XX. COMMUNICATIONS BIOPHYSICS*

Prof. W. A. Rosenblith†
Prof. M. A. B. Brazier‡
Prof. M. Eden
Prof. M. H. Goldstein, Jr.
Prof. W. T. Peake
Prof. W. M. Siebert
Dr. J. S. Barlow**
Dr. A. Cavaggioni††
W. A. Clark†
Dr. B. G. Farley†
Dr. G. L. Gerstein†
Dr. E. Giberman‡‡
Dr. R. D. Hall
Dr. N. Y-S. Kiang***
Dr. T. T. Sandel†
Dr. Eda Berger Vidale
J. A. Aldrich
R. M. Brown
S. K. Burns
R. R. Capranica
Eleanor K. Chance
R. J. Clayton
A. H. Crist
P. R. Gray
J. L. Hall II
F. T. Hambrecht
J. G. Krishnayya
R. G. Mark
P. Mermelstein
C. E. Molnar†††
Ann O'Rourke
R. R. Pfeiffer***
Cynthia Pyle
M. Sachs
D. M. Snodderly, Jr.
G. F. Svihula
I. Thomae
T. F. Weiss
J. R. Welch
M. L. Wiederhold
G. R. Wilde
S. Zilles

R. C. Baecker
B. O. Butterfield
T. Cohn
C. W. Einolf
A. Fevrier
A. Gabrielian
E. J. Hoffman
D. K. Joseph
D. Langbein
W. C. Marmon
R. M. Mason
J. Meyer
J. A. Parnell
A. P. Tripp

A. MINIMUM DETECTABLE INTERAURAL INTENSITY DIFFERENCE

We have measured the precision of listeners in judging the relative position of a lateralized binaural stimulus with respect to a centered binaural stimulus. The stimuli were clicks produced by applying 100-μsec rectangular voltage pulses to PDR-10 earphones. The centered stimulus was a train of 15 clicks at a rate of 10 per second with zero interaural intensity difference. The lateralized stimulus was a similar train varied in interaural intensity difference. The centered and lateralized stimuli were presented at the same average intensity, and this average intensity was a parameter of the experiment.

Figure XX-1 shows the performance of listeners in this task as per cent correct lateralizations versus interaural intensity difference for the lateralized stimulus, with

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†Staff Member, Center Development Office, M.I.T.

‡Visiting Professor in Communication Sciences from the Brain Research Institute, University of California in Los Angeles.

**Research Associate in Communication Sciences from the Neurophysiological Laboratory of the Neurology Service of the Massachusetts General Hospital.

††From Istituto di Fisiologia, Università di Pisa.

‡‡From the Department of Physics, Weizmann Institute of Science, Israel.

***Also at Massachusetts Eye and Ear Infirmary, Boston, Massachusetts.

†††Air Force Cambridge Research Center, Bedford, Massachusetts.

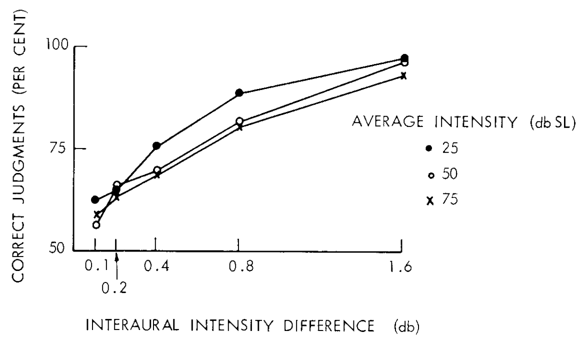


Fig. XX-1. Per cent correct lateralizations vs interaural intensity difference. (Average of 3 subjects.)

average intensity as a parameter. These results are inconclusive because they represent the average over three subjects, and there was considerable intersubject variability. The 75 per cent correct level lies between 0.4 db and 0.6 db, and there is some indication that the 75 per cent correct level increases as average intensity increases.

D. K. Joseph, J. L. Hall II

B. LATERALIZATION PERFORMANCE FOR SINGLE CLICKS BY THE METHOD OF PAIRED COMPARISONS

We have measured the precision of listeners in judging the relative position of a lateralized binaural stimulus with respect to a centered binaural stimulus. The stimuli were clicks produced by applying 100-μsec rectangular voltage pulses to PDR-10 earphones. The centered stimulus was presented with zero interaural time disparity; the lateralized pair varied in interaural time disparity. This stimulus configuration affords a minimum of information and/or redundancy to the listener and can be considered a limiting case for comparable configurations of stimuli in similar experiments, given a paired comparison task. A more general treatment would include differences in number of clicks presented at various rates for both the standard and test sequences.

Figure XX-2 shows the performance of listeners in this task as per cent correct lateralization versus interaural delay for the lateralized pair. For comparison, the performance of two listeners on a highly redundant stimulus sequence is also shown. The redundant sequence consisted of a 2-sec click train at 25 clicks per second for the centered stimulus, and a 2-sec click train at 5 clicks per second for the lateralized stimulus. The data for redundant stimuli are from experiments that are being performed at present and will not be discussed further in this report, except to note that the performance is much better with such signals than it is with single click pairs.

These results lead us to conclude that this approach is potentially fruitful for understanding the nature of what might be considered optimal redundancy in binaural auditory

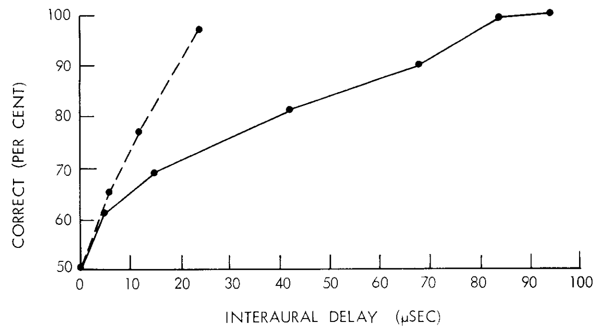


Fig. XX-2.

Per cent correct vs interaural delay. (Separation time, 0.5 sec.) Solid curve: Binaural clicks for 6 subjects. Dashed curve: Binaural click trains (50 in 2 seconds; then 10 in 2 seconds) for 2 subjects (Sandel and Hall).

lateralization performance, and the experiments in this direction will continue.

T. E. Cohn, J. L. Hall II, T. T. Sandel

C. EFFECTS OF OLIVOCOCHLEAR BUNDLE STIMULATION ON ACOUSTICALLY EVOKED POTENTIALS

Galambos[1] first showed that electrical excitation of the crossed olivocochlear bundle could reduce the amplitude of auditory nerve responses to acoustic stimuli. Recently, Desmedt,[2] recording with gross electrodes, and Fex,[3] recording with microelectrodes, have added quantitative information on the activity of this efferent auditory system. While the work reported here was in progress Desmedt[2] published results showing that olivocochlear-bundle (OCB) activation could be thought of as producing an equivalent decibel reduction of the acoustic stimulus, at least over an intensity range of 40 db from physiological threshold for gross-electrode evoked responses.

In our experiments on cats, the floor of the fourth ventricle was exposed and stimulating electrodes were placed on the site of the decussation of the crossed OCB. Responses evoked by clicks and short noise bursts were recorded at the round window and from the skull over the auditory area of the cerebral cortex. We desired to record from "both ends" of the auditory system in order to determine whether the effects of OCB stimulation could be localized to the periphery.

The cochlear microphonic (CM) and the amplitude of the neural components N_1 and N_2 of round window recordings were measured, as well as the latency of N_1 and the response amplitude at the auditory cortex (C). Acoustic stimuli were presented at a rate of one per second and could be preceded by a tetanic train of shocks to the OCB.

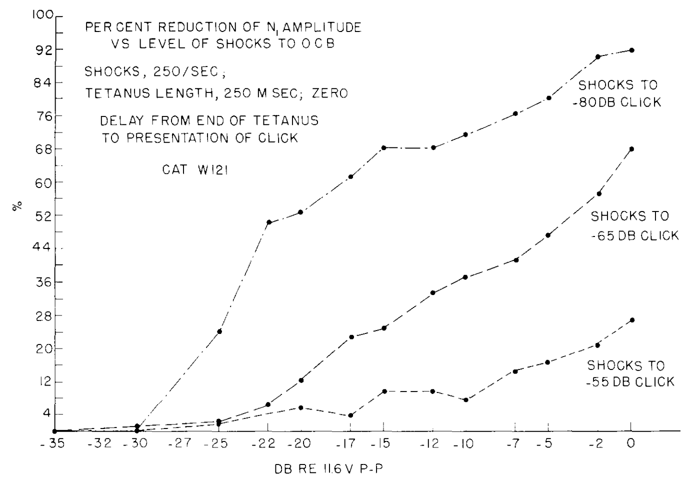
In most respects the results obtained confirmed those that have been reported by Galambos[1] and Desmedt.[2] The optimum shock repetition rate for reduction of neural responses was found to vary from 330 per second to 400 per second. An optimum duration of the tetanus was found for a given repetition rate and a given delay from the end of the tetanus to the acoustic stimulus. Too few shocks have no effect, and as the duration of the tetanus is made too long the reduction of response amplitude decreases. The optimum shock configuration was usually found to consist of approximately 60 shocks.

For stimuli within 25 db of VDL threshold the response amplitude could be reduced to the point where no response was seen in the average of 32 responses. When responses were reduced by increasing the strength of the shocks to the OCB the response component amplitudes were found to maintain very nearly the same relationship to one another as in the no-shock condition.

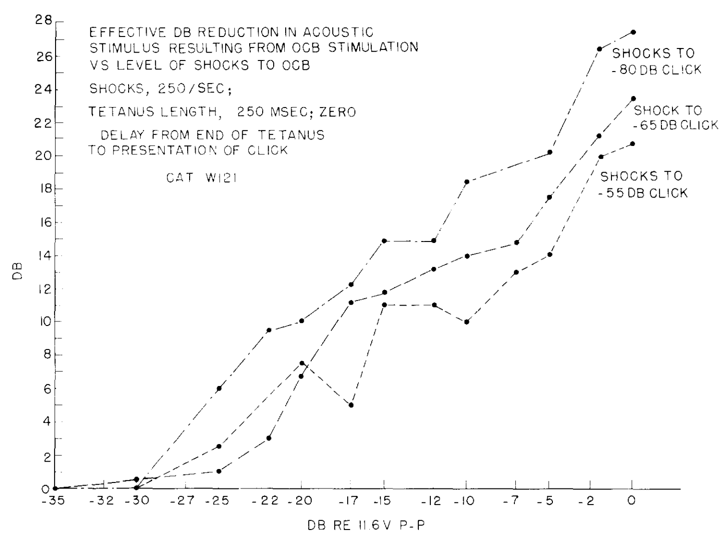
As the neural responses are reduced by OCB stimulation the amplitude of the cochlear microphonic is increased. In some cases, for relatively strong shocks, CM was doubled. As N_1 is decreased at a given click intensity, its peak latency does not maintain the same relationship to its amplitude as is found in a standard intensity series. Without OCB shocks the latency of N_1 decreases almost linearly with increase of N_1. At intensities within 20 db of VDL threshold the latency of N_1 increases as its amplitude is decreased by OCB stimulation, but at intensities ~40 db above threshold the latency remains constant as N_1 is decreased, while at higher intensities the latency may actually decrease. As the delay of presentation of the click from the end of the shock tetanus is increased, the N_1 response amplitude recovers to its no-shock value within 75-100 msec.

Desmedt suggests that a given shock configuration produces an effective reduction of acoustic stimuli that is "largely independent of the intensity which happens to be chosen for the testing click, provided the latter is kept within about 40 db of threshold."[4] If the effectiveness of OCB stimulation is measured as a percentage reduction of N_1, the reduction for a given shock configuration is seen to be much greater at low intensities than high (Fig. XX-3a). If the reduced response amplitude is matched to the response of a lower intensity click without OCB shocks, an equivalent decibel reduction in acoustic stimulus can be computed. Even with this measure, OCB shocks are seen to be somewhat more effective in reducing responses to low intensity stimuli (Fig. XX-3b).

To investigate the effects of OCB stimulation on high intensity stimuli, 0.1-msec noise bursts were used. With these stimuli the CM is a random function so that its amplitude in the average of 64 responses is small compared with N_1 and N_2. Without averaging, at intensities higher than 60 db above threshold, CM is so large that it often obscures N_1 and N_2 recorded at the round window. In Fig. XX-4 response amplitudes are plotted against intensity for noise-burst stimulation. It will be seen that there is a dip in the N_1 and N_2 intensity series at -30 db. When shocks are administered preceding a noise burst at an intensity



(a)



(b)

Fig. XX-3. (a) and (b) contain data from the same experiment. In both plots the abscissa gives peak-to-peak amplitude of shocks in db re 11.6 volts. Click intensities are in db re 5-volt 0.1-msec square pulse to a PDR-10 earphone. In (b) effective reduction is computed by matching reduced peak-to-peak N_1 amplitude with OCB shocks to no-shock conditions at a lower intensity. All points are from the averaged response to 32 identical stimuli.

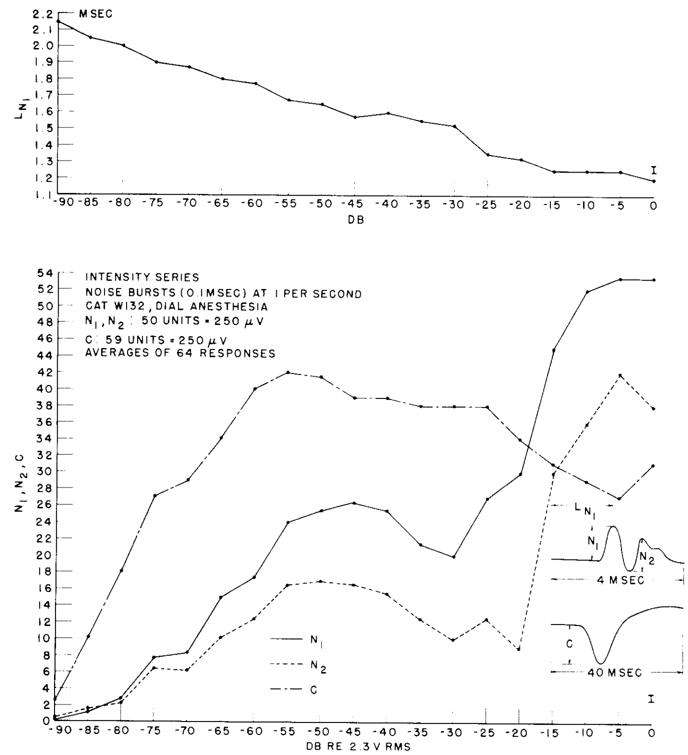


Fig. XX-4. Noise-burst intensity series. Noise bursts are produced by presenting noise of 30 cps-20 kc bandwidth to an electronic switch set to give 0.1-msec bursts. Rise time of switch, 25 μsec; 0 db noise is 2.3 volts rms.

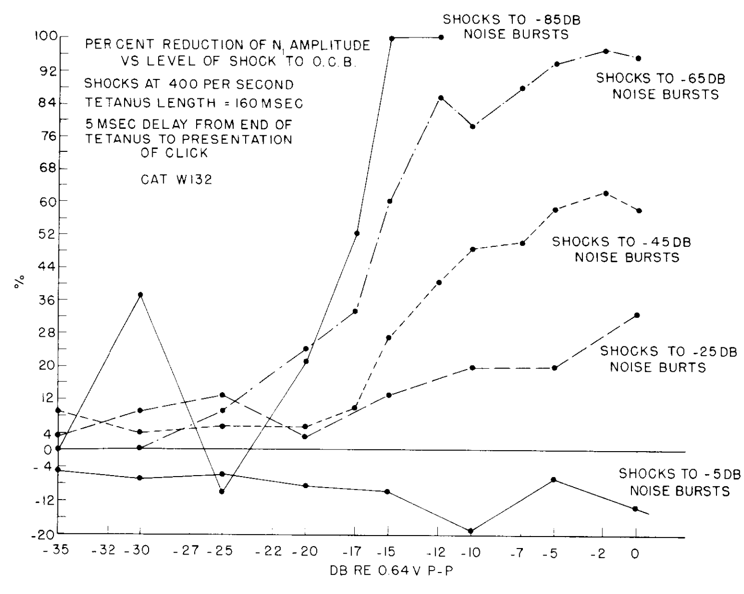


Fig. XX-5. Percentage reduction of N_1 base line-to-peak amplitude brought about by OCB shocks plotted as a function of the peak-to-peak voltage of shocks in db re 0.64 volt.

corresponding to the bottom of such a dip the response amplitude decreases, so that here the concept of an effective reduction of acoustic stimulus does not apply.

Figure XX-5 shows the percentage reduction (brought about by OCB stimulation) of the amplitude of N_1 response to 5 different intensities of noise bursts. The points for shocks below -20 db re 0.64 volt peak-to-peak give an indication of the fluctuations found in the averaged responses. Note that there is no evidence for reduction of the N_1 response to -5 db noise bursts, even with shocks 15 db more intense than those capable of completely abolishing the averaged response to -85 db noise burst.

Further details will be found in a Master's thesis of one of the authors.[5]

M. L. Wiederhold, Eleanor K. Chance

References

1. R. Galambos, Suppression of auditory nerve activity by stimulation of efferent fibers to the cochlea, J. Neurophysiol. 19, 424 (1956).
2. J. E. Desmedt, Auditory-evoked potentials from cochlea to cortex as influenced by activation of the efferent olivo-cochlea bundle, J. Acoust. Soc. Am. 34, 1478 (1962).
3. J. Fex, Auditory activity in centrifugal and centripetal cochlear fibres in cat, Acta. Physiol. Scand. 55, Supp. 189 (1962).
4. J. E. Desmedt, op. cit., p. 1483.
5. M. L. Wiederhold, Effects of Efferent Pathways on Acoustic Evoked Responses in the Auditory Nervous System, S.M. Thesis, Department of Electrical Engineering, M.I.T., June 1963.

D. NOTE ON THE MACH ILLUSION

Under appropriate viewing conditions, the illusion discussed in this report appears to "invert." This inversion persists if object and/or observer move. We note that a possible explanation of this behavior is the utilization of "defocus" as a monocular depth cue.

The illusion[1] can be constructed by folding a 3 × 5 index card as in Fig. XX-6. An observer looking into the pleats monocularly can easily convince himself that near edges are far, and vice versa. As shown in Fig. XX-7, the projection that the observer

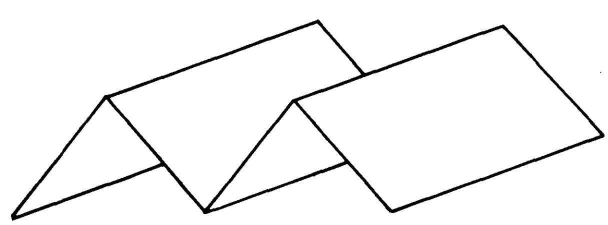
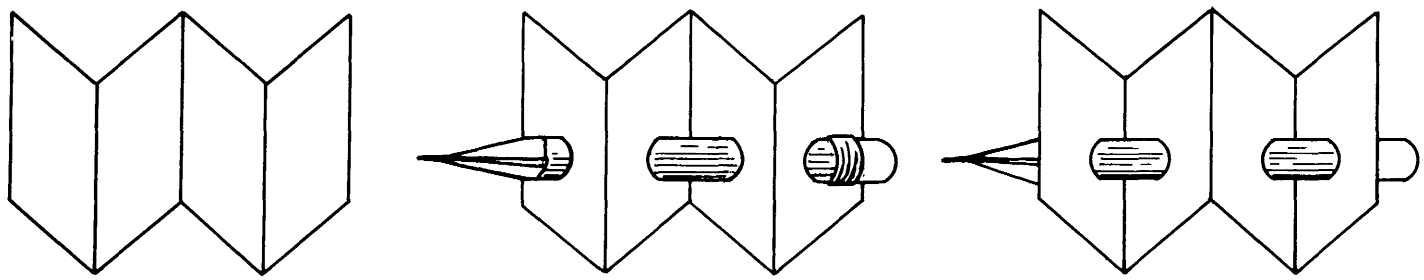


Fig. XX-6. The illusion.



(a) (b) (c)

Fig. XX-7. (a) Front view of the illusion. (b) and (c) Two possible ways of interpreting the view shown in (a).

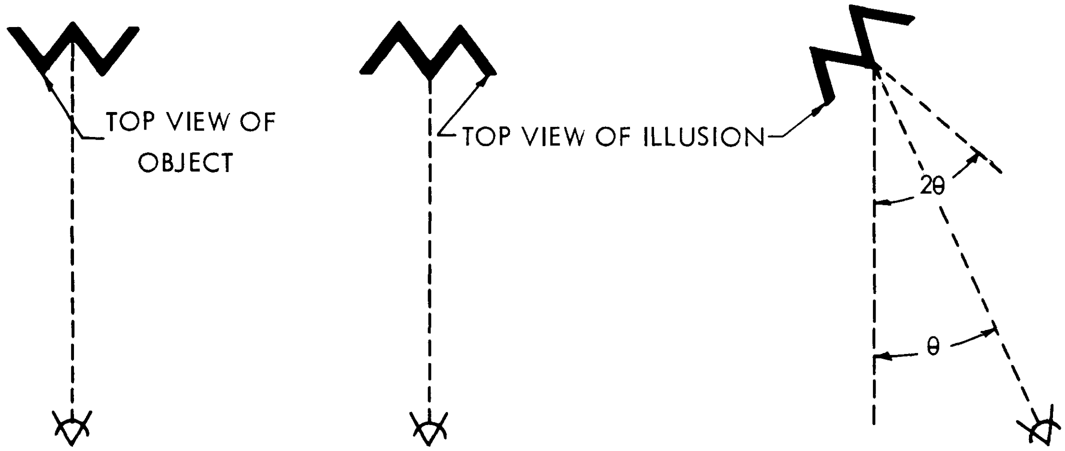


Fig. XX-8. As the observer moves, the illusion appears to move.

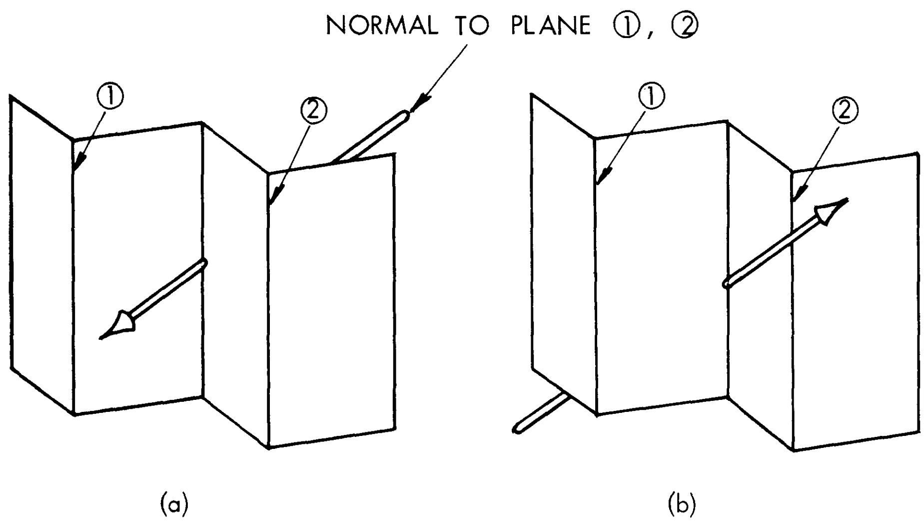


Fig. XX-9. (a) The object as viewed by an eye to the right of the normal to the plane determined by lines ① and ② . The apparent position (b) of this normal in the illusion is to the observer's right, thereby indicating that the illusion has twisted more than the eye has moved.

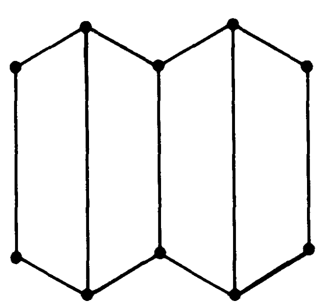


Fig. XX-10. Front view of card. The faces of the inversion are trapezoidal with the small edges near the observer.

sees really is ambiguous, which accounts for the ease of inversion.

Unlike many similar illusions, the object is solid. Hence observer motion transmits new information to the eye. Even so, the illusion does not vanish – it appears to gyrate as the observer does. As Professor Eden[1] points out, the apparent motion is predictable by the postulate that the observer sees the reflection of the object in a mirror passing through the object normal to the line of sight. (See Figs. XX-8 and XX-9.) This approximation is invalid when the observer is close to the object.

When the eye is close to the object, distortions occur and the inversion is no longer the mirror image of the original (see Fig. XX-10).

As is apparent from the figures, many objects can produce the same projection on the observer's picture plane. Thus it is not remarkable that an illusion is possible. It is the fact that only <u>one</u> illusion configuration occurs that is remarkable.[2] See Fig. XX-11. The unique "choice" of the inversion from the set of all configurations

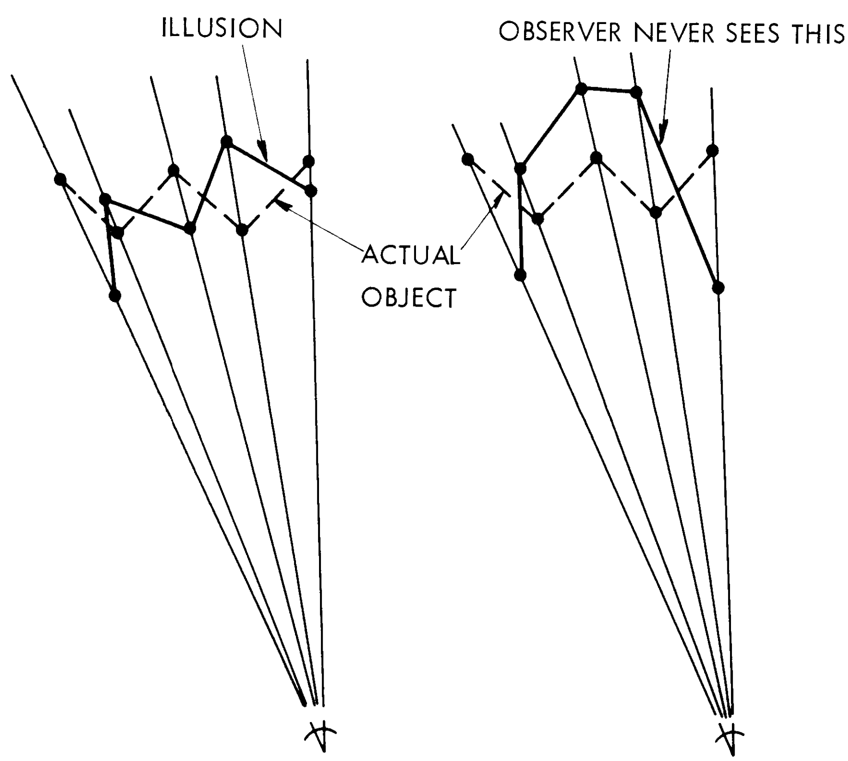


Fig. XX-11. The observer sees either the object or its inversion. He does not see any of the other configurations that make the same projection on the retina.

with identical retinal projections is not the result of:

A preference for rectilinearity. Curved surfaces are also uniquely invertible.

A preference for apparent stationarity. The illusion moves as the observer does.[3]

A preference for rigid body motion. The illusion distorts as it moves.

Overlap cues.

Shading. Shadows are often nonphysical in that no light source could generate them.

Texture gradients. All of these gradients are backwards in the illusion.

If we postulate that the eye is sensitive to the blur resulting from slight amounts of defocus, this singular inversion can be readily explained. The circle of confusion created by a point 31 cm from an eye focussed at 30 cm is approximately 2 microns across, roughly the distance between cones in the fovea, or the diameter of the diffraction pattern of the pupil. Acuity tests indicate that in some situations effects as small as this are readily perceived.

As shown in Fig. XX-12, when the eye is focussed at one range, points nearer to the eye can produce the same blur as points farther away. With the thin-lens approximation, $1/x + 1/z = 2/y$.

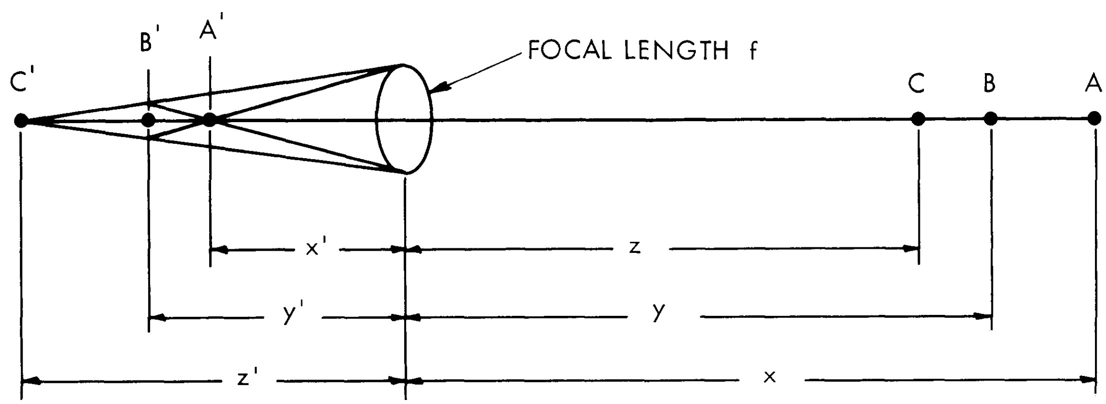


Fig. XX-12. The screen images point B. Points A and C produce the same circle of confusion on the retina. From the lens formula,

$$\frac{1}{x'} + \frac{1}{x} = \frac{1}{f}$$

$$\frac{1}{z'} + \frac{1}{z} = \frac{1}{f} \qquad \text{which imply } \left(\frac{1}{x'} + \frac{1}{z'} - \frac{2}{y'}\right) + \left(\frac{1}{x} + \frac{1}{z} - \frac{2}{y}\right) = 0.$$

$$\frac{1}{y'} + \frac{1}{y} = \frac{1}{f}$$

By similar triangles,

$$\frac{y' - x'}{x'} = \frac{z' - y'}{z'} \qquad \text{which implies } \frac{1}{x'} + \frac{1}{z'} - \frac{2}{y'} = 0.$$

Thus $\frac{1}{x} + \frac{1}{z} = \frac{2}{y}$.

Thus two points can be mistaken for one another if they lie on the same radial to the eye and the harmonic mean of their distances from the eye is the fixation distance.

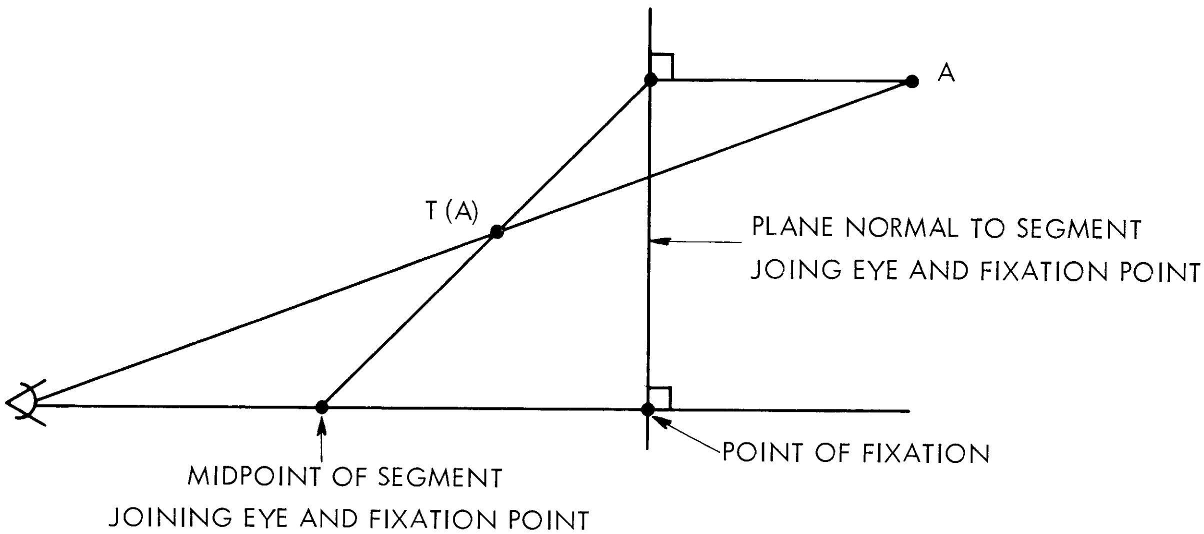


Fig. XX-13. A construction for T.

The transformation, T, mapping each point into the unique other point that produces the same defocus blur is easily visualized with the construction of Fig. XX-13. Some properties of T are:

T keeps straight lines straight.

$T^2 = I$.

At large fixation distances, T approaches a reflection.

Transformation T can be applied to objects and generally the resultant point set is in subjective agreement with the illusion.

Unfortunately, for objects subtending large angles at the eye, straight lines appear to be curved slightly. At best we could expect the thin lens formulas to be valid near the optical axes. Moreover, T shows a sensitivity to fixation distance which is difficult to observe in the illusion. Further tests are being made to estimate the magnitude of these deviations.

W. L. Black

References

1. See M. Eden, A three-dimensional optical illusion, Quarterly Progress Report No. 64, Research Laboratory of Electronics, M.I.T., January 15, 1962, p. 267 for a more complete description.

2. One can invert only part of an object, but the inverted portion is congruent to the corresponding portion when the whole object is inverted.

3. In an inverting telescope the inversion seems to be stationary and the object seems to move as the observer does. Such a telescope does not invert depth; it rotates the scene through π radians about the axis of the telescope.

E. WORK COMPLETED

These brief reports are abstracts of theses and a summary of a project completed during the past academic year, and not reported on previously.

Instrumentation

1. AN ON-LINE DIGITAL ELECTRONIC CORRELATOR

One of the many applications of correlation techniques has been their use in the analysis of waveforms recorded during electrophysiological experiments.

A suggestion of C. E. Molnar has led to the design of a digital correlator that can process signals with the frequency range of EEG data on-line. The correlator quantizes the input signal to 16 levels (4 bits). Samples of the input signal are taken periodically, the shortest sampling period being 5 msec. For this sampling rate the input signal must be filtered so that its spectrum is practically zero at higher frequencies than 100 cps. Autocorrelograms or crosscorrelograms are computed by a novel technique of precessing previously stored samples on a delay line relative to stationary accumulating sums. Each of these accumulating sums corresponds to the value of the correlogram at a particular value of delay. Samples emerging from the delay line are always displaced in time from the present input sample by an amount corresponding to the value of the associated accumulating sums.

The correlator has two modes of operation, one mode providing 200 correlogram points with an observation interval of several minutes, and the other providing 100 correlogram points with an observation interval up to several weeks. The sampling interval may be changed by a switch, with values of 5, 10, 20, 40, and 80 msec provided. This is also the interval between computed points in the correlogram. The input signal must be filtered so that it contains practically no energy at a frequency that is higher than the reciprocal of twice the sampling interval. Autocorrelograms are computed for positive delays only, whereas crosscorrelograms are computed for both positive and negative delays.

The correlogram is available as an analog signal from an 8-bit digital-to-analog converter, and is displayed continuously on an oscilloscope during computation. A strip chart recorder output is also provided. Digital readout on punched paper tape is possible with minor modifications.

The correlator is entirely composed of commercially available digital modules.

This study was presented to the Department of Electrical Engineering, M.I.T., in partial fulfillment of the requirements for the degree of Master of Science, May 15, 1963.

G. R. Wilde

2. A MULTICHANNEL ELECTROENCEPHALOGRAPHIC TELEMETERING SYSTEM

This report is an abstract of an S. M. Thesis submitted to the Department of Electrical Engineering, M. I. T., May 17, 1963.

A four-channel electroencephalographic telemetering system that is small enough to be carried by an animal that is of the size of a cat has been designed and built.

Descriptions of the differential amplifiers, pulse duration multiplexing circuitry, transmitter and receiver, and decoding circuitry are given. Details for reproduction of the system, and a simple module method for adding more channels are described in the author's thesis.

Each channel of the four-channel system has a frequency range of 0.7-2000 cps with a noise level referred to the input of 5 microvolts peak-to-peak at 10,000 ohms. The over-all operating range of the system is 200 feet.

A report based on this thesis will appear as Technical Report 413 of the Research Laboratory of Electronics.

F. T. Hambrecht

3. A SIGNAL GENERATOR FOR USE IN FREQUENCY-DISCRIMINATION EXPERIMENTS

A self-contained test generator for use in frequency-discrimination measurements has been developed. A random-word generator is used to control the sequence of presentations to the subject; this generator may be set to give 0, 0.25, 0.5, 0.75, and 1.0 probabilities of a high-then-low frequency presentation. The total number of tests and decisions is counted by electromagnetic counters. Provision is made for time-chopping of the output signal so that its effects on the discrimination ability of the subject may be evaluated.

This study was submitted as a Bachelor's thesis to the Department of Electrical Engineering, M. I. T., 1963.

A. P. Tripp

4. LOW-FREQUENCY RATE METER WITH FAST RESPONSE

This instrument is a self-contained, completely transistorized, portable frequency meter that is capable of measuring rates from 3 cycles per minute to 500 cps. With the use of 12 ranges, an accuracy of ±5 per cent can be achieved. The response is such that any change in frequency between two input pulses will be detected.

The interval between each consecutive input pulse is measured and a voltage proportional to this interval is generated. This voltage remains constant during the following interval. The pulse frequency is the reciprocal of this voltage.

This study was submitted as a Bachelor's thesis to the Department of Electrical Engineering, M. I. T., 1963.

C. W. Einolf, Jr.

Psychophysics

1. INTERAURAL TIME-DIFFERENCE THRESHOLDS FOR BANDLIMITED NOISE

In a large class of auditory discriminations, significant information is carried in the changing structure of the signal in time. This research concerned one way of studying the sensitivity of the auditory system to such time structure – the ability of human observers to discriminate interaural time shifts in bandlimited noise signals – and measurements were made by psychophysical methods. The psychophysical data can be viewed as reflecting the limitations imposed on performance by nonadditive signal-dependent noise in the auditory system. It was found that performance improves strongly with increasing bandwidth and signal energy, over the range of the parameters employed in this investigation. There was considerable evidence of the effect of non-sensory factors on performance.

This study was submitted to the Department of Electrical Engineering, M. I. T., 1963, in partial fulfillment of the requirements for the degree of Electrical Engineer.

J. A. Aldrich

2. HUMAN DISCRIMINATION OF AUDITORY DURATION

In a Bachelor's thesis submitted to the Department of Physics, M. I. T., 1963, a psychophysical model combining statistical decision theory with knowledge of the anatomy and physiology of audition is discussed. In the framework of this theory an experiment on the judgment of auditory duration was planned and executed. The model's predictions for the experiment are presented. Three subjects were tested in a forced-choice experiment that was perfomed to judge which of two auditory signals was longer. Their discrimination between 1000-cps sinusoids separated by empty intervals and empty intervals separated by sinusoids was investigated at three signal durations, 300 msec, 100 msec, and 33 msec.

The model predicts reasonably well the shape of the function relating percentage correct to increment duration. There are large individual differences in comparative performance at the three base durations. Interpretations of these effects are proposed and discussed. There appears to be a significant sensory difference between the judgments of the filled and the empty intervals. Suggested modifications of experimental procedure are made in the light of the data and the prior results of other investigators.

R. C. Baecker

3. A PROCEDURE FOR n-ALTERNATIVE FORCED-CHOICE PSYCHOPHYSICAL TESTING

In a Bachelor's thesis submitted to the Department of Physics, M.I.T., May 17, 1963, an n-alternative forced-choice testing scheme is described. First, a brief explanation of the purpose of the study and the approach that was used throughout the experimental work is given. Second, a description is given of the device that was used in these tests, the design and construction of which comprised the major part of this work. Finally, data that were obtained are used to point out one of the pitfalls in using this testing scheme.

J. S. Meyer

Physiology

1. ACTIVITY OF SINGLE NEURONS IN THE LATERAL GENICULATE OF THE RAT

This report is an abstract of a thesis submitted to the Department of Electrical Engineering, M.I.T., June 1963, in partial fulfillment of the requirements for the degree of Master of Science.

This research is based on a preliminary investigation of the problem of describing the receptive fields of single cells in the lateral geniculate of lightly anesthetized rats. Patterns of ongoing single-unit activity exhibiting the "grouped characteristics" reported by previous experimenters are demonstrated and discussed. The effects of anesthesia are considered and variations in responsiveness to photic stimulation are noted.

Two types of receptive fields of the lateral geniculate of the rat are described. One is an "ON" unit, the other an "OFF" unit. Both have a uniform response type throughout the field when a small spot of light is used as a stimulus, and are strongly responsive to diffuse light. These two fields are compared with similar receptive fields found in other animals.

Tungsten microelectrodes were used and a procedure for manufacture of the electrodes, including a mechanized technique for etching, is described.

D. M. Snodderly, Jr.

2. ANALYSIS OF A CAT'S "MEOW"

The recorded "meows" from four cats were studied in this project. The principal conclusion is that in the majority of instances, the "meow" of the cat is determined primarily by the rate of vocal-fold vibration as opposed to the shape of the vocal and nasal tracts.

J. A. Rome

3. VOICE OF THE BULLFROG

The vocalizations of the bullfrog (Rana catesbeiana) were studied by spectrographic analysis of recordings from three different sources, including laboratory recordings of male and female frogs. Oscilloscope pictures of the sound-pressure waveform were also studied. The vocal source is a train of pulses which has a repetition rate of approximately 90 per second. The spectral distribution of the call is primarily in two bands: 90-600 cps, and 900-1600 cps. A model of the bullfrog vocal system is proposed. Vocalizations of eight other Rana species are discussed.

This study was presented to the Department of Physics, M. I. T., as a Bachelor's thesis, 1963.

A. Fevrier

4. INVESTIGATION OF FILTER SYSTEMS FOR THE EKG WAVEFORM

In a Bachelor's thesis submitted to the Department of Electrical Engineering, M. I. T., 1963, the EKG waveforms of anesthetized frogs were studied to determine the optimum single-band filtering system for the EKG. The R pulse of the QRS complex was chosen as the strongest indicator of the heart beat. It was found that the signal-to-noise ratio for this pulse is optimum in the 15-30 cps frequency band.

W. C. Marmon