axis decreases rather than increases. The data points for each observer are connected by dotted lines. The no noise value (horizontal gray line) is the average across three of the observers. One of the observers did not complete the no noise condition. All the observers that did run could read the no noise condition the fastest. We used this as a reference for all other reading rates.

The curves of reading rates as a function of log central frequency have an inverted U shape, characteristic of the tuning function for a channel. Reading of text masked by noise of central frequency 2.8 c/letter was the slowest. The further we move away from 2.8 cycles per letter, the more reading rate recovered. At extreme central frequencies, reading rate approached the rate on a blank field.

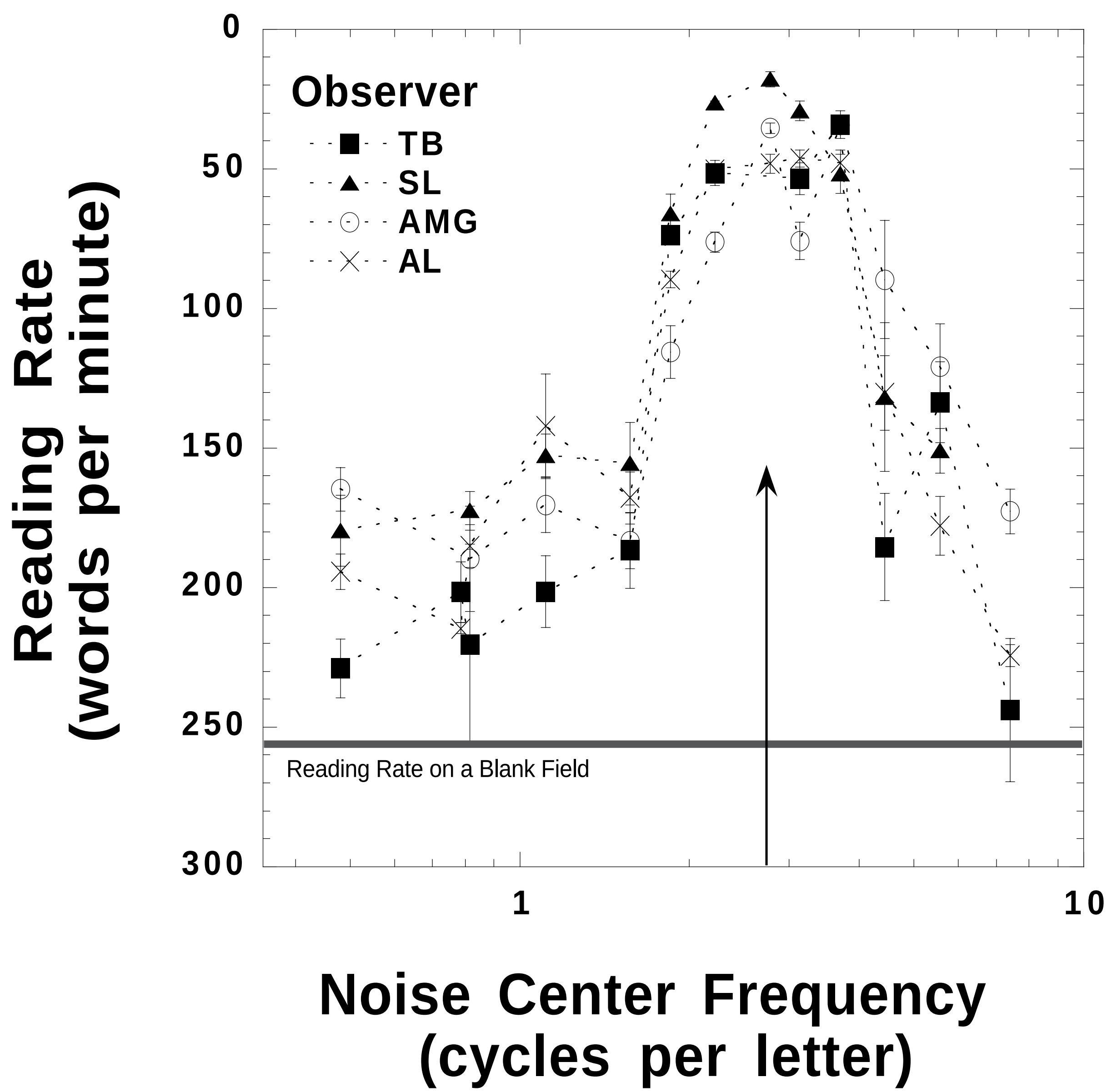

Figure 6. Reading rates as a function of center frequency of the noise. The dotted lines connect the points for each observer. Reading was most impaired by noise at 2.8 cycles per letter, indicated by the vertical arrow. Vertical bars represent plus or minus one standard error of the mean. The horizontal gray line at the bottom represents the average reading rate without noise.

Discussion

Critical band masking characterizes the spatial frequency tuning of a channel by measuring the effectiveness of each noise frequency in impairing performance of the task. This technique has previously been utilized by researchers to find channels, but never before been applied to ordinary reading, only letter identification and word search (Solomon and Pelli, 1994) (Scharff, Hill and Ahumada Jr., 2000).

Our channel is 2.8 cycles per letter. Therefore, noise at this frequency impairs reading most, and noise at nearby frequencies has less effect. As we move further away from the critical bandwidth, the interference by the noise decreases.

This notion of a single channel for reading was suggested by Legge et al. (1985). They investigated the visual requirements of reading and revealed that with low pass filtering, reading rate increased with bandwidth only up to 2 cycles per letter.

Solomon and Pelli (1994) found that observers use a channel centered at 3 cycles per letter to identify letters. This is comparable to our finding of a channel for reading at 2.8 cycles per letter.

The above results indicate that certain noise frequencies can greatly impair readability and that our visual system uses the same channel for identifying letters and reading. Scharff, Hill, and Ahumada (2000) found that textured backgrounds containing a frequency band of 0.75 to 1.5 cycles per letter had the greatest effect on readability on web pages. This result is lower than ours, but their letters were much smaller than ours: only 0.25 degrees. This is consistent with Majaj, Pelli, Kurshan, and Palomares (2001) (2001) finding that channel frequency is a nonlinear function of stroke frequency.

Conclusion

Using a noise-masking paradigm, we found that the visual channel for reading is similar to that for identifying letters in that we only use one channel to identify letters and to read text. Masking that channel greatly impairs reading. At the worst frequency (2.8 c/letter) noise reduced reading by a factor of ten. This is an important consideration for any text that is put on a textured background.

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