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Binocular Unmasking: An Analog to Binaural Unmasking?

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A visual analog to binaural unmasking was explored. The observer's task was to detect, under stereoscopic viewing conditions, an apertured sinusoidal grating added to a square patch of visual noise. In the experimental condition, the square patch of noise was presented within a frame such that the right-eye noise was a shifted version of the left-eye noise. Because of the disparity in the noise images, subjects perceived, under stereoscopic viewing conditions, that the noise patch was located behind the frame. When sinusoidal signals were added to this noise patch, the signals were clearly more detectable when the signal disparity was zero than when the signal disparity equaled that of the noise patch, demonstrating the existence of visual unmasking. Hence, under appropriate circumstances, binocular processing, in addition to providing information about depth, can also enhance the detectability of visual patterns.

THERE HAVE BEEN NUMEROUS DEMONSTRATIONS of the ability of the auditory system to use the information available in an interaural comparison to unmask a sound that is undetectable monaurally (1). This ability helps us, for instance, to isolate and attend to one sound source in a noisy room to the exclusion of others (the so-called "cocktail party effect"). Its importance in auditory processing is undisputed, and a number of models have been advanced to explain how the signal is extracted from the noise background (2). There are, however, no published reports of its direct counterpart in vision (3). This fact struck us as curious, especially because there is sufficient information available in interocular comparisons to permit visual unmasking in situations that are analogous to those in which auditory unmasking occurs. To show why this is the case, we (i) describe an auditory situation that produces a strong unmasking effect; (ii) show how a simple linear model of interaural processing can unmask the signal; (iii) describe an analogous binocular situation; and (iv) show how the compara-

ble linear model of interocular processing can unmask the visual signal. Finally, we present data that demonstrate the existence of binocular unmasking in this situation.

Consider an experiment in which a band-limited Gaussian noise of unit spectral density, $n(t)$, is presented to the left ear, and a time-delayed version of the same noise, $n(t-\delta)$, is presented to the right ear, where δ is the amount of delay in seconds. The listener's task is to detect a pure tone added in

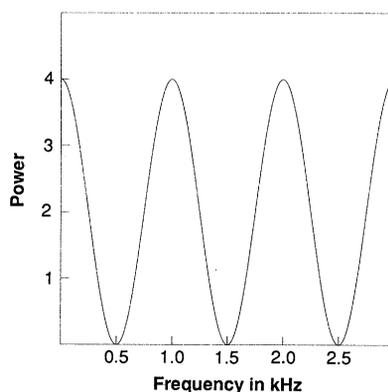


Fig. 1. Spectral density function for $n(t) + n(t-\delta)$, where $n(t)$ is a band-limited (0 to 3 kHz) Gaussian noise, and δ , the delay parameter, equals 1 ms.

phase to the noise in both ears. When the tone is presented, the left ear receives $n(t) + A\sin(2\pi ft)$ while the right ear receives $n(t-\delta) + A\sin(2\pi ft)$, where f is the tone's frequency and A is its amplitude. If we now compare detection thresholds for the case when $\delta = 0$ to the case in which $\delta = 1/(2f)$, we find that the tonal threshold when $\delta = 1/(2f)$ can be from 10 to 14 decibels (dB) lower than the tonal threshold when $\delta = 0$ (4). Because the binaural threshold when $\delta = 0$ is approximately equivalent to the monaural threshold for the same level of masking noise, the decibel difference in threshold is the amount of unmasking attributable to binaural processing and is often referred to as the masking level difference (MLD).

A simple linear model in which the left and right ear inputs are added together illustrates how the auditory system could be extracting the signal from the noise. When noise alone is presented to the two ears, addition produces $n(t) + n(t-\delta)$. The power spectral density function G for $n(t) + n(t-\delta)$ is

$$G[f] = 2 + 2\cos(2\pi f\delta) \quad (1)$$

The plot for this function for $\delta = 1$ ms is in Fig. 1. Power density is a periodic function of frequency with peaks occurring at 0, 1000, 2000, and 3000 Hz, and troughs occurring at 500, 1500, and 2500 Hz. Therefore, if we present an in-phase pure tone to both ears with a frequency in the center of a notch (for example, 500 Hz in Fig. 1), that tone should be more easily detected than one whose frequency is at a peak (5).

In the visual counterpart to this auditory paradigm a square patch of two-dimensional band-limited Gaussian noise, $n(x,y)$, is presented to the left eye where n specifies the luminance value at any point (x,y) in the patch. The same noise patch is presented in the corresponding position to the right eye but shifted to the right by an amount equal to d in centimeters so that the right eye field becomes $n(x-d,y)$. When these two images, both surrounded by a square frame, are presented in a stereoscope they will fuse so that the viewer sees one Gaussian field, located behind a single square window. If the left (unshifted) and right (shifted) noise patterns are added together by the visual system, point by point, the resulting luminance pattern is given by $n(x,y) + n(x-d,y)$. The two-dimensional spectral density function for this luminance pattern varies sinusoidally with spatial frequency along its horizontal axis, that is,

$$G[\xi,\eta] = 2 + 2\cos(2\pi\xi d) \quad (2)$$

where ξ and η are the spatial-frequency

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variables corresponding to the horizontal and vertical directions, respectively. Clearly, the spectral density function along the horizontal axis is identical to the one shown in Fig. 1, except that notches are now a function of the amount of displacement, d , between the two patterns. According to this analysis, a luminance pattern, varying sinusoidally along the horizontal axis, and thus oriented at 90 degrees, with spatial frequency f , added in phase to both eyes, should be more visible if $d = 1/(2f)$ than if $d = 0$. (In the latter case, the power spectral density function for the sum of both patterns is flat.)

To investigate this hypothesis, we generated displays of the type shown in Fig. 2 as 8 bits per pixel images with an IBM AT computer interfaced with an ITI FG-100 image processing board. Such pictures were shown through a square aperture on a high resolution black and white television monitor (Panasonic, model WV 5370) (6). Observers viewed these images through a simple lens stereoscope (7). In these viewing conditions, the visual angle between adjacent pixels was 3.38 minutes of arc.

The upper left pattern in Fig. 2 consists of a square patch of band-limited two-dimensional Gaussian noise (140 by 140 pixels) embedded in a surround (width, 15 pixels) of uniform noise (8). To the right of this pattern (and separated from it by a dark area that was not visible through the stereoscope) is the shifted version ($d = 4$ pixels) of this same noise field, also appearing within the same frame used in the left pattern (9). Because of the 4-pixel disparity between the left and right Gaussian fields, the subject sees, under stereoscopic viewing conditions, a single square frame or window, behind which appears a fused field of Gaussian noise. The bottom left pattern consists of the same frame enclosing an independently generated Gaussian field to which a Gaussian-modulated sinusoidal grating of the Gabor type (10) has been added. This signal, centered in the middle of the field, has a 32-pixel space constant, the grating phase is 0 degree, its orientation is 90 degrees, and its wavelength is 8 pixels. In the bottom right pattern, the Gaussian noise has been shifted by 4 pixels within the 140 by 140 field, but the Gabor signal is added at the same locations within this field (11).

On each trial, an image consisting of four fields and surrounds like those in Fig. 2 was displayed. Within a block of trials, the signals were randomly presented an equal number of times in the top and in the bottom pair of noise fields; moreover, the signals were displayed, also in random order, at four levels of contrast, selected on the basis of pretesting. The test image appeared on the otherwise blank screen 500 ms after the

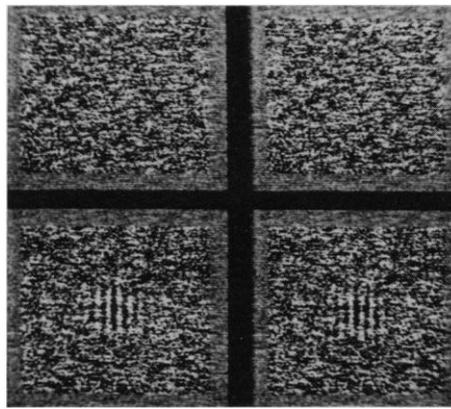


Fig. 2. High-contrast photograph of a typical screen image for condition A. The Gabor signal is present in the lower two images.

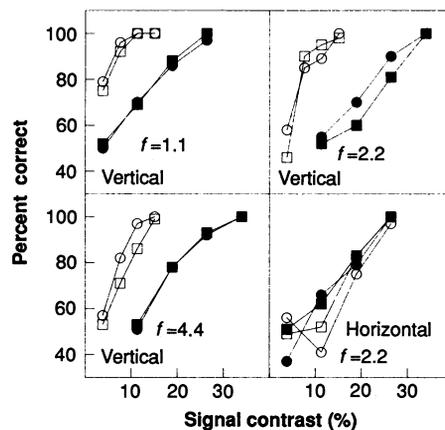


Fig. 3. Percent correct as a function of signal contrast in four experiments for subjects GM (circles) and DB (squares) in condition A (unfilled symbols) and in condition B (filled symbols). Spatial frequency (f) (cycles per degree) and orientation of the Gabor are specified in each panel.

observer, seated in a dimly illuminated room, pressed a start button; the image remained in view for 1 s. The observer's task was to indicate, by pushing the appropriate response key, whether the signal was present in the upper or in the lower part of the display: a two-alternative, spatial forced-choice task. Responses were recorded, but no feedback was given. Display, timing, and scoring functions were performed by the computer.

When the signal was presented at high contrast in this situation (condition A) the viewer saw it as standing in front of the noise background and on approximately the same plane as that of the surrounding frame. When the amplitude of the Gabor target was near threshold, the observers reported that they saw a shimmering surface located in front of the noise background.

Given that the displacement of the noise field (in pixels) was equal to one-half of the wavelength, we would expect visual un-

masking to occur. To show that visual unmasking was occurring, however, a control condition was required. In the latter condition (condition B) the left-side signal plus noise field was of the same type as the corresponding field in condition A. The signal presented to the right eye, however, was shifted by the same amount as the noise. Because both signal and background were shifted by the same amount, there was no opportunity for binocular unmasking to occur. A difference in detectability between conditions A and B, therefore, provides a measure of the degree of binocular unmasking.

We determined the percentage correct as a function of signal contrast (12) for both conditions A and B for two subjects (Fig. 3, upper left). The signal was a vertical Gabor [wavelength, 16 pixels; spatial frequency (f), 1.1 cycles per degree]. The upper right and lower left panels of Fig. 3 show psychometric functions for the same two observers for two other vertical Gabor signals with wavelengths of 8 and 4 pixels, respectively (2.2 and 4.4 cycles per degree). For the conditions represented in each of the panels, the shift in the background noise was one-half of the signal wavelength, and each data point on the psychometric functions is based on 100 trials. Significant unmasking occurs at all three wavelengths with the largest degree of unmasking occurring at a spatial frequency of 2.2 cycles per degree (Fig. 3).

To test the extent to which this effect was dependent on the orientation of the Gabor pattern, the experiment above was repeated with a Gabor (wavelength, 8 pixels) oriented horizontally rather than vertically (Fig. 3, lower right panel). As before, in the experimental condition, the background was shifted laterally by 4 pixels but the Gabor was not, while in the control condition both background and Gabor were shifted laterally by the same amount. There was no apparent difference between the experimental and control conditions when the Gabor was oriented horizontally (Fig. 3, lower right panel). This finding supports a spectral analysis of the effect, because the height of the spectral density function for the summed left and right Gaussian noises varies with respect to the horizontal spatial frequency variable (see Eq. 2) but is independent of the vertical spatial frequency variable. When there is no notch in a particular orientation, but still binocular disparity, there is no binocular unmasking. Thus, the existence of the MLD does not depend on binocular disparity per se.

There is binocular unmasking in the visual system as predicted from a simple linear model of binocular interaction (Fig. 3). The size of the effect, however, is smaller in

vision than in audition. In the analogous auditory experiment, MLDs of 12 dB are typical. In the present visual experiment, the extent of visual unmasking varied between 3 and 6 dB [10 log(C_B/C_A), where C_A and C_B are signal contrasts at threshold in conditions A and B, respectively.] It should be noted, however, that in audition the size of the MLD increases (up to a certain limit) with the intensity of the noise background (13). Indeed, studies under way in this laboratory indicate that a similar relation may hold in vision as well. Thus, it is possible that the size of visual MLDs might approach that of auditory MLDs under appropriate levels of noise intensity.

In developing the arguments for the existence of a visual MLD, we have appealed to a linear model of binocular interaction. Such models in audition can account for a large portion of the MLD literature even though they are not without serious competitors (2). It is interesting to note, in this regard, that studies of binocular interactions in simple cells of the cat striate cortex have concluded that most of these interactions could be accounted for by linear summation of neural signals from each eye (14). Thus, it is possible that a linear signal processing model may form the basis for visual unmasking.

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3. B. Julesz and others [see R. L. De Valois and K. K. De Valois, *Spatial Vision* (Oxford Univ. Press, London, 1988), pp. 298–315, for a review] have shown that the interocular disparity information that is available when two random dot fields are viewed stereoscopically can produce a perception of depth and form that cannot be seen in either of the monocularly viewed fields. A somewhat analogous effect can be observed in audition. Introducing interaural delays or phase shifts in noise signals presented to the two ears results in the perception of binaural pitch (N. I. Durlach and H. S. Colburn, *ibid.*, pp. 410–413). This pitch sensation, like the emergence of form in random dot stereograms, results from binaural interaction and cannot be perceived in either of the monaural components. Thus, manipulating the appropriate interocular parameters in vision and interaural parameters in audition gives rise to perceptions of forms that are not present in the individual signals. It is well known in audition that manipulating the same interaural parameters leads to significant unmasking effects when a sinusoidal signal is added to the noise in one or both ears. However, we were unable to find any studies in which the manipulation of the interocular parameters of a visual noise enhanced the detectability of a sinusoidal grating. Thus, we do not know of any direct analog in vision to the MLD effect in audition.
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5. For a theory of this sort to be able to quantitatively predict the results of experiments, further elaboration and specification of both processes and error parameters are required. For an example of such a

model see Durlach's equalization and cancellation theory [N. I. Durlach, in *Foundations of Modern Auditory Theory*, J. V. Tobias, Ed. (Academic Press, New York, 1972), vol. 2, pp. 369–462], in which the signal from one ear is subtracted from rather than added to the signal from the other ear. With a limited number of error parameters, his linear model provides a good account of MLDs in audition.

6. A γ -corrected look-up table was used to ensure a linear relation between the assigned gray level in the data and the luminance on the television monitor, with luminance ranging from 0.13 cd/m² (gray level, 0) to 7.5 cd/m² (gray level, 255).
7. K. N. Ogle, *Optics* (Thomas, Springfield, IL, 1961), p. 99.
8. Uniform random deviates ranging from -40 to +40 were added to the mean gray level of 128 to produce the frame. Michelson contrast [(maximum - minimum luminance)/(maximum + minimum luminance)] for the frame was 30%.
9. The Gaussian field was obtained by rescaling a 140 by 140 matrix of random normal deviates so that their standard deviation equaled 80. The values in this table were then peak clipped at 1.6 standard deviation units to insure that they ranged between -128 and +127. The gray levels for the Gaussian field were obtained by adding 128 to these rescaled values. The mean luminance of the Gaussian field

(gray level, 128) was 3.8 cd/m², its effective bandwidth was 8.8 cycles per degree, and the root mean square variation (RMS = $[\sum(L_i - L_m)^2/n]^{1/2}$, where L_i is the mean luminance of the display and L_m is the pixel luminance) around this mean luminance value (SD, 80 gray levels) was 2.3 cd/m². With peak clipping, however, the RMS luminance value was reduced to 2.1 cd/m².

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11. The gray level programmed for each pixel location in the Gabor signal is given by $A \cos[2\pi(x - x_0)/\lambda] \exp(-0.5a^2[(x - x_0)^2 + (y - y_0)^2])$. In this expression, a is the reciprocal of the space constant, λ is the wavelength of the Gabor, A specifies its gray level amplitude, and (x_0, y_0) is the center of the 140 by 140 pixel field.
12. Signal strength for the sinusoidal grating is specified in terms of Michelson contrast.
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Identification of an Allatotropin from Adult *Manduca sexta*

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A peptide that strongly stimulates the secretion of juvenile hormone from corpora allata in vitro (allatotropin) has been purified from extracts of heads of pharate adult *Manduca sexta*. The primary structure of this 13-residue peptide has been determined: H-Gly-Phe-Lys-Asn-Val-Glu-Met-Met-Thr-Ala-Arg-Gly-Phe-NH₂. This neurohormone has no sequence similarity with any known neuropeptide from other organisms. Synthetic allatotropin, as well as truncation fragments, including one with the five amino terminal residues deleted, showed in vitro activity indistinguishable from that of native allatotropin.

JUVENILE HORMONE (JH) PLAYS A VITAL role in insect development, primarily in the control of metamorphosis, adult sexual maturation, and reproduction (1, 2). JH is synthesized and released by the corpora allata (CA), a pair of endocrine glands connected with the brain via nerve fibers. These fibers are composed of axons of cerebral neurons and neurosecretory cells (3). Investigations have focused on the mechanisms involved in the regulation of JH synthesis in the CA (4). Factors that either stimulate [allatotropin (AT)] (5–7) or inhibit [allatostatin and allatohibin] (8) JH biosynthesis have been described in several insect species. So far the chemical nature of these hormones has been ambiguous. We now report the purification, sequence analysis, and total synthesis of an AT from the adult tobacco hornworm, *Manduca sexta*.

Throughout our purification procedure we used an in vitro radiochemical method (9) for assaying the ability of test samples containing AT to stimulate the secretion of

JH from CA of adult female *M. sexta* 0 to 4 hours after eclosion. This method measures incorporation of the labeled methyl moiety from L-[methyl-¹⁴C]methionine into JH in the ultimate step of its biosynthesis. In this assay all labeled hormone is secreted directly into the medium.

Starting material for this purification was from 10,000 trimmed pharate adult heads of *M. sexta* (approximately 25% of the head, containing the brain-corpora cardiaca-CA complex) already accumulated during the isolation of eclosion hormone (10). These heads were defatted with acetone and extracted with an acidic solution (1M acetic acid and 20 mM HCl) containing protease inhibitors (10). Extracts were applied direct-

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