On spatial-frequency channels and attention

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In an effort to explain the role of spatial frequency channels in vision, there have been many suggestions, notably by Julesz (1975, 1980; Julesz & Schumer, 1981), Levinson and Frome (Frome, Levinson, Danielson, & Clavadetscher, 1979; Levinson & Frome, 1979), and Braddick and Atkinson (1982), linking them to attention. This idea seems very reasonable in view of the fact that the visual system can selectively attend to stimuli of different spatial frequency spectra that are simultaneously present in a visual scene provided their spectra are more than about 1.5 octaves distant from each other. Consider, for instance, Figure 1, in which the letter T can be easily recognized and, without change of regard, the fine text consisting of the characters E, F, Q, and O can also be "read" if this is what the observer desires to do. Extending from this, one can imagine a text of fine letters whose density variations formed not just a single letter T, but an entire text made up of characters the size of T of Figure 1 (for practical reasons, we chose to illustrate the point with a single letter). It would then be possible to selectively read either the fine text or the coarse text at will without change of viewing distance. The ratio of horizontal dimensions of the T to the two-letter patterns "EF" and "QO" is 4:1, resulting in a 2-octave spatial frequency separation.

In a recent article, Gellatly (1983) reported on the results of experiments he designed to test such proposals, particularly in the form suggested by Julesz, linking attention to spatial frequency channels, which he called the "Julesz theory" and which we will refer to simply as the "Hypothesis." As a matter of fact, one can recognize two forms of the Hypothesis: In the weak form, it states that the visual system can favor a spatial frequency channel by perceiving stimuli whose spectra match this channel while suppressing adequately separated spectra that are simultaneously present in the stimulus. If, in addition, the selection of the favored channel could be achieved as a result of voluntary shifts of attention, then the strong form of the Hypothesis would hold. In the latter case, one could state that spatial frequency channels permit perceptual zooming on finer or coarser picture detail without having to change regard. Gellatly used a frequency-contingent color aftereffect studied by Harris (1970). To examine frequency-contingent color aftereffects, he adapted subjects to red-black and green-black square gratings with fundamental frequencies f and nf , respectively, and then

Figure 1

showed them a composite black-and-white test grating that contained f and nf . When observers viewed these test patterns, some of them observed frequency-contingent color aftereffects for both the top and bottom stripes that contained only pure square gratings of f and nf fundamentals, respectively. In the center stripe, which was a composite of the square gratings in the top and bottom stripes, most saw the stronger of the two colors, some the weaker, and some others reported no color aftereffects. The composite grating in the middle stripe was arranged such that, when concentrating on the lower frequency grating on the top, the observer could force his attention to perceive the composite grating in the middle as a perceptual continuation of the top grating with the lower frequency. Similarly, when the observer concentrated on the higher frequency grating on the bottom, he could then inspect the composite grating in the middle as the perceptual continuation of the bottom grating having the higher frequency. On the basis of the above results, Gellatly questioned the validity of the hypothesis that spatial frequency channels might influence attention shifts.

However, the mere fact that most subjects reported a color aftereffect in the composite pattern is positive evidence for the weak form of the Hypothesis, since it corroborates that they were indeed ignoring some spatial frequency spectra in favor of another. Furthermore, although a pure square grating contains only the odd harmonics of its fundamental, his composite grating contained, in addition, nonnegligible components at $2f$, $4f$, and zero spatial frequencies (e.g., for $n = 3$, the above components had amplitudes that were calculated to be

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86.6%, 43.3%, and 66.7% of the fundamental's amplitude). This means that the frequency components are too close, falling in each others' critical bands. Since the non-linear effects of such complicated phenomena as frequency-contingent color aftereffects are still enigmatic, his results, although of appreciable interest, are not conclusive.

Furthermore, Gellatly did not ask his subjects in a follow-up study whether they were able to perceive the composite grating as the perceptual continuation of the low- or high-frequency gratings. Obviously, if they could do so, then the strong form of the Hypothesis would have been corroborated, contrary to Gellatly's claim. Therefore, in order to avoid a logical paradox, one would have to conclude that the frequency-contingent color aftereffect did not work for his kind of compound gratings. On the other hand, if subjects in the follow-up study could not shift their attention to each of the frequencies in the compound grating at will, then two logical possibilities concurred. Either one realized that the negative outcome precluded the composite grating of Gellatly's being used as a proper stimulus for evoking different color aftereffects by shifting attention or one regarded this negative outcome as proof for the rejection of the strong form of the Hypothesis; and then why bother with additional tests, such as color aftereffects? So, in essence, the only unanswered question remaining is whether it is possible to shift attention to different frequencies in compound gratings. Because Gellatly's compound grating had too many frequencies within each others' critical bands, we created another kind of compound grating, to be discussed next.

Although Figure 1 illustrates the role of attention in spatial frequency channel selection, we present yet another family of visual stimuli (Figures 2 and 3), in which the perception of compound gratings yields further evidence for the validity of the strong form of the Hypothesis. In these images, the top and bottom thirds contain horizontally varying sinusoids of average luminance I and frequencies f and nf , respectively, ($n = 3$ and 5 for Figures 2 and 3). In the middle is shown a pattern that contains only

Figure 2

Figure 3

two pure sinusoids of equal contrast C at f and nf . The value of C was chosen to make the average luminance of this composite waveform equal to I . We hope the reader agrees that: (1) the two components of the middle stimulus are easily separated and distinguished at will; (2) the detection of f (nf) in the middle is easier if we first concentrate on the top (bottom) third and then move our eyes toward the middle; and (3) the detection of f (nf) is easier for $n = 5$ (which is 2.5 octaves above f) than it is for $n = 3$. These were the observations of subjects who were tested in a pilot study.

The above arguments seem to corroborate the strong form of the Hypothesis, according to which spatial frequency channels can aid in shifting attention, thus permitting perceptual zooming.

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