PHENOMENAL SIMULTANEITY AND THE PERCEPTUAL MOMENT HYPOTHESIS

BY D. A. ALLPORT

Department of Psychology, University of Aberdeen

Successive brief visual stimuli falling within a critical time interval are phenomenally simultaneous. This paper examines two models of perceptual sampling which purport to account for phenomenal simultaneity. The first is Stroud's (1955) theory that the sensory input is quantized into successive, discrete summation periods or 'moments' (the Discrete Moment Hypothesis). An alternative model which has not generally been considered represents the 'moment' as a continuous, running sample of the input (the Travelling Moment Hypothesis).

Two experiments on phenomenal simultaneity are reported which provide a critical test between these two hypotheses. The results were entirely incompatible with the discrete moment model, which is therefore rejected. The travelling moment model accounted well for the results. These also suggest a possible relation between the limits of phenomenal simultaneity and the critical duration of brightness summation.

The suggestion has been put forward in many forms that, at some stage in the nervous system, the sensory input is packaged for analysis into successive, temporally discrete samples or 'chunks'. Underlying this suggestion is the idea that the brain operates in some way discontinuously in time on its inputs, an idea which will be referred to, for convenience, as the Perceptual Intermittency Hypothesis. This is to distinguish it from the related notion of intermittency in the selection of response, often referred to simply as 'central' intermittency, recently reviewed by Bertelson (1966). Perceptual intermittency has been proposed as an explanation for a remarkable variety of perceptual and other phenomena (Ansbacher, 1944; Boynton, 1961; Broadbent, 1958; Callaway & Alexander, 1960; Harter, 1967; Kinsbourne & Warrington, 1964; Kristofferson, 1967; Ladefoged & Broadbent, 1960; Lichtenstein, 1961; McReynolds, 1953; Michon, 1967; Murphree, 1954; Shallice, 1964; Stroud, 1955; White, 1963; Young & Stark, 1963; among others).

The hypothesis of perceptual intermittency envisaged by these writers has been coupled—sometimes implicitly—with an additional and much stronger postulate, namely that information regarding the temporal order of events falling within a given input sample is lost, e.g. as the result of a summation process. It is assumed, that is, that change in the input with respect to time can be represented only as between successive input samples, all events within a given sample being effectively simultaneous. The sample length thus becomes an irreducible unit, or quantum, of subjective duration—the perceptual moment. This much stronger postulate will be referred to as the Discrete Moment Hypothesis. Stroud (1955) provides its best known and most explicit formulation, but it is also assumed, explicitly or implicitly, by all of the writers listed above (with the possible exception of Broadbent, 1958) and in numerous other discussions of perceptual intermittency.

Historically the Discrete Moment Hypothesis has been linked with certain relatively specific suggestions about (a) periodic scansion as a basis for pattern recognition (Pitts & McCulloch, 1947), and (b) possible effects of cortical excitability cycles (e.g. Lindsley, 1952; see also the recent review by Harter, 1967). Logically, however, the
Discrete Moment Hypothesis is independent of any such speculations as to mechanism, and is considered here in its basic form. Certainly the evidence most often put forward in its support, concerning the temporal limits of interaction in the sensory input—and in particular, the span of phenomenal simultaneity between successive discriminable stimuli—has not been shown to relate to either (a) or (b) above.

In assessing the Discrete Moment Hypothesis two important points have been generally overlooked. First, it should be emphasized that loss of time-order information within the sample period is not entailed by the idea of discontinuity of operation (perceptual intermittency) per se. For instance, the handling of morse sequences in successive discrete 'chunks', as suggested in the original paper by Craik (1948), clearly presupposes the preservation of order information within each chunk. There is no contradiction here.

More importantly for the present argument, there is no reason a priori why the perceptual moment, defined as the span of subjective simultaneity, should be quantized in time. The logical alternative to this, which has not generally been considered, is that the 'moment', thus defined, corresponds to a continuously moving segment of the input function (the Travelling Moment Hypothesis). On this hypothesis all successive events in the input separated by less than the span of the travelling moment will be phenomenally simultaneous, although this relation, unlike the discrete case, is not transitive. In terms of information processing by the nervous system, the Travelling Moment Hypothesis requires a continuous, running sample of the sensory input, the basis for decision at any instant being some function, e.g. a moving average, of the input sampled over the previous 1/10 sec. (or whatever the length of the moving sample happens to be).

A simple spatial analogy may help to make this distinction clear. To a man standing on the platform, the occupants of a passing train are revealed compartment by compartment as each window draws by. His glimpses of the interior of the train are essentially discontinuous in time. To an observer in one of the compartments, on the other hand, the field of view is always bounded by his own carriage window. New elements of the passing scene enter his view continuously from one side of the window, while others drop out of it at the other. Given a temporal rather than a spatial extension, the moving window analogy corresponds to the idea of a continuous 'travelling moment'.

The alternatives of temporally discrete v. continuous operation between them partition the set of possible models of input sampling in the nervous system, at least at any one level of perceptual analysis. (Consequently, experiments which could decide between these two broad classes of alternative would be optimally efficient in the sense outlined by Broadbent, 1956.) Yet very little of the evidence which has been put forward in support of a Discrete Moment Hypothesis has been even considered in the light of the continuous alternatives. To my knowledge the first published treatment of a travelling moment model, at least since James (1890), is due to Shallice (1964). In an illuminating theoretical paper Shallice considered four models of perceptual sampling derived from quality control procedures: two inherently continuous in operation and two discontinuous (including Stroud's discrete moment model). Unfortunately for a general decision on continuity v. discontinuity of perceptual sampling the results remained inconclusive.
Perceptual Moment Hypothesis

Nearly all of Stroud's own evidence, for example, with the possible exception of the 'temporal numerosity' data (see White, 1963), can be accounted for equally well in terms of a travelling moment, where 'moment' is a period of temporal summation. Indeed some of the phenomena considered by Stroud—notably that of stroboscopic movement—could definitely not be predicted from his theory. According to the Discrete Moment Hypothesis, temporal interactions between successive events in the input should either occur or not occur in an all-or-none fashion, depending on whether the representation of these events overlaps in the same perceptual moment. The difficulty is that temporal interactions in perception are frequently not of an all-or-none type. The literature abounds with evidence to this effect. For a further discussion of Stroud's evidence, and of the other studies referred to at the beginning of this paper, see Allport (1966).

What is strikingly absent from the literature is any adequate experimental test of either the Discrete or the Travelling Moment Hypotheses, as distinct from the demonstration of phenomena compatible with them. The present paper is intended to fill this gap in the experimental literature.

General method

Two experiments on visual phenomenal simultaneity, designed to provide a critical test between discrete and continuous (travelling) moment models, will be described.

Display. The display employed in both experiments consisted of an illuminated horizontal line which could occupy successively a sequence of 12 positions ('steps') on an oscilloscope screen, equally spaced one above the other. The position of the line changed instantaneously from one step to the next, and the whole sequence recycled continuously. The cycle time, and hence the rate of stepping, was controlled by the subject. In the simplest arrangement (Fig. 1a) the first step in the cycle followed immediately after the last, so that each position in this case was occupied for \( t/12 \) of the complete cycle time, \( t \). The line commenced either at the top and stepped downwards or at the bottom and stepped upwards.

Apparatus. The line patterns were displayed on the screen of a Cossor 1049 Mk. III oscilloscope. A cathode-ray tube containing a very short persistence 'blue' phosphor was employed. Rise and decay times of the trace were symmetrical with a time constant of c. 0.20 msec. The line was formed by a horizontal sweep on the x-axis internal time-base at 1.5 kc/sec., with trace suppression during flyback.

A voltage staircase was supplied to the y-plates of the cathode-ray tube by an Advance V.L.F. function generator SG 88. The central feature of this instrument is a glass disk, driven by a Velodyne motor, which rotates in the path of a narrow optical beam shining on to a photomultiplier. Any simple function blocked out in opaque material on the disk can thus be translated into a voltage as a function of time by the disk rotation. When running, the instrument emits a clearly audible whine, which changes in pitch as the rotation rate is altered. In order to prevent the use of auditory cues in setting a given repetition rate of the display, the subject wore a pair of well-padded headphones through which a masking noise of c. 60 db was presented. At this level subjects were unable to say with better than chance accuracy whether the function generator was running or not.

Stimulus arrangements. The subject observed the display binocularly from a distance of 6 ft., supported by a chin-rest. The lines on the cathode-ray tube screen were 2.5 in. long and sharply focused. Vertical separation between adjacent steps was constant at 0.18 in. (9' of visual angle), giving a total height of 2 in. (1° 36' visual angle). A curved white screen subpending 40° of visual angle concealed all but the cathode-ray tube screen itself, which was visible through a 2.5 in sq. aperture. Trace intensity was adjusted to 16 ft.-l. (100 ft.-l. in Expt. I, condition B). To determine the luminance of the trace the vertical separation between adjacent lines was reduced until they were contiguous, and Talbot brightness of the trace (\( S_i \)) recycling at 25 c/sec. measured with an S.E.I. photometer. Ambient room illumination was low—c. 0.01 ft.-l. at the reduction screen.
Subjects. Twelve university student volunteers, aged 18–25 yr., served as subjects for both experiments. They were tested individually, and were unaware of the purpose of the experiments.

Preliminary observations

At a very slow repetition rate subjects report typically a single horizontal line which appears to jump intermittently to a new position a little above (or below) its previous one. On decreasing the period of the display (i.e. increasing repetition rate) the subject sees not just one, but an increasing number of horizontal lines in apparent movement up (or down) the screen en bloc together. (The idea of using such an arrangement for measuring the limits of phenomenal simultaneity was suggested by Crawford in an unpublished study; Crawford, 1964.) As the number of perceptually ‘simultaneous’ lines becomes greater than half the total number of line positions (typically around 4–5 c/sec.) a figure-ground reversal occurs. The display is now more readily perceived as a stationary array of horizontal lines across which moves a dark band of shadow, temporarily obscuring some of them. This same phenomenon of ‘shadow’ movement is still readily observed with a display of only two line positions.

A further reduction in the total cycle time, τ, eliminates even the apparent motion of the ‘shadow’. The entire display is now seen as a stationary array of lines flickering apparently in synchrony. A fine-grained ‘trickling’ effect, superimposed on the stationary lines, is reported by some subjects to persist up to the much higher frequencies at which flicker fusion occurs. Nevertheless the transition to apparent simultaneity (synchronous flicker) of all successive line elements in the repeating cycle, on abolition of the ‘shadow’ movement, is relatively abrupt. The period of the display, T, at which this occurs is taken as a measure of the span of simultaneity.

Increasing the vertical separation of the steps was found to increase T, linearly. A preliminary experiment obtained results to this effect, paralleling data reported by Neuhaus (1929, tables 4–7) for a two-stimulus display, but with higher absolute values of T. This effect clearly has to be accounted for in any satisfactory model of phenomenal simultaneity. Fortunately it does not affect the predictions which these experiments were designed to test, and so will not be considered further here.

EXPERIMENT I

The effect of intra-cycle temporal pattern on the span of simultaneity

The span of phenomenal simultaneity, T, was determined under two intra-cycle temporal arrangements of the repeating ‘staircase’ display. Separate predictions were derived, and tested, from both the Discrete and Travelling Moment Hypotheses.

Method

The general method has already been given in a preceding section.

Stimulus arrangements. (1) Full cycle (S1): the 12-step display recycled continuously, the first step in the sequence following immediately after the last. (2) Half-cycle (S2): the sequence of 12 line positions occupied only half the complete cycle time. At the end of step 12 the cathode-ray tube beam was deflected off the screen for the remaining half-cycle, then recommenced at step 1 (see Fig. 1).

Two levels of trace intensity were used. In condition A (dim) the trace intensity was 16 ft.-l. In condition B (bright) it was increased to 100 ft.-l.

Design and procedure. The subject slowly adjusted the period (τ) of the display to phenomenal simultaneity, T, i.e. to the critical repetition rate at which all the lines just appeared to be flashing synchronously, with no indication of temporal differences between them. He was instructed to use as his principal criterion of simultaneity the absence of seen movement, either of the lines or of the ‘shadow’.

Between each adjustment the experimenter set the period of the display alternately well below and well above T, and differing from it by a random amount. These will be referred to as ascending and descending trials respectively. On descending trials the subject was instructed to reduce τ slowly and carefully to simultaneity, going, if necessary, only very slightly beyond it and back again, until he found a point at which apparent movement was eliminated, but could be
Perceptual Moment Hypothesis

reintroduced by a very small increase in \( \tau \). On ascending trials he was similarly to increase \( \tau \) slowly until the first signs of movement were detected, and again to ‘bracket’ the simultaneity point by as slight shifts of repetition rate as possible.

The subject was told to fixate within the area of the cathode-ray oscilloscope display, but no other control of eye movements was made.

Each subject performed four trials, two ascending and two descending, under each of the four stimulus conditions. The order of presentation was counterbalanced. Before the experimental trials about 10 min. were allowed for instructions and practice at the procedure, using the full-cycle arrangement \((S_1)\) only. The subjects were unaware of the object of the experiment and of the nature of the temporal arrangements in the displays.

\[\text{(a) Full cycle (}\boldsymbol{S_1}\text{)}\]

\[\text{Position of illuminated line}\]

\[\text{Complete cycle time, } \tau\]

\[\text{(b) Half cycle (}\boldsymbol{S_2}\text{)}\]

\[\text{Position of illuminated line}\]

\[\text{Complete cycle time, } \tau\]

Fig. 1. Diagram of intra-cycle temporal arrangements for full- and half-cycle displays (Expt. I). Horizontal bars represent the proportion of the cycle for which each line position or ‘step’ is illuminated.

Predictions

1. The Discrete Moment Hypothesis

Ex hypothesi, when all the steps in the cycle fall within one discrete ‘moment’ (of duration \(M\)) they are perceived as simultaneous.

\(a\) Synchronized ‘moments’ . Given the possibility, envisaged by Stroud, of triggering the onset of moments \(t_0, t_1, t_2, \ldots\) to periodicities in the input, the Discrete Moment Hypothesis predicts the following results.

For the full-cycle display \((S_1)\), simultaneity is reached on both ascending and descending trials when \(\tau = M\) (Fig. 2a). For the half-cycle display \((S_2)\), however, phenomenal simultaneity can be obtained either when \(\tau = M\) or when \(\tau = 2M\) (see Fig. 2b). Now on ascending trials the subject starts from ‘simultaneity’ (no apparent movement) and increases \(\tau\) until movement reappears. This should first occur when

Copyright (c) 2001 Bell & Howell Information and Learning Company
Copyright (c) British Psychological Society
\( \tau \) becomes just greater than \( M \), i.e. when successive moments are no longer synchronized with each complete cycle of the display. The subject should therefore set \( T_s = M \). On descending trials, on the other hand, simultaneity will first be reached when \( \tau = 2M \), i.e. when alternate moments are 'filled' and 'unfilled'. Provided the subject follows the instructions and does not greatly overshoot this point, he will then set \( T_s = 2M \). On descending trials, therefore, \( T_s \) for a half-cycle display should be twice that set for a full-cycle display (Fig. 2).

(b) If \( M \) were extremely variable, tending to synchronize with the input over a very wide range of \( \tau \), then 'bracketing' of \( T_s \) required by the instructions would be virtually impossible. \( M \) would remain locked to \( \tau \) no matter how the subject varied the repetition rate. However, as indicated in the preliminary observations, the bracketing procedure was in fact quite easily carried out and yielded a relatively abrupt and stable value of \( T_s \). Thus \( M \) must be assumed variable, if at all, only within narrow limits.

(c) Self-paced moments. Without Stroud's assumption of a facility for synchronization with the input (i.e. if \( M = \text{const.} \) \( T_s \) should be reached, for both \( S_1 \) and \( S_1 \), when \( \tau = M \). (With \( S_1 \) it might just be possible, on occasion, to set the half-cycle of the display in phase with the 'moment' sequence at \( \tau = 2M \), although again, as for 1a above, this could only occur on descending trials.)
Perceptual Moment Hypothesis

A much more definite and significant prediction regarding the half-cycle display is as follows: around both \( \tau = M \) and (to a lesser extent) \( \tau = 2M \) the period or half-period of the display should 'beat' slowly against the spontaneous 'moment' frequency, causing the apparent width of the 'shadow' to oscillate between zero and its maximum extent.

2. The Continuous (Travelling) Moment Hypothesis

According to this hypothesis successive sensory events will be perceived as simultaneous whenever their temporal separation is less than the extent of the travelling moment. They will, however, be perceived as simultaneous only as long as they are thus represented together within the moment span. In the present experiment, with a repeating sequence of stimuli, the criterion for \( T_s \) was not merely momentary simultaneity but continued absence of seen movement or any other temporal ordering. A subject obtaining an occasional momentary impression of simultaneity, immediately replaced by seen movement, would justifiably reduce the cycle time further until the apparent movement was eliminated. In other words, the criterion of simultaneity is met if and only if all successive elements in the repeating sequence are continuously present within the travelling moment span. That is, for all intra-cycle temporal arrangements, on both ascending and descending trials, when \( \tau \geq M \).

Results

Ascending v. descending trials

The differences in \( T_s \) between ascending and descending trials, while statistically significant, did not exceed 4 msec. (Table 1). Contrary to the prediction from Stroud's Discrete Moment Hypothesis (1a, above), this difference was no larger for half- than for full-cycle displays (rather the reverse) and nowhere near the predicted ratio of 2:1. No individual settings even approach this ratio (see 1c, above). For the remainder of the analysis these differences were therefore regarded as negligible, and data from ascending and descending trials have been pooled.

<table>
<thead>
<tr>
<th>Display</th>
<th>Intensity</th>
<th>( T_s ) (desc.) - ( T_s ) (asc.)</th>
<th>( t )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full cycle</td>
<td>A (dim)</td>
<td>3.7</td>
<td>2.45</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td></td>
<td>B (bright)</td>
<td>3.9</td>
<td>3.31</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Half cycle</td>
<td>A (dim)</td>
<td>4.1</td>
<td>2.70</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td></td>
<td>B (bright)</td>
<td>2.4</td>
<td>2.42</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

Effects of intra-cycle temporal pattern

The principal remaining results are summarized in Table 2. There are no very large differences in \( T_s \) between half- and full-cycle displays, but the latter required a consistently shorter cycle time to reach simultaneity at both intensities.

Effect of intensity

Between conditions A and B the oscilloscope trace intensity was increased by 0.8 log units, and this is reflected in a significant drop in \( T_s \) for both \( S_t \) and

Copyright (c) 2001 Bell & Howell Information and Learning Company
Copyright (c) British Psychological Society
$S_4$ (see Table 2). Now in setting up the experiment, the trace brilliance was calibrated only for $S_1$. But for a given repetition rate the time spent at any one step in the half-cycle display, and hence the total light energy delivered during the cycle, is of course just half that for the full-cycle arrangement. Consequently the effective brightness of the $S_4$ was in fact 0·3 log units below the corresponding $S_1$ arrangements.

Table 2. Critical cycle time, $T_*$, giving phenomenal simultaneity (msec.)

<table>
<thead>
<tr>
<th>Display</th>
<th>Intensity</th>
<th>Mean $T_*$</th>
<th>$\sigma$</th>
<th>Comparison</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full cycle ($S_1$)</td>
<td>A</td>
<td>86·2</td>
<td>12·5</td>
<td>$S_1$ v. $S_4$ (A)</td>
<td>3·45**</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>70·7</td>
<td>8·1</td>
<td>$S_1$ v. $S_4$ (B)</td>
<td>2·92*</td>
</tr>
<tr>
<td>Half cycle ($S_4$)</td>
<td>A</td>
<td>95·5</td>
<td>15·0</td>
<td>$S_4$ A v. B</td>
<td>5·49***</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>81·4</td>
<td>14·6</td>
<td>$S_4$ A v. B</td>
<td>2·44*</td>
</tr>
</tbody>
</table>

* $P < 0·05$. ** $P < 0·01$. *** $P < 0·001$.

Fig. 3. Effect of trace intensity on the critical period of the display (repetition interval) giving phenomenal simultaneity between all successive line positions in the cycle.

The resulting brightness differences have been taken into account in Fig. 3. The straight line, fitted by the method of least squares, represents a decrease in $T_*$ of 20 msec. per log unit increase in intensity. The degree of fit obtained suggests that trace intensity is in fact the single major determinant of $T_*$ for all four stimulus arrangements.

Discussion

The results of this experiment entirely fail to support the predictions made from Stroud’s Discrete Moment Hypothesis (1a above). Without the assumption of syn-
Perceptual Moment Hypothesis

chronization with a periodic input (1c above) the quantitative predictions are less
clear-cut, and cannot be said to have been unambiguously falsified. Qualitatively,
however, no effect which might be interpreted as ‘beating’ between the display and
the hypothetical moment frequency (clearly predicted by 1c) was observed for any
of the patterns on any occasion. These results, in the opinion of the writer, therefore
oblige us to reject the notion of a discrete perceptual moment.

The travelling moment model, on the other hand, predicts no difference in the span
of simultaneity between different intra-cycle temporal patterns. Where the effect of
luminance is held constant (see Fig. 3), this prediction is substantially fulfilled.

In view of the remaining slight ambiguity of these results concerning the fixed-
period discrete moment model, a second, and much simpler, experiment was carried
out. The results of this second experiment were incompatible with any form of the
Discrete Moment Hypothesis.

**EXPERIMENT II**

*Direction of ‘shadow’ motion*

In this simple experiment subjects were asked to report merely in which direction
the ‘shadow’ appeared to be moving.

**Method**

Direction of stepping of the line, upwards or downwards, was randomized between trials, the
direction on any trial being unknown to the subject. On each trial the cycle time of the display
was increased from well below simultaneity (synchronous flicker of all 12 lines) until the subject
reported clear movement of the ‘shadow’, in the form of a narrow dark band covering one or two
lines, across the display. He was then asked in which direction the ‘shadow’ appeared to be
moving. Some subjects described both a slow and a quick—almost instantaneous—phase of the
shadow motion, in which case they were asked to report the direction of movement of the slow
phase. Each subject performed four trials.

**Predictions**

Let the steps be numbered 1, 2, 3, ..., 12 in the order in which they occur within
the cycle. According to the Discrete Moment Hypothesis, all the steps within the
cycle will be phenomenally simultaneous when they are included within the same
discrete ‘moment’. When the moment length just includes, say, 11 of the 12 steps,
the ‘shadow’ presumably represents the excluded ith line. Then in successive discrete
moments the ith line will be replaced by line i−1, i−2, i−3, ... and the ‘shadow’
will appear to travel in the direction opposite to that of the sequence of line positions.
This applies to all versions of the Discrete Moment Hypothesis. The situation can be
illustrated as follows:

<table>
<thead>
<tr>
<th>Steps...</th>
<th>8 9 1 2 3 4 5 6 7 8</th>
<th>9 1 2 3 4 5 6 7</th>
<th>8 9 1 2 3 4 5 6</th>
<th>7 8 9 1 2 3 4 5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete</td>
<td>M&lt;sub&gt;1&lt;/sub&gt;</td>
<td>M&lt;sub&gt;2&lt;/sub&gt;</td>
<td>M&lt;sub&gt;3&lt;/sub&gt;</td>
<td>M&lt;sub&gt;4&lt;/sub&gt;</td>
<td></td>
</tr>
<tr>
<td>moments</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Step excluded from moment</td>
<td>Time →</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Schematic representation of ‘shadow’ effect according to the Discrete Moment Hypothesis.
(Diagram is for a display of nine steps.)

If, on the other hand, the span of simultaneity is determined by a continuous
‘travelling moment’, again including n−1 of the n steps at any instant, the excluded
ith line will be, successively, \( i + 1, i + 2, i + 3, \ldots \) The reader should verify this statement for himself, if necessary, by visualizing the sequence of integers given above moving past a window which exposes \( n - 1 \) at a time. Consequently the ‘shadow’ will appear to travel in the same direction as the sequence of line positions.

This observation is therefore crucial in distinguishing between temporally continuous and discrete models of the ‘perceptual moment’.

Results and discussion

All subjects on all trials reported movement of the shadow in the same direction as the physical sequence of line positions in the display.

This result is incompatible with any form of the Discrete Perceptual Moment Hypothesis, which is therefore rejected. Other observations reinforce this general conclusion. For instance, at slower repetition rates of the display, when the ‘shadow’ appears to span more lines, it should also—on the basis of the Discrete Moment Hypothesis—appear to travel faster across the display. This was not observed. In fact, the reverse occurs, as the travelling moment model predicts. The results are of course entirely compatible with the Travelling Moment Hypothesis.

General discussion

The conventional account of phenomenal simultaneity and stroboscopic movement (e.g. Osgood, 1963) is based on some extension of Korte’s ‘laws’ (Korte, 1915), which make no reference to the idea of a perceptual moment. Now whatever their precise form, an underlying assumption of such ‘laws’ is that it is the time interval between individual stimulus events (onsets) which is the critical variable. But in Expt. I it was found that simultaneity is reached at a constant cycle rate, regardless of individual stimulus intervals within the cycle. A similar finding has been reported by Lichtenstein (1961), who took it to support Stroud’s Discrete Moment Hypothesis. However, the particular arrangements of his experiment precluded any discrimination between a discrete and a continuous (travelling) moment, with which his results were equally compatible. The results of the two experiments reported here show that the limit of simultaneity and apparent movement is determined by a process formally equivalent to a travelling moment—for which Korte’s ‘laws’ may be seen to represent simply the special case with only two stimuli.

The discrimination of simultaneity between spatially separate events (the subject-matter of these experiments) should of course not be confused with the detection of intermittency in any single visual location (flicker). The observations reported above were in any case all made at frequencies well below CFF with respect to the individual lines.

It has been pointed out (Kinsbourne & Warrington, 1964; Kahneman, 1967) that the span of simultaneity coincides with the temporal limits of a number of different types of interaction between stimuli, including backwards visual masking or meta-contrast. The idea has also been advanced (Eriksen & Hoffman, 1963; Kahneman, 1965) that visual masking between successive stimuli may be at least partly accounted for in terms of temporal summation, resulting in reduced figure-ground contrast. In this connexion there is a remarkable similarity between the slope of \( T_s \) as a func-
tion of intensity (Expt. I, Fig. 3) and that found for the critical duration of visual brightness summation (e.g. Graham & Kemp, 1938; Keller, 1941; Biersdorf, 1955; Herrick, 1956). (Absolute values of intensity in Fig. 3 are based on the Talbot brightness of the cathode-ray tube trace itself. For comparison with the brightness summation data these should perhaps be averaged over the 1.5° height of the display, which would have the effect of bringing the absolute values into much closer agreement.) There is also evidence, in the case of the disk-ring suppression effect, that the critical interval for masking varies inversely with intensity in much the same way as in brightness summation (Holland, 1963). The similarity in each case may of course be fortuitous, but it is tempting and certainly economical to suppose, in view of the previous suggestions, that the temporal limits of these varieties of stimulus interaction depend on (or are matched to) some common underlying mechanism. If so, then Stroud may have been thus far correct in identifying the 'moment' with a period of temporal integration. His mistake was to ascribe it to a temporally discrete operation.

**Conclusion**

The experiments reported here have shown that the 'perceptual moment'—if by that is meant the span of simultaneity between successive visual stimuli—does not depend on a temporally discrete operation on the input. Consequently all forms of the Discrete Moment Hypothesis, including those theories which attempt to relate cortical excitability cycles, or periodic scansion, to subjective simultaneity (loss of time-order information in the input), must likewise be rejected. On the other hand, a continuous sampling process (the travelling moment model) accounts well for the results. If the arguments presented here are correct, then any remaining intermittency in the perceptual process, suggested for instance by the data obtained in temporal numerosity experiments, must be more central in origin than the phenomena of apparent movement, meta-contrast, and brightness summation most often described in the terminology of the perceptual moment. *A fortiori*, evidence of the temporal characteristics of these effects can have little relevance to the hypothesis of perceptual intermittency, which must look elsewhere for its empirical support.

I wish to thank Dr D. E. Broadbent and Professor R. L. Gregory, who supervised this work, for much advice and encouragement. The experiments were carried out in the Psychological Laboratory, Cambridge University, and supported by a grant from the Science Research Council.

**References**


(Manuscript received 23 June 1967; revised manuscript received 13 May 1968)