Dynamic visuometric techniques

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A general technique is described to automate the measurement of visual thresholds. The method is based on the dynamic analog of the method of adjustment, incorporating continuous feedback. Threshold is treated as a system interaction between some level of response and sensed input. The S tracks a stimulus that continually oscillates in magnitude around threshold. The accuracy and variability of the S's response provides a dynamic and functional assessment of the threshold under the condition of the experiment. Techniques for instrumenting several visuometric procedures are described.

The measurement of human visual thresholds using the classical psychophysical method of limits involves generating a systematic step variation in the intensity or magnitude of the test stimulus. For example, in a brightness experiment the test light is initially set well below threshold and slowly increased until threshold is reached. The process is then reversed by varying the stimulus downward. It is recognized that this is often a tedious and unnecessarily time-consuming procedure because many of the S's perceptual judgments to the different intensities of the light stimulus are clearly above or below the ultimate threshold determination. In addition to the effects of a series of subthreshold and superthreshold stimuli on the S's interest and attention level, stimuli well above threshold may also produce adaptation effects that add to the variability of response.

The ideal procedure would involve rapidly locating and maintaining a stimulus at an intensity level that would always be close to the threshold. The simplest approach would be to employ the method of adjustment, and allow the S to control directly the intensity of the light stimulus to correspond to his threshold of visibility. The main disadvantage in this method is the lack of control over the rate of change of the test stimulus.

This paper describes an automated technique for continuously controlling the rate of change of the stimulus, while maintaining the stimulus at a near-threshold level over the entire trial period. The basic visuometric procedure involves generating a smooth variation in a specified physical dimension of a visual

stimulus, such as intensity or size. The variation in the stimulus can be set at a constant rate or set according to a preprogrammed periodic or aperiodic variable velocity.

In the first procedure to be described, the S manually controlled the direction of this stimulus change. The S accomplished this by discretely pressing a horizontally positioned lever or toggle switch either to the left or right. This action was designed to keep the stimulus from increasing or decreasing beyond the just-visible threshold. This operation is similar to the Békésy (1947) audiometer. In the second procedure, the S controlled not only the direction of stimulus change, but could also vary the basic rate of stimulus increase and decrease by the rate and direction of continuous manual motion applied to a flexible control lever. An illustration of these two versions of threshold measurement is given in the following study, which was concerned with the effects of horizontal motion on visual acuity. It should be noted that other dynamic threshold measures can be obtained using the same method and slightly different instrumentation.

CONSTANT-VELOCITY METHOD

To study dynamic visual acuity, a Landolt ring was projected on a screen in front of a S. The stimulus was moved horizontally across the screen at different rates. The size of the ring was also made to increase at a constant velocity as long as

the S pressed a lever or a switch to the right, and to decrease in size as long as the lever was pressed to the left. The Ss were instructed to keep the gap in the Landolt ring at a just-visible size by pressing the lever in the desired direction. In other words, the Ss were exercising a degree of feedback control over their stimulus input. The result of this procedure was that the critical stimulus oscillated about threshold at all times, and the threshold varied as a function of the experimental variable.

Figure 1 illustrates a simplified overhead view of the experimental arrangement. The S is shown seated in front of a large curvilinear screen. The Landolt ring was projected from overhead by a Bausch & Lomb Clason visual acuity meter. A mirror galvanometer was attached to the front of the projector. When the galvanometer was activated by a function generator, the mirror oscillated and generated a horizontal motion of the stimulus on the screen. At the same time, a continuous variation in the size of the stimulus ring was generated by the variable projection lens system of the Clason meter. The lens system was designed to be moved back and forth on a special cam in order to keep the image on the screen focused automatically as the size of the projected image was increased or decreased. This variable lens system was linked to a drive mechanism (Bodine motor). The S's manual responses were transduced by two strain gauges bonded to a rigid horizontal lever. A discretely applied force of 2 g moved the lever 5 mm to the left or right. This pressure was sufficient to set up a signal, which, when fed to the drive mechanism, activated a relay that switched the

Fig. 1. Basic experimental arrangement. The S is seated in front of the display screen. The stimulus is presented from the overhead projector.

Fig. 2. An illustrative oscillograph record. The smooth diagonal trace at the beginning of the record represents the total range of stimulus variation. At time t_1 , the S begins to respond and his threshold level is displayed.

electrical polarity of the rotating motor. This reversed the direction of the motor, and thereby, reversed the increase or decrease in stimulus size in order to maintain the stimulus at the "just-noticeable size." A toggle switch would accomplish the same thing, but it is slower to manipulate.

The pattern of variation in stimulus size as regulated by the S was recorded on an oscillograph. An illustration of an experimental trial is displayed in Fig. 2. As indicated by the diagonal trace in the bottom part of the oscillograph record, the stimulus size increased and decreased in a smooth manner and at a constant rate, as determined by the rate of motor movement. The size of the gap in the Landolt ring varied between 0.5 and 6.5 min of visual angle at a rate of 0.8 min of visual angle per second. The oscillograph trace moving to the right in Fig. 2 represents an increase in stimulus size until the maximum size is achieved at the right boundary. The trace to the left represents a decrease in stimulus size. The boundary at the left represents the minimum size of 0.5 min or 0% magnitude. The boundary at the right represents the maximum size of 6.5 min or 100% magnitude. The S's threshold normally falls between the two extremes.

In the example in Fig. 2, the S began to respond at time t_1 . At this point the stimulus was increasing in size until the gap became visible. The S immediately reversed the motor to decrease the size of the

stimulus until it became almost indistinguishable. He continued in this manner throughout the trial, relying on the visual feedback from the previous response to guide himself in the ensuing response. By introducing dynamic feedback into the experiment, the Ss were able to refine continually their responses and to reduce the error between the momentary stimulus value and their ultimate threshold level. The design of this type of task is such that the greater the degree of perceptual-motor response accuracy exhibited by the S, the smaller is the stimulus variation from his threshold level in the immediately following moment. In this way the value of the stimulus is always maintained around the individual's threshold level for each of the given experimental conditions.

The position of the gap was randomized on each trial into the standard eight positions. The absolute threshold was computed by measuring the mean displacement of the oscillation from the right-hand stimulus boundary, which represented 6.5 min of visual angle. The amplitude of the oscillation corresponded to the difference threshold plus a simple reaction-time component. As indicated in Fig. 2, the degree of oscillation was rather steady around the threshold level.

As a result of the relatively slow, but continuous change in stimulus size, there was an inherent lag between the perceived change in the stimulus size and the subsequent readjustment of the stimulus to the threshold level. Furthermore, since the rate of change of the stimulus was constant, the S's task of pressing the lever could become somewhat rhythmic as the threshold was established. There was the danger, therefore, that the S would be guided by his sense of time instead of his threshold. The following procedure, which is slightly more complex, was meant to remedy some of the above-mentioned difficulties.

VARIABLE-VELOCITY METHOD

This method is similar to the above technique, except that the velocity of stimulus change was varied throughout the trials according to a semirandom form. This was done to eliminate the rhythmic response anticipation based on time association. The "velocity of stimulus change" refers to the rate of change in the size dimension of the stimulus in this experiment, or in another experiment it might involve the rate of change of brightness, shape, or position of the stimulus in space.

A second main characteristic of this method is that the Ss were able to regulate manually the direction of stimulus change, as well as to control the rate of increase

and decrease in the specified stimulus dimension by the rate of motion applied to the control lever. So the control lever served as a dc-coupled transducer of hand position and motion.

The addition of velocity control to direction control allowed each S a second degree of freedom in the search for his threshold. Ss were able to eliminate some of the inherent lag between perception and the adjustment responses by generating a velocity change that would compensate for the preprogrammed stimulus change. With the constant-velocity method, the stimulus change may be too slow at one moment and too rapid at another for the S to accurately maintain the stimulus at threshold. For example, a large overshoot of the threshold could occur as a result of variation in attention level over the trial period. This error could be corrected much more rapidly by simply increasing and, if necessary, decreasing the rate at which the stimulus size is varied. This is accomplished by moving a flexible control lever in the appropriate direction at the appropriate rate. The lever movement generates a change in the dc signal, which serves to increase or decrease the rate of movement of a simple dc motor or a high-torque galvanometer system.

The actual oscillograph records in Fig. 3 illustrate two variable stimulus waves and the pattern of threshold response that the S generated on two different trials. The variability of response was reduced with the addition of velocity control, despite

Fig. 3. Two sample trials representing the stimulus and threshold response pattern of a S.

Fig. 4. A block diagram of the general system. This indicates the closed-loop relationship existing between the S's threshold responses and the stimulus pattern. The stimulus-generator component acted as a forcing function to provide a variable-velocity stimulus pattern which oscillated through the S's threshold range.

the fact that the rate of stimulus change was variable and semi-nonpredictable. (The reduction in variability over the constant-velocity method can be as much as one-half.) The threshold response pattern was displaced to the left in Trial 1 and to the right in Trial 2. This represented two different threshold values, which corresponded to two different levels of the independent variable, which was horizontal motion in this study. Specific data is cited in Putz (1969).

VISUOMETRIC INSTRUMENTATION

Although the nature of the research problem always defines the specific instrumentation procedure, certain visuometric techniques are common in measuring thresholds dynamically. The general system can be illustrated by means of a block diagram, shown in Fig. 4. The visuometric system functions much like a compensatory tracking arrangement. The drive mechanism or controller responds to the analog error existing between the stimulus function generator and the S's transduced response at all times. So the S literally tracks his own threshold.

An appropriate display for the system would be an oscilloscope, a projection screen, or a physical object capable of being changed along one of its specified dimensions by an appropriate drive mechanism.

The drive mechanism consists of either an electrical amplifier circuit built into an oscilloscope display or a specially designed electrical-mechanical device. In the initial study of dynamic visual acuity, reported above, the projected stimulus was increased and decreased by the mobile lens system of

a Clason projector, driven by a Heller Bodine motor. In later studies on the perception of the upright, stimulus cues were projected on a screen and tilted to different angles (Putz, 1969, 1970). This was accomplished by a small dove prism inserted in the projection tube of a slide projector. The prism was rotated by a drive mechanism known as a limited rotation motor, which induced variations in the orientation of the stimulus object. In a study on brightness perception, a circular neutral density wedge was employed. The wedge was also rotated by a limited rotation motor that varied the illumination of the stimulus (Smith, Putz, & Coleman, 1968; Smith & Arndt, 1969). A device similar to the Howard and Dolman apparatus was used to study depth perception; the comparison rod was moved by a stepping motor.

We have used three manual control levers to transduce the S's responses: a potentiometer with a handle, a strain-gauge system, and a commercial tracking control device. The strain-gauge device illustrated

in Fig. 5 consists of a thin rectangular steel lever with strain gauges attached on either side to form a Wheatstone bridge. The transducer was connected to a Beckman preamplifier with a strain-gauge, signal-conditioning coupler. A dc signal is generated in direct proportion to the position and rate of hand movement. The lever is naturally spring-loaded to return to the center position when released. The commercial device is an isometric hand control marketed by Measurement Systems Corporation. The handle is stiff, and the S detects no deflection. The control responds to finger pressure of less than 1 g and has a linear direct-current output.

The electrical signal from the transducer was designed to activate a drive mechanism that induced feedback changes in the stimulus. Three drive mechanisms were tried. The least satisfactory of these from the standpoint of controllability was the reversing and variable-speed Bodine motor employed for the initial study on acuity. In this situation, the S was provided with a large potentiometer, which was substituted for the potentiometer in the speed-control circuit, a component in the G.K. Heller Motor Controller unit (Model S10). A second potentiometer was connected in the same manner to the commercial speed controller, which was rotated by a cam to effect continuous changes in the velocity and direction of the motor and the stimulus. Directional changes were accomplished by inserting a relay that switched the electrical polarity as the potentiometer approached the zero-velocity position setting. The Ss were instructed to turn the potentiometer to compensate for the changes in stimulus size, which was induced by the motor arrangement, and thereby to maintain the stimulus at a just-visible threshold level. This system depended on rate control, which generated a fair amount of extra variability. A stepping motor, or an analog-controlled limited-rotation motor with an external forcing function, proved to be considerably more effective as a drive mechanism for the variable-velocity

Fig. 5. A lateral hand-motion transducer using strain gauges. (Type, CD-7; resistance, 500 ohms; gauge factor, 3.35.)

Fig. 6. This modified projector unit is capable of projecting a stimulus pattern that oscillates horizontally and at the same time changes its upright orientation.

method of threshold assessment.

In another study a stepping motor (Slo-Syn Bifilar dc motor) was geared down to generate position variations, perceived as continuous, in the stimulus. This device, and the appropriate translator module triggered by a -15-V pulse, can provide adequate real-time control over the rate and direction of movement of a stimulus object. This is particularly useful for controlling the position of targets in the third dimension. In most cases the S manipulates an analog hand control and the analog response is converted to digital pulses in order to drive the stepping motor. This system is useful if digital logic is available.

A high-torque galvanometer or a limited rotation motor (Mechanics for Electronics, Model 154) was used to rotate the optics in a modified slide projector. The projector is shown in Fig. 6. The insert in the top right-hand corner illustrates how a dove prism was mounted in a large bearing that was inserted into the projector's lens holder. A small pulley connected the limited rotation motor to the mobile-lens arrangement. The motor rotated in direct response to a change in a dc signal between 0 and $\pm 8\text{ V}$, generated by the S's hand transducer in response to the stimulus. The orientation of the stimulus grid was controlled with a precision of a 10th of a

degree. A second galvanometer with mirror was mounted in the extended front compartment of the projector. This served to oscillate the stimulus horizontally across the visual display screen. With this projector arrangement, the Ss' thresholds for dynamic vertical perception could be assessed as a function of the rate of horizontal stimulus motion in accordance with the variable-velocity method described above (Putz, 1970).

In general, control devices and drive mechanisms are selected which minimize lags and overshoots and maximize the potential for direct time and space control over the variable stimulus. The high-torque galvanometer or limited rotation motor accomplishes this best.

Another important consideration concerns the generation of appropriate forcing functions for establishing the basic pattern of stimulus increase and decrease. Almost any low-frequency function generator will generate stable periodic waves, such as a triangular or sinusoidal wave form. The function generator is used to drive the limited rotation motors; it can be interfaced with the servo or stepping motor for additional control.

The generation of an aperiodic wave form (or semirandom variable-velocity curve, as it is called here) is more difficult and involves the use of a special

programmable analog wave generator such as a Data Track (R. I. Controls). In a study of visual acuity and brightness discrimination (Smith, Putz, & Coleman, 1968; Putz, 1969), a small computer (160A, Control Data Corporation) was programmed to generate a smooth forcing function. The forcing function was converted to analog form as plus and minus variations in a slow dc signal oscillating around 0 V with a frequency of 6.5 cycles/min. The forcing function was programmed by selecting randomly a series of values from one of four tables of sinusoidal half waves, which differed in amplitude. After program control had progressed sequentially through the values, a new set of values from a second table was selected. In this manner, variations in position, velocity, and acceleration were generated while maintaining the internal smooth coherence of the complex wave form in any given trial period. Two typical computer-programmed variable waves are illustrated in Fig. 3. The analog voltage corresponding to the wave form was fed to the high-torque galvanometers in order to generate changes in the vertical orientations of the stimulus that was being investigated.

The last consideration is the assessment or quantification of the threshold level. If the response of the S is recorded on an oscillograph, it is easy to obtain a visual indication of the threshold by observing the position of the oscillatory trace on the record. The use of a recorder for measurement presupposes that the position of the trace has been calibrated to the change in stimulus magnitude. In the studies mentioned, an oscillograph record was kept of the threshold variation over the experimental trials. In addition, the Ss' responses were digitized by an analog-digital converter (Packard-Bell M3 Multiverter) at a rate of 100 samples per second. This was immediately fed into the small on-line CDC-160A computer, and an absolute mean error score for every 5 sec of the trial period was accumulated. The value of the score represented the size of the physical stimulus at threshold.

SUMMARY

The basic technique described here can be conceptualized as a dynamic analog of the psychophysical method of adjustment. Threshold is treated as a systems interaction between some level of response and sensed input, and its measurement can be approximated by assessing the space and time factors existing between the organism's sensory and motor systems.

This method of arriving at a threshold of visual function is similar to the method of adjustment in that the S is given remote

control of a stimulus and is required to adjust the stimulus so that it is just perceptible. Or he may be asked to match or equate a variable-comparison stimulus with a standard stimulus. The dynamic analogs of this method were found to eliminate some of the inherent weakness of control to which this method is often subject.

In the constant-velocity method, the E sets the rate of change of the stimulus while allowing the S to locate and dynamically track his own threshold by controlling the directional variation of the stimulus. The second method, which is a refinement of the first, serves to reduce the predictability of stimulus change by introducing a variable-velocity stimulus change. In addition, the variable-velocity method tends to reduce the inherent lag between perception and response by

providing the S with velocity as well as direction control over the stimulus variation. Overall, the dynamic method of assessing visual thresholds reduces the time and variability of threshold measurement, an important factor when many threshold observations are required under different experimental conditions.

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NOTES

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