Binary estimation¹

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Abstract

A new psychophysical method was applied in two experiments in which Ss used binary decisions to estimate directly the position of a stimulus with respect to a specified physical scale. Linear functions were obtained for visual judgments of stimulus location and luminance.

Introduction

One of science's long standing interests has been the specification of man's ability to estimate relative magnitudes of physical stimuli. A number of psychophysical techniques are available to determine the functions relating physical measures of the world to response measures of the human (Guilford, 1954). In this paper a new technique is described which perhaps will span a large range of physical dimensions. This technique consists of a person bisecting intervals on a physical scale, and in this regard it resembles the older ratio methods (Guilford, 1954). However, in the latter a single judgment is required on each trial for each stimulus; whereas in the present method, binary estimation, a sequence of judgments involving a diminishing part of the physical scale is given on the same trial for the same stimulus conditions.

The rationale for the method arises from the fact that the information content of a class of stimuli can be characterized by labelling all possible members of the class with binary numbers (Attneave, 1959). The number of digits in the largest such binary representation is the number of "bits" of information to be dealt with in the class. If a yes-no decision is associated with each digit of the binary number, then a sequence of decisions defines each stimulus. Obviously, the procedure should be reversed in dealing with a given stimulus class; i.e., there is usually an intuitive decision sequence which applies. This intuitive sequence can be used to enumerate stimuli and provide the number of bits of information, equal to the number of decisions. Such a decision rule can be applied in psychophysics by having a person overtly indicate the binary sequence required to specify a particular member of a stimulus class. For example, the position of a point on a line segment can be determined by having a person state "one" when the stimulus point appears in the right half of the line and "zero" when in the left half. After this response is given, and without stimulus alteration, the half appearing to contain the point is bisected, thus yielding the second digit of the sequence. The procedure continues until no more binary decisions can be made. It is to be noted that the physical region in which the decision is rendered may be limited by two entirely subjective reference

points determined by previous decisions, and following a decision one reference point always changes. The series of *ones* and *zeros* generated is considered the stimulus estimate for the trial. The nature of this binary number, ranging from 0 to 1 in the decimal system, is compared to the physical distance of the point from the left end of the unit length line segment, also specified in the decimal system.²

Apparatus and Procedure

The feasibility of the method was tested for two physical dimensions. In one experiment comparison was made between binary and absolute estimation of the position of a point on a straight line. A black line 0.4-mm thick and 42.8-cm long, was drawn on each of six sheets of white paper (42.8-cm x 35-cm) which were pasted to pieces of black cardboard. The lines were parallel to the bottom margin of the papers and a black point of 1.6-mm diameter was placed on each line at one of six distances from the left edge: 8.4-cm, 16.7-cm, 20.2-cm, 25.4-cm, 28.8-cm, or 37.2-cm. In a well lighted room these stimuli were shown singly in a plane perpendicular to the bisector of the subject's (S) binocular lines of sight. This bisector was centered on the stimulus line, located 56-cm from the eyes. Head movement was minimal.

Thirty undergraduate men were participants, 15 employed binary estimation and 15 judged the absolute distance of the point in inches from the left edge of the line. To help explain the binary method S was shown a sample pattern (point at 25.4-cm) with the correct sequential bisections marked off in pencil on the line. If an S still misunderstood the task after the instructions, he was not used in the study. The Ss judging absolute distance were told the total line length before testing began. An S made two judgments of each of the five test points in a random order; the sixth point at 25.4-cm was always used for practice.

In a second experiment binary estimation was used by three men and two women to locate the variable luminance of a square with respect to the standard luminance scale defined by two adjacent squares. In this instance a black box was divided into three equal compartments, each containing a 100 watt incandescent lamp. A window, 10.5-cm on a side, was cut from the front of each compartment and the opening covered by Lucite. Under these conditions a window luminance was 360 ft-L as measured with a Spectra spot meter. Neutral density filters could be placed before the three individual squares which were spaced in a horizontal row. The S viewed the display frontally from a distance of approximately 100-cm and head movement was permitted. The left square always was covered by a filter of 4.0 log density, the right square by a filter of .10 log density, whereas the center square had one of nine filters: .20, .40, .80, 1.00, 1.40, 1.60, 1.80, or 3.00. An S made four judgments of each luminance of the middle square in a random order. Detailed instructions were read, including a description of the method's use in locating the position of a point on a line, but subject variance found in pilot work led us to require exactly five binary decisions for each stimulus presentation (for luminance estimation only). The room was dimly illuminated, and Ss began adapting to these conditions 5-min. before testing.

Results and Discussion

Binary and absolute scores from the two experiments were converted into decimal numbers on a unit interval, and means and standard deviations were computed for test stimuli (see Attneave, 1959 and Gregory, 1963). The results for position of a point on a line are given in

Fig. 1. Mean point estimates as a function of physical point distance along a line. Open circles and right pointing pips represent means and standard deviations respectively for 30 absolute estimates obtained from 15 Ss. Filled circles and left pointing pips are for comparable binary estimates. All values have been transformed into decimal values on a unit interval.

Fig. 1. The mean accuracy attained by both the binary and absolute methods is very high, a finding which coincides well with previous work on this dimension (Humphries, 1960; Stevens & Galanter, 1957; Wolfe, 1923). Although all binary values (mean error = -2.8%) are slightly less than the actual position of the point and the absolute scores (mean error = +2.4%), the deviation of the mean is large enough to account for the difference. The somewhat greater variability of binary

Fig. 2. Mean binary estimates of luminance as a function of log filter density. The vertical extents represent one standard deviation above and below the mean which is based upon 20 estimates obtained from four Ss. Estimates have been transformed into decimal values on a unit interval.

estimates is probably due to Ss' lack of experience with the technique. On the average about five binary decisions were given on each trial though some Ss gave as many as eight and some as few as three.

In Fig. 2 the means and standard deviations for luminance judgments are plotted as a function of log filter density of the test square. As determined by a least squares solution, the means can be fit quite well by a straight line (goodness of fit, $r = .99$). We are reluctant to attribute special significance to this function, however, because of the variability of the mean, and because alternative ways of plotting and describing the data are possible. Accordingly, the luminance estimates are not easily compared with existing results whose interpretation is itself the subject of controversy (cf., Helson, 1964; Restle, 1961; Stevens & Galanter, 1957).

Besides specific empirical use, binary estimation may provide a test of the theoretical hypothesis stated most explicitly by Restle (1961) and Helson (1964) that all psychophysical judgments are derived from binary decisions. One advantage of a binary technique is that detailed analysis of the judgment process is available through the study of individual decisions (digits) within a binary estimate (number). The method's primary disadvantage seems to lie in its application by untrained Ss. In future work it would be desirable to have an independent check on the degree to which Ss are complying with instructions.

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Notes

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2. For a brief discussion of the relation between binary and decimal representation see Gregory (1963).