Perception of Changes in Certain Exteroceptive Stimuli

Rates of change in place and extent are discriminated more precisely than rates of change in energy.

J. M. Notterman, R. D. L. Filion, and F. J. Mandriota

Purposive behavior, once it has been appropriately established, tends to proceed smoothly in a fairly continuous fashion. The bird alighting on the limb of a tree does so quite directly. Apparently it is capable of responding to exteroceptive and proprioceptive signals in such manner that it can decelerate its motion precisely at the correct time derivatives of its position. These time derivatives must be at least of first order, thereby permitting a comparison of stimulus rates—a basis for obtaining difference thresholds for ds/dt. The results of such a comparison may also be interpreted as being a second-order judgment, or that required for d^2s/dt^2. The fact that detection of second-order variation is necessary for efficient control of error oscillation is indicated by feedback theory (*1*).

In Wiener's familiar example of feedback, he emphasizes both the partially unconscious character of these signals and the fact that this information must be available more or less continuously as a function of time:

"Now suppose that I pick up a lead-pencil . . . our motion proceeds in such a way that we may say roughly that the amount by which the pencil is not yet picked up is decreased in each stage. . . .

"To perform an action in such a manner, there must be a report to the nervous system, conscious, or unconscious, of the amount by which we have failed to pick the pencil up at each instant" (*2*).

The behaving organism responds not only to the static magnitudes of stimuli exciting different sensory systems but also to the manner in which these magnitudes vary as a function of time. The time derivatives of stimulus magnitude are determined partly by the environment itself (for example, the pencil in Wiener's example might be rolling back and forth on a ship's table), and partly by the feedback consequences of the organism's own immediately prior behavior. As with any other closed loop system, one must assume not only that changes in the momentary value of a discrepancy (that is, the difference in position between the pencil and the hand) are detectable, but also that changes in the rate at which the discrepancy is being reduced to zero are detectable. If these two changes were not detectable, then the detecting and correcting entity, whether electromechanical or biological, would tend to overshoot or to undershoot or to oscillate about its mark. Despite the behavioral implications of these principles, no description of the general capacity to perceive changes in stimulus rate seems to be available.

The many studies concerned with visual velocity discrimination constitute a major contribution toward such elucidation (*3*). These studies have involved research upon the human being's ability to perceive differences in speed of moving objects, including points of light displayed on an oscilloscope. For example, a subject may be asked to look upon a dot moving horizontally at constant speed within a viewing frame across the otherwise opaque face of a cathode ray tube and to judge whether its velocity is faster or slower than that of another such stimulus. From a series of these judgments, the change necessary to perceive either an incremental or decremental difference 50 percent of the time (or "just noticeable difference" if the two are averaged) may be computed (*4*).

Our objective, however, is to present psychophysical evidence which permits certain generalizations to be made about the human's ability to perceive differences in rates of change for a variety of exteroceptive stimuli. These exteroceptive stimuli fall into two classes: *extensive*, defined as changes principally in place or in extent; and *intensive*, which are changes principally in energy content (*5*). The first category includes moving points, expanding lines, and expanding circles; the second includes increasing visual luminance and increasing auditory intensity. The generalizations should be of interest to the cybernetic theoretician, in that they bear upon self-regulating, closed-loop models of biological information processing. They should also be of interest to the applied scientist, in that they may suggest how best to present information describing the changing nature of sequential events. Finally, they should be of value to the life scientist and medical specialist concerned with the structure and function of sensory systems.

General Procedural Considerations

Determination of thresholds for the same subjects for the different types of stimuli previously mentioned was made possible through the part-time services over a period of several years of two female subjects having normal vision and hearing. This traditional sampling approach to psychophysics places emphasis upon reduction of random variation in extraneous parameters; it does so by concentrating on repeated within-subject comparisons.

Several preliminary experiments helped form the basis for deciding upon an overall procedural plan (*6*). The key consideration was mode of stimulus presentation—whether it should be isochronal, isometric, or heterodimensional. An isochronal mode is one in which standard and comparison stimuli are presented for the same period of time; that is, duration of stimulus exposure is constant. Thus, the more rapidly a stimulus changes, the greater its final magnitude or extent. Final stimulus value is therefore perfectly correlated with stimulus rate, and accordingly has the potential to serve as a collateral cue

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for judging differences in rate. An isometric mode is one in which the final positions or magnitudes of the stimulus are kept constant. Therefore, the faster the stimulus rate, the briefer the stimulus exposure. Since duration of stimulus presentation is perfectly correlated (inversely) with stimulus rate, it can come to serve as an ancillary cue for judgments of differences between isometrically compared rates. A heterodimensional mode is one in which neither final magnitude nor duration is kept constant. A given stimulus rate may be presented for one of several durations and may attain any of various final magnitudes. It is therefore required of the subject that he perceive rate directly (that is, sensorily) from the stimulus exposure itself, or that he infer it by mentally relating a particular change in magnitude to its accompanying duration (*7*).

The idea, of course, is to keep standard stimulus rates the same for all three modes and thereby to determine how correlated magnitude and duration cues affect fineness of judgment. Since the just noticeable difference for duration at values appropriate to the three standard rates used was about a 15 percent change, and, for linear extent, only 10 percent, it was hypothesized that judgments based upon isometric presentations should be inferior to those based upon isochronal ones (*8*). And inasmuch as heterodimensional exposures have support from neither magnitude nor duration cues, judgments based upon this type of presentation should be the worst of the three.

Results obtained when discrimination of oscilloscope-displayed point velocity (previously described) was used as a test situation are shown in Fig. 1, which indicates that these predictions are borne out for both subjects at each standard (*9*). For each subject, the thresholds shown at the three standards are based upon a minimum of 100 forced-choice comparisons (20 with each of five comparison stimuli—two greater in rate, two lesser, and one equal). The subjects were instructed to observe each pair of comparison and standard stimuli and to respond (by pressing one of two labeled push buttons) in terms of whether the former was "faster" or "slower." These judgments were made after some 75 practice trials, not included in the averaging procedure. The curves shown for B.H. and Y.D., respectively, therefore represent a minimum of 900 comparisons, the mean curves a minimum of 1800.

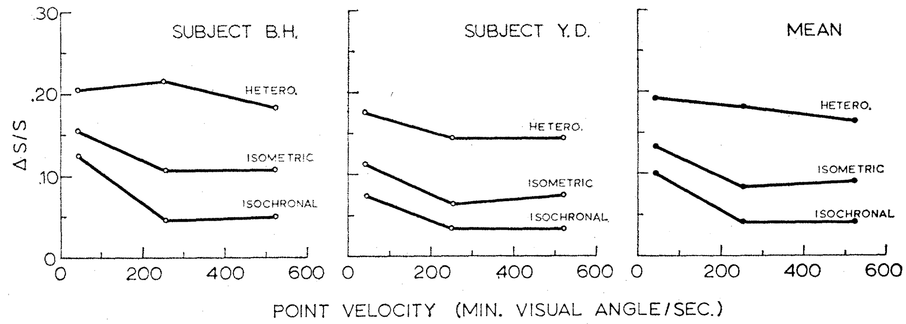

Fig. 1. Comparison of point velocity difference thresholds obtained under isochronal, isometric, and heterodimensional modes of stimulus presentation.

Since the isochronal mode resulted in the most sensitive discriminations, and for reasons of discriminative capacity (that is, superiority of magnitude over duration cues for the ranges examined) that seemed likely to transcend the special sensory effects of individual types of stimuli, it was decided to use the isochronal manner of presentation consistently (*10*).

Once this decision was made, it became immediately apparent that control observations were required to separate the effects of sensory exposure to the stimulus rates per se from that of specific rate plus its concomitant cue of final magnitude. As shown in Fig. 2, the strategy used was to eliminate exposure to the "ramp," and to present information giving initial and final values only (the "blanked" condition). In all isochronal cases explored, the initial value (*Ref.* in Fig. 2) was set at zero rate. For visual velocity, this meant that after a ready signal was momentarily sounded, a dot appeared at the extreme left edge of the viewing frame (1 inch or 2½ centimeters square), remained stationary for 0.75 second, and then—in the continuous condition—began moving horizontally to the right at a given velocity for 0.6 second, at which time it stopped and remained in its final position for an additional 0.75 second before it disappeared (*11*). In the blanked condition, movement was not displayed. For both expanding lines and circles, the initial value was a spot in the center of the oscilloscope face; no mask was used. The zero values for intensive stimuli required special consideration and are therefore discussed separately in connection with the actual data obtained. The same distinction between continuous and blanked conditions, however, was established as with the extensive stimuli.

A chin rest assured a constant binocular viewing distance of 10 inches (25 centimeters), thereby permitting specification of extensive stimuli in terms of visual angle. Three standard rates were used to compare points, lines, and circles: 40.12, 256.35, and 512.71 minutes of visual angle per sec-

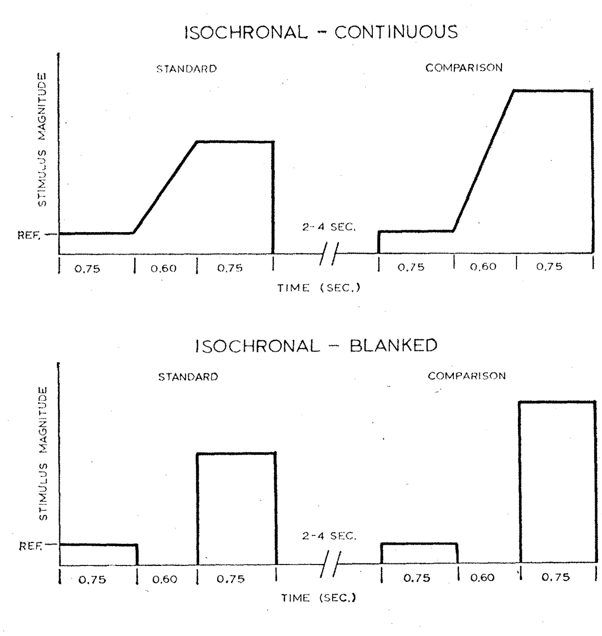

Fig. 2. General schema for presenting isochronal-continuous and isochronal-blanked ("end value only") stimuli.

ond. These rates apply to velocity as measured relative to oscilloscope background for the moving individual points, for either end of the expanding lines, and for any position along the expanding circumference of the circles. Comparison stimuli were so selected in pilot research as to permit the emergence of appropriate distributions of correct (or incorrect) responses.

Research Findings

In Fig. 1 it may be observed that the point velocity thresholds for isometric and isochronal conditions (respectively, about 10 and 6 percent) are lower than the thresholds for their presumed, supportive cues (respectively, about 15 percent for duration and about 10 percent for extent). This finding argues that having stimulus (and therefore sensory) information available on a *continuous* basis enhances the accuracy of difference judgment. Such a deduction follows, since if the judgments had been made independently of the "ramp" information, the difference thresholds for point velocity would have been equal to the mode-related duration or extent cues; the

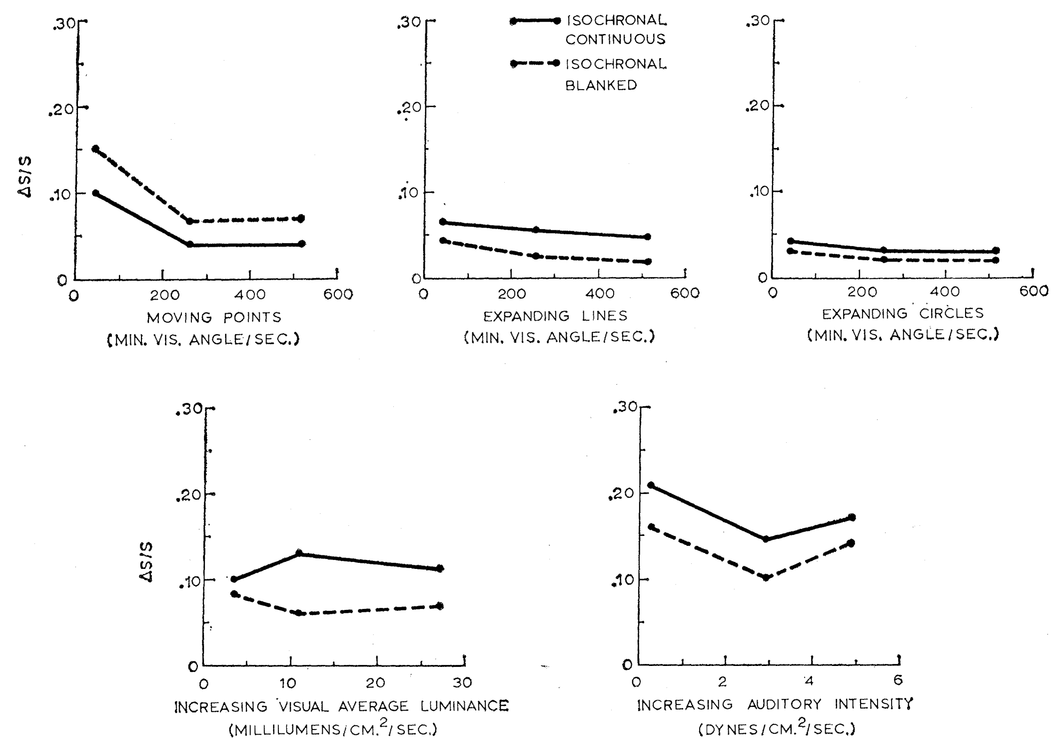

Fig. 3. Comparison of difference thresholds obtained for the indicated types of stimuli under isochronal-continuous and isochronal-blanked conditions.

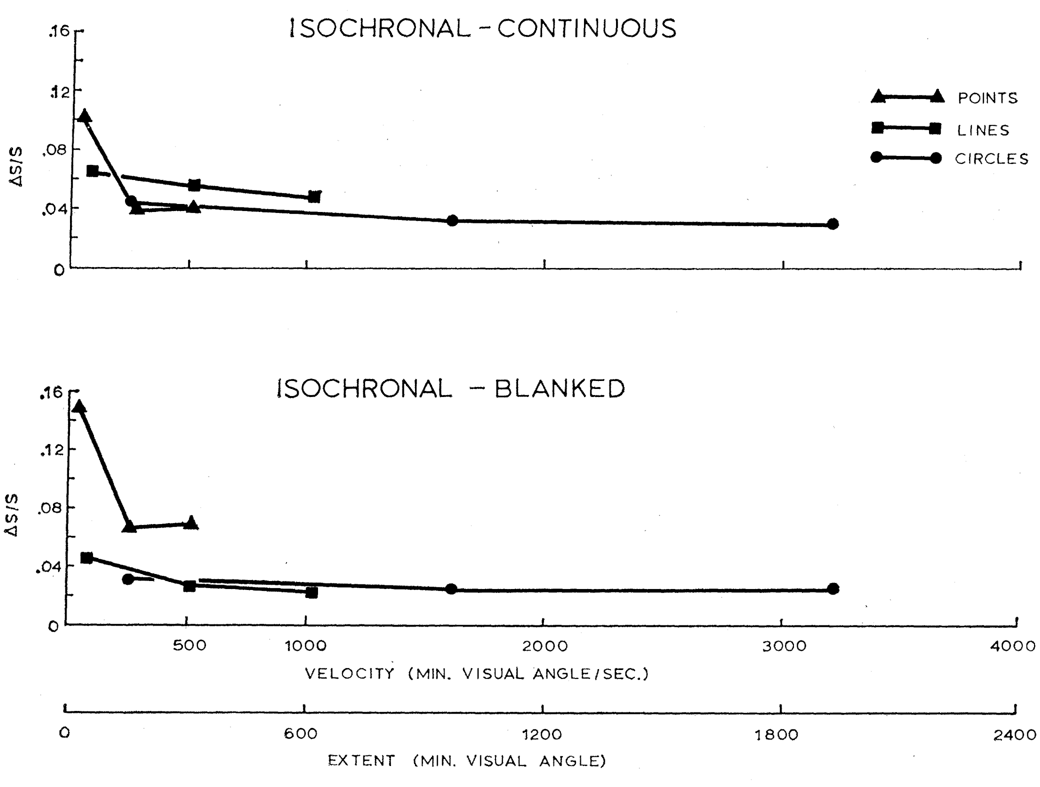

Fig. 4. Comparison of difference thresholds among extensive stimuli when relative velocity and extent are taken into account.

thresholds would certainly not have been lower.

But the summary data of Fig. 3 indicate that this analysis is far from complete. (All told, the entire figure is based upon at least 6000 comparisons: 2 subjects × 100 comparisons per point × 6 points × 5 types of stimuli.) With the exception of point velocity, the graphs are consistent in showing that the continuous condition is *inferior* to the blanked condition. This finding seems paradoxical in that exposure to the changing stimulus itself (presumably serving as one source of information), as well as to the final stimulus magnitude (presumably serving as another), yields *higher* thresholds than exposure to the final value alone. It seems reasonable to hypothesize that there is inherently something about direct attention to increasing stimulus values (other than continuous changes in position of a point) that leads to inferior judgments. This phenomenon lends itself to explanation in terms of a "suppression of an excess of information" (*12*). When continuous exposure to stimulation is involved, as in the situation under discussion, complex interactions among various adaptive and inhibitory neurological processes are known to occur. These interactions lead to nonlinearities between momentary stimulus magnitudes and perceived sensation (*13*). The foregoing would seem to be especially true when, as in the present case, the stimuli are not only continuous but are also increasing in value during the time that they are exposed to the subject (*14*).

The assemblage of conjectures concerning informational overload expressed above appears to account reasonably well for the superiority of blanked-intensive over continuous-intensive isochronal thresholds depicted in the lower half of Fig. 3.

For extensive data, this explanation is not so immediately germane, but the same suppositions can be put to something of a test in the following manner: The relative expansion of lines (that is, the joint outward movement of the line's two end points) was twice the rate of individual point velocities alone; and the relative expansion of circumferences was $2\pi r$, where r is the velocity of the separately moving points. (The expanding line was, of course, the invisible diameter of the expanding circle.) Since the expanding circle may be considered as comprising an infinite number of point velocities (the circumference), each radiating in its own vector, the moving point and the expanding circle have in common the attribute of momentary passage over "on/off" sensory endings. The expanding line, however, is characterized by stimulation, the refractory and adaptive effects of which exist for a period of 0.6-second exposure in the center of the line, and for progressively less duration with increasing distance from the midpoint. The resulting nonlinearities of sensation may be such as to elevate the threshold for judging changes in rate of increase of extent. Apart from the possibly deleterious influence of "excess information," from which perception of all continuously presented stimuli suffer, it would seem that observation of expanding lines possesses its own unique "overloading" disadvantages (*15*).

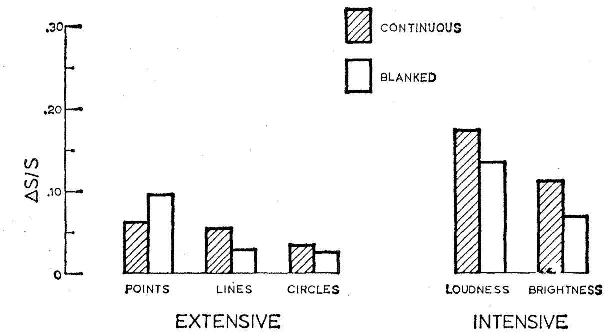

Fig. 5. General comparison of difference thresholds for representative extensive and intensive stimulus rates.

Accordingly, we are led to expect that, in the continuous condition, the difference thresholds based upon *relative* velocities for points and circles should be similar and that the difference thresholds for lines should be higher (that is, less precise) than for either points or circles. The upper portion of Fig. 4 indicates that such appears to be the trend, with the sole exception of the slowest point velocity (and, consequently, the shortest length of movement)—a departure possibly attributable to the interfering effects of nystagmus.

For the blanked condition, the analysis must take into account the fact that point velocities have the poorest thresholds of the three extensive types of stimuli; in fact, these thresholds are sufficiently inferior to provide the one instance in which blanked presentation is worse than continuous stimulation. We are led to the following explanation: The final values of blanked lines and circles have an inherent dimensional property, namely, extent. It happens to be the very property which, in the isochronal-blanked condition, is maximally informative of inferred stimulus rate. The point itself has no such attribute, apart from positional reference to the sides of the viewing frame. In addition, it is more difficult to locate the suddenly emerging point than it is to locate the reappearing line or circle. Finally, it should be noted that for none of the stimuli is sensory overloading under observed change a consideration, as it was in the continuous condition. Therefore, under the blanked condition, the difference thresholds for expanding lines and circles should be close to each other, and that of moving points quite separate and higher, indicating less precise judgments. The lower portion of Fig. 4 shows that this is the case.

A general comparison between extensive and intensive stimulus categories is facilitated by obtaining grand means for the subject means at each standard, as shown in Fig. 5. Intensive stimuli yield higher difference thresholds than extensive, at least under conditions of the research and over the ranges of stimulus rates examined. For auditory intensity (specified in dynes per square centimeter per second) the standard rates had their initial values at a level just below binaural absolute threshold for both subjects, and consisted of 400-hertz tones. For visual intensity, the customary problems presented by rod-cone retinal duplicity were dealt with in this way: Room illumination was adjust until a pair of nonenergized electroluminescent panels (one pair for each of the three standards and their related comparison stimuli) had a luminance of 0.191 millilamberts (*16*). This value is about 10 times greater than the absolute threshold for cone vision and approximately 1/100 the brightness of white paper under good reading conditions (*17*). In short, a condition of quite moderate but definite light adaptation prevailed. Such a state was required in order to assure quick recovery from exposure to the increasing brightness of the panels over the course of a trial (exposure to one standard and one of the comparison stimuli), thereby permitting temporal parameters to be identical with the other isochronal pairs of stimulus rates. Pilot experimentation was undertaken to make certain that the same level of visual adaptation was present at the onset of a new stimulus as existed for the immediately prior stimulus. Moreover, the same time-order control as was used with the other types of stimuli was employed in this case; that is, on half the trials the comparison followed the standard, and vice versa for the other half.

Measurements undertaken in our laboratory revealed that the panels generated luminance that was nearly exponential as a function of time, rather than linear. It is for this reason that the psychophysical curves shown in Fig. 3 have "Increasing visual average luminance" on the abscissa, expressed in millilumens per square centimeter per second (*18*). In view of other sources of error in dealing with time-variant brightness on a binocular basis (notably, the absence of constant pupil size, and the probable presence of some rod function), the departure from perfect ramp stimulus specification, while undesirable, is not crucial. It seems to us that the relative superiority of time-variant luminance thresholds over time-variant loudness thresholds for the stimulus rates and magnitudes involved is sufficiently marked as to be beyond explanation in terms of the problems of stimulus specification encountered with the former. In fact, such data as are available bearing upon the absolute threshold for second-order stimuli indicate that thresholds are *increased* compared to first-order stimuli (*19*). Such being the case, it might have been anticipated that the brightness thresholds should have been higher than the threshold of loudness, but the reverse is true. Finally, it should be noted that the results of comparing the two sensory systems involved are in agreement with what one might expect based upon Stevens's power functions relating subjective magnitude to stimulus magnitude (*20*).

The issue of why intensive stimulus rates yield higher thresholds than extensive stimuli yield may be related to the place and number of sensory endings influenced during stimulus presentation and to the degree of resulting adaptation. Under both continuous and blanked conditions, extensive stimulation affects fewer sensory endings than intensive stimulation. For example, the point, line, and circumference excite mainly the specific cones upon which their luminescent patterns fall; and, in the continuous case, these patterns (because they are changing in a first time-derivative fashion) pass over successively different (or additional, in the case of the line) elements. Even in the blanked case, the final end-values for standard and comparison stimuli also come to rest upon different receptors, except when the comparison stimulus equals the standard, and these judgments presumably would be split between the two response choices. Areal luminance (or brightness), however, affects considerably more of a population of cones; and the cones remain the same specific elements under both continuous and blanked circumstances, even though the amount by which they are stimulated during these circumstances may differ. Similarly, auditory intensity tends to excite the cochlea in a collective manner, with the qualification that different, but fairly large, segments of the organ of Corti are maximally sensitive to different frequencies.

In short, sensory adaptation to intensive stimuli entails greater likelihood of cumulative refractory influence upon thresholds than adaptation to extensive stimuli.

Are the generalizations depicted in Fig. 5 meaningful in broad biological terms? In this connection, a comment of Rushton's is appropriate: "Sensory systems are in fact for the most part a-c detectors, and this is effective since it is the *change* in the environment that is biologically important" (*21*). If one then reflects upon which environmental changes occur most frequently in the experience of the typical mammal, it seems likely that they are those which we have termed extensive, since virtually every motion of the head produces changes in patterns of light falling upon the retina. Disparities of brightness and loudness, while certainly present, are not nearly so ubiquitous, at least under ordinary circumstances.

Summary

Although cybernetic models of one sort or another have become quite common in behavioral research, and although these models theoretically require a capacity for system detection of changes in error, no general psychophysical description of the individual human being's ability to discriminate different rates of stimulation is available. An initial survey of this type has been attempted and is reported here.

For reasons which appear to be related to the biological mechanisms underlying sensory information processing, it is concluded, first, that ancillary cues of rate-related final magnitude are more valuable than cues of stimulus duration; second, that direct attention to on-going change is less precise than attention to final values only; and third, that differences in isochronal stimulus rates occurring in place or extent are more readily perceived than differences in isochronal rate of change in energy content, at least for the stimuli and ranges examined.

References and Notes

1. H. Lauer, R. Lesnick, L. E. Matson, *Servomechanism Fundamentals* (McGraw-Hill, New York, 1947). An example of circumstances under which judgments of the difference threshold for stimulus rates may be interpreted as being judgments of the absolute threshold for stimulus acceleration is given in J. M. Notterman, G. A. Cicala, D. E. Page, *Science* **131**, 983 (1960).
2. N. Wiener, *Cybernetics* (Wiley, New York, 1948), p. 14.
3. A review may be found in C. H. Graham, *Vision and Visual Perception* (Wiley, New York, 1965), chap. 20, pp. 575–588. An extension of the line of thought relating feedback models to behavior theory is available in J. M. Notterman, *Behavior: A Systematic Approach* (Random House, New York, 1970); see particularly chaps. 4 and 9, which elaborate on the foregoing paragraphs.
4. An algebraic equivalent of the average *z*-score method is convenient and was used in the research reported here; see R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, New York, 1954), p. 205.
5. The terms extensive and intensive are not quite synonymous with Stevens's terms metathetic and prothetic, although it would appear that they should be [see S. S. Stevens, in *Sensory Communication*, W. A. Rosenblith, Ed. (M.I.T. Press, Cambridge, Mass., 1961), pp. 6–7]. For example, Stevens includes "apparent length" with prothetic stimuli, and we place "expanding lines" principally in the extensive category. As elucidated subsequently, the accent is on the word "principally."
6. F. J. Mandriota, D. E. Mintz, J. M. Notterman, *Science* **138**, 437 (1962). This reference summarizes much of the pilot work.
7. As von Kries puts it, "Psychologically speaking, therefore, an indirect perception of motion of this kind involves both the idea of an interval of time and that of two places." Cited in F. J. Mandriota, thesis, Princeton University (1962).
8. These values are an average based upon threshold data gathered for each of the two subjects. At least 100 comparisons were made separately by the subjects for each of three duration and extent standards. The duration standards were the specific time equivalents of the isometric velocity standards reported in this study; namely, 8.57, 1.34, and 0.67 second. Physically, a spot of the same size and brightness as the moving standards appeared in the center of the field and remained (in the case of standards) for the indicated period. The extent standards were the distance equivalents of the isochronal velocity standards; namely, 24.07, 153.81, and 307.63 minutes of visual angle. Physical aspects of stimulus exposure were identical with those termed "blanked" condition, as described subsequently in the text. The values obtained for both duration and extent thresholds are comparable to those reported in the literature; see Mandriota (*6*).
9. An earlier article, one that shows curves based upon six standards, is available (*6*).

10. It is worth noting that earlier accounts of point velocity thresholds describe a minimum at about 60 to 180 minutes of visual angle per second; see W. E. Hick, *Quart. J. Exp. Psychol.* **2**, 33 (1950); J. M. Notterman and D. E. Page, *Science* **126**, 652 (1957); J. M. Notterman, G. A. Cicala, D. E. Page, *ibid.* **131**, 983 (1960). These studies all involved isometric, 1.5-inch stimulus traverses, whereas the current study has 1 inch as a maximum. Therefore, our best guess as to the basis for the presence of a minimum Weber ratio concerns the length of stimulus traverse, probably as it influences duration of exposure regardless of mode of exposure. Data are available from a pilot subject which support this conjecture, in that Weber ratios were decreased by approximately half in going from 0.4 to 0.6 second of isochronal stimulus rate duration.
11. Two oscilloscopes (Tektronix model 535 and Hewlett-Packard model 130-A) were used to present identical, electronically generated stimuli to the two subjects simultaneously. Both oscilloscopes were fitted with P11 5-inch cathode ray tubes having relatively short persistence traces. Each oscilloscope's tube face illumination was adjusted to a low level of brightness (0.0057 millilamberts) and supplied the only ambient illumination in the otherwise dark subjects' cubicle. The spot-stimulus was 0.03 inch in diameter, and 0.029 millilamberts in brightness.
12. G. von Békésy, *Sensory Inhibition* (Princeton Univ. Press, Princeton, N.J., 1967), pp. 1–34.
13. Some unusual masking phenomena may be representative of these nonlinearities; see, for example, D. N. Robinson, *J. Opt. Soc. Am.* **58**, 2 (1968); E. Donchin and D. B. Lindsley, *Vision Res.* **5**, No. 1/2 (1965). Stevens [*Science* **170**, 1043 (1970)] offers valuable comment on perceptual nonlinearities and central processing.
14. See R. S. Woodworth and H. Schlosberg, *Experimental Psychology* (Holt, New York, 1954), p. 270.
15. Although the precise values of the thresholds obtained might differ under *contracting* conditions for the line (as well as for the circle), and for point movement from right to left instead of from left to right, we have no substantial reason to believe that the ordering of thresholds reported here would be altered.
16. A 400-hertz modulator was used in conjunction with PRO-203W RCA electroluminescent panels, cropped to 1 by 2 inches, to generate stimuli of varying luminance. A dimly illuminated fixation cross, etched on a Plexiglas plate, was centered on each panel. For the three standards, the maximum driving voltages were 120, 240, and 600 volts, respectively.
17. S. H. Bartley, in *Handbook of Experimental Psychology*, S. S. Stevens, Ed. (Wiley, New York, 1951), p. 945.
18. Averages were obtained by dividing the final luminance less the initial luminance (0.191 millilamberts) by 0.6 second.
19. R. D. L. Filion, thesis, Princeton University (1963).
20. S. S. Stevens. *Science* **170**, 1043 (1970).
21. W. A. H. Rushton, in *Sensory Communication*, W. A. Rosenblith, Ed. (M.I.T. Press, Cambridge, Mass., 1961), p. 176.
22. Supported by U.S. Air Force Office of Scientific Research contract AF 49 (638)-1258. We are grateful to S. C. Fowler, C. E. Sherrick, and D. Weitzman for their comments on the manuscript. Dr. Fowler, who currently shares the senior author's laboratory, was especially generous with his time.

The Scientific Advisory System: Some Observations

This system has little effect on the broad technical decision made in Washington.

Martin L. Perl

Since World War II, scientists and engineers have been going to Washington in increasing numbers to help the government make decisions on technical questions. These questions concern every aspect of our technological society—nuclear weapons, missiles, space travel, cancer research, pesticides, and mental health. Some scientists and engineers go for 1 or 2 days a month; others take a leave of absence from their institutions or corporations and spend several years in Washington. Some serve on committees attached to the executive branch of the government; others serve through semigovernmental institutions like the National Academy of Sciences. A few work with the Congress. All of these scientists and engineers, the committees they serve on, and the positions they hold in Washington together constitute the scientific advisory system (*1*). This article is about that system, or more precisely, about a paradox connected with that system.

The paradox is easily presented. Most people will agree that the United States is besieged with perilous technological problems—how to stop the arms race and bring about nuclear disarmament, how to stop the technological destruction of the natural environment, how to raise the standard of living, or at least prevent mass starvation, in the poor countries. Most people will also agree that these problems have become much more severe in the last two decades. But in these same two decades, the United States has received enormous amounts of scientific and technical information and advice from the scientists and engineers of this country. This information is almost always technically correct and thorough; it is almost always given with the intention of solving or mitigating the problems sketched above. The paradox is simply this: How have we gotten into so much technological trouble while getting so much well-intentioned and correct technological advice?

A broad analysis of this paradox might require a study of the relationship between the scientific advisory system and the "technostructures" postulated by Galbraith (*2*). Or one might examine whether the advisory system is an example of the "techniques" that Jacques Ellul (*3*) believes are the essence of our technological society. However, I restrict my analysis to a discussion of the role played by the advisory system in the technical decision-making processes in Washington. In addition, I do not attempt to present a complete description and evaluation of the scientific advisory system, nor do I discuss the role of the scientific advisory system in the larger decisions on military technology.

Few people realize the size and complexity of the scientific advisory system, and I know of no complete study of the magnitude and structure of this system. Therefore, I refer here to a recent, but not exhaustive, study (*4*) that was carried out by a group of Stanford graduates and undergraduates, for whom I was faculty adviser. The study notes that the Executive Office of the President has advisory committees that involve several hundred prominent scientists and engineers. The best known of these committees is the President's Science Advisory Committee. Outside the Executive Office of the President, but inside the executive

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