THE LOCATION OF CLICKS IN SHORT TEMPORAL INTERVALS

by

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Abstract

Two experiments examined the ability of subjects to locate clicks occupying various positions in unstructured 2, 4, and 6 sec. intervals of time. In Experiment I, it was found that the effects on the subjective location of the click of the experimental factors of interval filling, interval duration, click position, and daily testing sessions, were to modify underlying response tendencies. The apparent response tendencies were a central tendency and a right bias. Experiment II investigated the hypothesis that the right bias resulted from the subjective association of differential amounts of mental content with the durations preceding and following the click. The results did not support the hypothesis but did suggest that the right bias resulted from the misperception of the location of the click by a constant amount of time regardless of the objective position of the click within the interval. An alternate hypothesis based upon the perception of the click as having an appreciable duration was proposed to account for the right bias.

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This paper presents two experiments which investigated the ability of human subjects to locate auditory stimuli in short intervals of time. The problem and the methodology for these experiments were originally derived from a series of studies exploring the psychological reality of grammar (click studies) and not, as might be expected, from the large body of literature on time perception. The studies of grammar, however, were only a point of departure, the experiments were concerned, not with grammar but with temporal location and the problem and results were interpreted within the conceptual framework of time perception. This being the case, the following review will concentrate on relevant areas of the time perception literature. Discussion of studies on the psychological reality of grammar will be limited to the extent necessary to demonstrate the connection between click studies and time perception.

A characteristic of the human animal is to be conscious of the passage of time. Each individual is able to organize the events that mark his existence into a temporal series and from this series to determine, with varying degrees of precision, how long some event or period lasted, or whether one event preceded or followed another event, or how much time separated one event from another. We are all familiar with the experience of time but what exactly do we experience and with what do we experience it? Time has no obvious physical basis like the light waves of sight or the airborne particles of smell and there is no obvious organ of time analogous to the eyes or the nose. The apparent absence of an external organ prompted philosophers and psychologists to search for an internal mechanism or process that would explain time experience.

Most philosophical inquiries into time are of interest solely for the insight they give into the systems of their proponents but a few philosophers have made suggestions with psychological relevance. Aristotle (Fraser, 1966) speculated that ". . . if any movement takes place in the mind we suppose that some time has elapsed, and the time that has passed is always thought to be in proportion to the movement." John Locke (1959) clearly adumbrated modern theories of time when he classified time perception as part sensation and part retention.

The early experimental investigation of time (Nichols, 1890) concentrated on whether or not it was subject to Webers' Law. Data accumulated on this problem during the first half of the present century (Blakely, 1933; Henry, 1948; Stott, 1933; Woodrow, 1930) until Woodrow (1951) was able to conclude that one of the few things known with reasonable certainty about time perception was that, for short intervals at least, Weber's Law did not hold.

In their search for the Weber fraction for time, most of the early workers proceeded on the assumption that there was a time sense in some way analogous to the other senses. William James (1890) had argued that the idea of a special time sense was as untenable as the idea of a special space sense, but the main thrust of theory and experimentation remained directed towards describing and/or discovering the time sense.

Vierordt (1868), after gathering estimates of intervals ranging from 0.25 to 8.0 seconds in length, stated the principle that " . . . overestimation is associated with short intervals of time and underestimation with long intervals." The principle implied that there was a point where overestimation changed to underestimation, that is, there was some interval where subjective time coincided with the 'real' time of clocks. Vierordt called it the "indifference interval" and the search for it has occupied a great number of researchers. The most commonly reported values for the indifference interval are from 0.6 to 0.8 seconds (Fraisse, 1963) but the range extends from under 0.36 to over 5.0 seconds (Woodrow, 1951). A number of reviewers (McKellar, 1968; Woodrow, 1951) suggest that people build up frames of reference depending upon the range of intervals to which they are exposed. McKellar concluded that the whole search for an indifference interval had been a waste of time. Fraisse (1963, p. 116-118), however, maintained that it was a legitimate concept. Starting from a finding by Gastaut (1949) that a light stimulus caused a cortical potential that lasted 0.5 to 0.6 seconds, Fraisse argued that the onset of an interval caused a comparable potential and if the offset occurs before the potential for the onset has subsided, an effort is required to perceive an interval at all. It is the effort involved which causes the overestimation. In longer intervals, if the offset occurs more than a few tenths of a second after the onset potential has subsided, an effort is required to associate the past and the present but in this case the effort causes underestimation. The first part of the argument is interesting but on the whole it is unconvincing.

The supposed existence of an indifference interval suggested to many theorists that the point of correspondence between subjective and objective time represented the period of some physiological rhythm and that the time sense existed in the form of a biological clock. In the search for the biological clock almost every rhythmical bodily process has had its proponents. After observing the effect of a fever on his wife's ability to judge durations, Hoagland (1933) reported that the time sense was dependent upon body temperature. He proposed brain metabolism as the clock and argued that as the fever increased the rate of metabolism in his wife's brain, her subjective time units shortened. Other suggestions have been: heart beat (reported in Woodrow, 1951), EEG (Holubar, 1969), reverberating neural circuits (Creelman, 1962), and an undefined neural pulse generator (Triesman, 1963). The whole idea was carried to its logical extreme by Gooddy (1966) who proposed that all of the periodic and quasi-periodic rhythms of the human organism combined to form the clock. Evidence against metabolic clocks was reported by Bell (1965). He found no difference in time estimates when he raised body temperature artificially. Ochberg, Pollack, and Meyer (1964) found no correlation between pulse rate and time judgements, and a comprehensive investigation of biological clocks by Cahoon (1969) found no significant relationship between time estimates and heart rate, respiration rate, alpha rate, or integrated EEG activity.

If the indifference interval actually does correspond to some biological rhythm, it is reasonable to expect periodic indifference intervals. That is, objective and subjective time should correspond on every beat or every multiple of beats of the biological pendulum. Early investigators did report periodic indifference intervals (Nichols, 1890) but the periods were all different and modern investigators are able to find only a single indifference interval.

It seems possible to conclude that although the concept of a biological clock has generated a great deal of research, it has not provided a satisfactory explanation of time experience.

An entirely different approach is exemplified by the work of Frankenhaeuser (1959). She hypothesized that an individual learns to judge the approximate amount of mental content that corresponds to familiar objective time units and therefore subjective time units are standard amounts of mental content. On the basis of this assumption, it follows that the experience of time is a function of attention, perception, and retention. That is, if an individual pays closer than normal attention to an event, both the amount perceived and the amount retained in memory are high, subjective time units are short, and the duration of the event is overestimated. Although the extrapolation to perception and retention is seldom made, a number of studies have investigated the effect of attention on duration estimates. Hulser (1924), Quasebarth (1924), Woodrow (1951), Von Sturmer (1966), and Von Sturmer, Wong, and Coltheart (1968) all concluded that the more attention given to the task of judging durations, the longer a given interval is judged to be. Conversely, Wundt (1903) and Bokander (1965) have both reported that the focusing of attention leads to an underestimation of duration. Similarly, although attention is not specified, uninteresting tasks are judged as longer than interesting ones (Loehlin, 1959) and simple tasks are judged longer than complex ones (Smith, 1969). Interestingly enough, Frankenhaeuser (1959) herself reports that the subjective lengthening of intervals filled with simple or boring tasks is a well-known phenomenon. She suggests that anticipation, or the active attending to the passage of time, is a concomitant of boredom and greatly increases the cognitive content of an interval. Ornstein (1969) elaborated on this explantion when he stated that expectancy leads to an increased sensitivity to stimuli. Whether the controversy over the effect of attention can be considered resolved or not, Frankenhaeuser's series of experiments apparently demonstrated direct relationships between amount of attention, amount perceived, amount retained, and judgements of duration. She concluded that memory is an inherent characteristic of time experience and the magnitude of remembered duration depends upon the amount of mental content associated with an objective time unit.

Ornstein (1969) agrees with Frankenhaeuser's position but does not think her theory goes far enough. He suggests that the economy with which the input is coded determines duration judgements. That is, if a great deal of input can be coded into a few "bits" the duration associated with that input is perceived as short. In a typical experiment, Ornstein's subjects attended to a complex stimuli for a period of time and then some of the subjects were given a clue or strategy that economically organized the stimulus. The group with the recoded input judged the interval to be much shorter than did the group that was not given a recoding strategy.

Regardless of what facet of time experience a particular study is investigating, the data collected are usually some form of judgements of the duration of short intervals. The length of the intervals used is usually in the order of seconds or minutes. Some physiologically oriented investigators prefer the time consuming method of temporal conditioning (Holubar, 1969) but otherwise there are four standard methods by which estimates of short durations are obtained (Wallace and Rabin, 1960).

1) Verbal estimation--an interval is delimited operatively by the experimentor and the subject verbally indicates the duration of the interval. If the subject overestimates, it is interpreted to mean his subjective temporal units are smaller than objective temporal units.

2) Production--the experimentor states a duration verbally in objective units and the subject produces an interval. If the subject

overestimates, that is, produces an interval longer in objective units than the one asked for, it indicates that his subjective temporal units are longer than objective ones.

3) Reproduction--the experimentor operatively produces an interval and the subject attempts to reproduce it. In this instance the terms over- and underestimation are meaningless. The task required of the subject is comparable to verbal estimation and production in sequence. The subject must first make an estimate of the interval presented by the experimentor and then produce an interval corresponding to that estimate. If there are errors, it is impossible to determine if they were made in the initial estimation, in the production, or as is most probable, at both stages.

4) Comparison--the experimentor produces two intervals and the subject must judge their relative durations. As with the method of reproduction, the terms overestimation and underestimation are ambiguous. If one interval is judged to be longer than the other interval when they are in fact objectively equal, it is difficult to decide whether the one was overestimated or the other underestimated.

It is common in the literature for results obtained by one method to be compared to results obtained with other methods. This practice is criticized because of the lack of knowledge about the equivalence of the methods (Grant, 1967; McKellar, 1968). Bindra and Waksberg (1956) attempted to engender terminological equivalence between methods but a number of studies (Carlson and Fineberg, 1968; Clausen, 1950; Hornstein and Rotter, 1969) have found that for the methods of verbal estimation, production, and reproduction, there is very little equivalence between the duration estimates.

For the three methods where an interval is produced by the experimentor, verbal estimation, reproduction, and comparison, the interval can be described as being either empty or filled. If an interval is empty, it is a period of silence with its limits marked by two clicks, short tones, or flashes of light. A typical filled interval is delimited by the onset and offset of a continuous sound but intervals may be filled with words, music, flashing lights, etc. (Loehlin, 1959). Meumann (1896) reported that filled intervals were perceived as longer than empty ones. Clausen (1950), however, reported that there was no difference between the two types of interval.

Studies employing the method of comparison invariably report a phenomenon termed the time-order-error or simply the time-error. An experiment by Kohler (1923) resulted in the following generalizations about time-error: 1) if the interstimulus interval (ISI) between two intervals to be compared is less than 3 seconds, the second interval is judged shorter and the time-error is positive. 2) if the ISI is approximately 3 seconds there is no time-error. 3) as the ISI is increased from 3 to 12 seconds the time-error becomes increasingly negative and the second interval is judged longer. Kohler found that with repetition, the positive error decreased. He suggested that the negative time-error resulted from the trace of the first interval fading with time but was unable to provide a satisfactory explanation of positive time-error. Needham (1934) reported that over successive days of experimentation, the positive time-error first decreased as it had in Kohler's study but then began to increase. In one study, Postman (1946) found results exactly comparable to Kohler's but in a later study (Postman, 1947) found a positive time-error regardless of the ISI. Stott (1935) used a constant ISI of 1.5 seconds and compared intervals of lengths ranging from 0.2 to 36.0 seconds. The second interval could be a maximum of 20% shorter or longer than the first interval. He concluded that the direction of the time-error depended upon the lengths of the intervals compared; if less than 1.67 seconds they were characterized by positive time-error and if they were both greater than 1.67 seconds, by negative time-error. After reviewing the time-error literature, Plutchik and Schwartz (1968) reported that the time-error can be ascribed to such factors as the time between the two intervals, interpolated stimuli, method of stimulus presentation, and individual differences. They concluded that the data on time-errors is inconsistent and the theories to explain it are vague.

The general opinion of time-error appears to be that the succession of stimuli introduces a distortion into the relevant judgements; a distortion that could be removed with the correct methodology (Bjorkman and Holmkvist, 1960). Frankenhaeuser (1959), however, has suggested that succession is inherent in the experience of time and rather than thinking of time-error as an error, it should be investigated as one of the important phenomena of time perception.

<u>Temporal Location and Click Studies</u>

There is a considerable body of evidence (reviewed by Fraisse, 1963) demonstrating the ability of individuals to order memories into the temporal sequence in which the events they represent actually occurred, but there has been little, if any, direct investigation of the accuracy with which an individual is able to locate an event in terms of its relative temporal proximity to adjacent events in a sequence. Given three events, A, B, and C such that A and C are separated by some interval of time and B follows A and precedes C, how accurately can B be located with respect to A and C? Guyau (1902) observed that "Hearing only locates stimuli very vaguely in space, but it locates them with admirable precision in time" but he did not elaborate upon what he meant by precision. Precise temporal location of a stimulus requires a quantitative judgement of the relative durations of the intervals separating the stimulus from the events on either side of it. Reportedly, very fine judgements of relative duration are a prerequisite of linguistic meaning in many languages (Peterson and Lehiste, 1960) so it is probable that individuals are able to make them.

It is apparent that a situation requiring comparative judgements of time intervals is, in many ways, similar to the method of comparison. In the method of comparison, however, there are two intervals, AB and CD, which usually are equal or differ by only a small amount and the subject is required only to make a qualitative judgement to the effect that CD is either longer or shorter than AB. If BC is thought of as an event to be located with respect to A and D, then such a binary judgement gives very little information about the accuracy of location. Any possible conclusions about temporal location derivable from the method of comparison are confounded by the fact that variation of the duration and filling of interval BC is a common experimental manipulation.

There is however, an area of research directly involved with the subjective location of stimuli within intervals. The experiments are called click studies and ostensibly they are investigating the psychological reality of grammar.

The dependent variable in click studies is the subjective location of a short click sound superimposed upon an auditory message, usually a sentence. Migration of the click from its objective position is explained on the basis of chunking of input (Ladefoged and Broadbent, 1960), or more often as resulting from the constituent structure of the sentence (Bever and Lackner, 1969; Fodor and Bever, 1965; Garrett, Bever, and Fodor, 1965). Fodor and Bever (1965) used sentences ranging in length from 8 to 22 words and each sentence had a single click placed in the major syntactic break or in one of four positions on either side of it. 80% of the responses were errors and 66% of the errors were toward the central click position. In general, clicks placed before the major syntactic break were perceived as occurring later in the sentence and clicks placed after the syntactic break were perceived as earlier. As a subsidiary result, they reported that during early trials 55.5% of the errors were to the left of the actual click position but during later trials only 47% of the errors were to the left. Ladefoged and Broadbent (1960) reported a persistent left bias in all click positions but their series was only 8 to 10 trials long and it is not clear whether they required their subjects to wait until a sentence was completed before locating the click.

In a major investigation of the click migration phenomenon, Reber and Anderson (1970) used agrammatical and anomolous word strings in addition to sentences. All word strings and sentences were a uniform 6 words in length and were read with either normal or monotone intonation. In accord with Fodor and Bever (1965) they found that clicks tended to migrate toward the central click position. This migration, however, was not symmetrical as would be predicted by a constituent structure hypothesis, clicks before the central position moved further to the right than clicks after the central position moved to the left. Furthermore, they found semantics to be irrelevant and syntax to have only a minor effect on the accuracy of click location. The factors that largely determined magnitude and direction of response error were click position and intonation. Clicks placed early in the word string were located with less accuracy than clicks placed later and monotone intonation resulted in greater overall accuracy of click location and much less shift in directional bias with later click positions than did normal intonation. The intonation effect is confounded, however, by the fact that the time required to read sentences with normal intonation was only half that required to read in a monotone. They also reported a significant trials effect in which responses to early trials showed an overall left bias and responses to later trials an overall right bias.

In a follow-up experiment, Reber and Anderson (1970) removed all linguistic factors and used six 370 millisecond bursts of white noise as the primary message. Again they found a decrease in errors with later click positions and an asymmetrical migration of the clicks toward the central position with early clicks moving more than later ones. In contrast to all the studies using linguistic messages, the nonlinguistic message produced no initial response bias to the left but showed a right bias from the beginning that did not change significantly with later trials. The similar patterns of response error resulting from messages as diverse as grammatically correct sentences and white noise prompted Reber and Anderson to conclude that accuracy of click location depended primarily upon such nonlinguistic factors as memory, attention, and response biases.

The Reber and Anderson (1970) nonlinguistic study was important, not only because it demonstrated that errors in click location did not depend upon semantic or syntactic factors, but also because it showed that click location did not depend upon the message being composed of words. It seems obvious that click studies were based upon the tacit assumption that subjects would locate the click by remembering the word with which it was associated. As long as the message was composed of a series of unique elements, no process other than an association between the click and an element was required to locate the click within the message. In the Reber and Anderson study, however, the elements comprising the message were identical and an association between the click and an element did not specify any unique location within the message. It is possible, of course, to propose that Ss gave a unique name to each element as the message progressed but the results also suggest the alternate possibility that the structure of the message had little or no bearing on the subjective location of the click. It may be the case that Ss located the click by making quantitative judgements of the relative durations separating the click from the onset and the offset of the message and not by associating it with an unique element.

If the subjects in click studies are locating the click by means of duration judgements, then click studies are investigating an aspect of time perception that has apparently been more or less ignored; temporal location. It was mentioned earlier that the classical technique which has the most relevance to temporal location is the method of comparison. As a paradigm for the investigation of temporal location, the click study approach has a number of advantages over the method of comparison. In the first place, the stimulus or event to be located is simple and standardized. Secondly, stimuli are placed throughout the interval instead of being restricted to the immediate vicinity of the central position. The third advantage is a concomitant of the comparison of durations that may be of very different lengths; the magnitude as well as the direction of the error is taken into consideration.

The conceptualization of click studies as temporal location studies makes response biases equivalent to time-errors. It was reasoned that an explanation of time-error might be facilitated by the quantification possible with the click study approach.

The experiments reported below were an investigation of the subjective location of clicks in unstructured intervals of time. Experiment I was undertaken, first, to determine if the patterns of error obtained in unstructured intervals were comparable to those occurring in click studies in general and the Reber and Anderson non-linguistic study in particular. And second, to explore time-error through analysis of response biases under a number of different conditions. The second experiment was based upon interpretation of the first and was concerned with an explanation of response biases.

Experiment I

The present experiment was based upon the Reber and Anderson (1970) nonlinguistic study although numerous modifications were instituted in line with the experimental aims stated above. Reber and Anderson used a message composed of alternate periods of white noise and silence. In this experiment the interval corresponding to the message was either uninterrupted white noise or uninterrupted silence. In time perception terms, both filled and empty intervals were used. In contrast to other click studies, Reber and Anderson controlled the duration of their message but used only a single duration of 2.77 seconds. They reported a significant difference between the errors in intervals of approximately 3.0 seconds and those in intervals of 5.5 seconds in their first linguistic experiment but attributed it to an intonation factor. There is, however, evidence from the method of comparison indicating that direction of the time-error is dependent upon the duration of the intervals used (Stott, 1935). The present experiment, then, used intervals of three different durations.

Most click studies have reported an overall shift in the duration of the response bias as trials progressed (Fodor and Bever, 1965; Reber and Anderson linguistic experiments, 1970). In addition, several studies using the method of comparison have reported a shift in the direction of the time-error over trials (Kohler, 1923; Needham, 1934; Postman, 1946). Reber and Anderson found no such shift after 180 trials per subject with a nonlinguistic message. On the expectation that the effect may require a greater number of trials, in the present experiment each subject made 900 responses over three days of testing.

Following Reber and Anderson, a "subliminal" control group was run where subjects responded to nonexistent clicks. The control was to investigate the response distribution which resulted from guessing.

Beyond the prediction that the patterns of error obtained would be similar to those reported by Reber and Anderson, the present experiment was mainly exploratory in nature.

Method

Subjects. 15 female graduate and undergraduate students at the University of British Columbia were recruited from those on campus during the intersessional period. They were paid $5.00 for taking part in three daily 1¼-hour sessions. Ages ranged from 18 to 25.

Ten subjects were run in the experimental group and five in the subliminal control group.

Materials. Filled intervals were a period of continuous white noise (0-10,000 Hz, uniform distribution). The limits of the interval were the onset and offset of the white noise. Empty intervals were an uninterrupted period of silence delimited by two short 1000 Hz tones. Intervals were either 2, 4, or 6 seconds in length. The clicks were .05 millisecond bursts of square wave noise, approximately equal in intensity to the tones. A click was placed at one of five possible positions in each interval. The click positions for each duration are illustrated in Table 1.

Insert Table 1 about here

The white noise and the tones were recorded on one channel of a stereophonic tape recorder and the click on the second channel.

By independently altering filling, duration, and click position, 30 basic intervals were produced. Ten replications of each interval were randomized into five blocks of 60 trials each with the constraint that each interval occurred twice in each block. The 300 intervals were placed on a tape approximately 6 seconds apart. During a 1.0 minute break between trial blocks, subjects received recorded instructions to turn to the next page in their response booklets.

The tape was played on an Uher Royal deluxe stereophonic tape player. Subliminal subjects heard the same tape as experimental subjects but with the click channel disconnected.

Forty-five test booklets of five pages each were constructed. Each page had 60 numbered horizontal lines 55 millimeters in length. Each response line had its end points marked with vertical lines but between the end points there were no marks or interruptions (Appendix A).

Procedure. Subjects were tested individually in a quiet, windowless room which was not soundproofed. Instructions were read to all subjects informing them that their task was to locate a click within an interval of time. The two types of interval filling were described to them and the following points were emphasized: 1) that a click did occur in every interval; 2) the intervals were of various lengths but in every case the whole length of the line represented the duration of the interval; 3) they must wait until an interval was completed before marking the click; 4) clicks could occur at any point in the interval. The method of responding was described and demonstrated.

Subliminal subjects were told about experiments where "eat more popcorn" was flashed on the screen during a movie at such speed that nobody was aware of seeing it but everybody ate more popcorn. They were assured that although they did not consciously hear the click, there was a greater than chance probability of them responding correctly. None of them questioned the basic reality of subliminal perception.

Before the actual experiment began, all subjects heard ten randomly chosen intervals to acquaint them with the stimuli and with the amount of time between trials.

At the conclusion of the third day's testing, all subjects were given a questionnaire (Appendix B) probing their perception of the stimuli used and any response strategies they might have been aware of using.

Results

The subjects in the experimental group made a total of 9,000 responses, 30 per subject, to each of the 30 basic intervals. Separate analyses were performed on two response measures. The first measure was concerned with the accuracy of click location and was the direction and magnitude in millimeters of the average deviation of the 10 responses made by each subject to each of the 30 basic intervals in each session. The fact that the same 55 millimeter response lines were used for intervals of 2, 4, and 6 seconds duration meant that the errors were not directly comparable in terms of time. That is, if a subject misperceived the location of a click by some constant amount of time, regardless of the duration of the interval, the resulting response error would be three times as large for a 2 second interval as for a 6 second interval. Errors, therefore, were transformed by dividing the deviations in millimeters by 2.750 for 2 second intervals; 1.375 for 4 seconds; and 0.917 for 6 seconds. This transformation, in effect, made the 2 second response line 20 units long, the 4 second response line 40 units long, and the 6 second response line 60 units long. Errors were thus measured in units that were thought of as 10ths of a second. This procedure had the drawback of weighting random error the greatest for 6 second intervals and the least for 2 second intervals but it was felt that comparability of errors across durations made it worthwhile.

Although the first measure contained information about response biases, it was reasoned that, since errors could be of much greater magnitude on one side of the click than on the other in all but the central click position, a few large errors on the long side of the click could obscure an actual tendency to respond on the short side. The second response measure, then, was concerned solely with directional bias. It was the proportion of total errors that were to the right (Pe,r) over the 10 replications of each interval per subject per session.

The experiment was a p x q x r x s factorial design with repeated measures on all factors. A separate analysis of variance was performed on each response measure.

Magnitude of error. Table 2 presents the analysis of variance summary table for the magnitude of error in 10ths of a second.

Insert Table 2 about here

For the purposes of comparison to click study results, the only relevant variable was click position. Click position had a highly significant effect on magnitude and direction of error ($F(4,36) = 12.73$, $p < .001$). Figure 1a shows average perceived click position in relation to actual click position, and Figure 1b shows the magnitude of the errors in 10ths of a second. It is apparent that magnitude of error decreased toward the center of the interval and that the direction of the error shifted from right to left in later click positions. This pattern of click migration is clearly similar to that reported by Reber and Anderson (1970).

Insert Figure 1 about here

There were no main effects for the factors of interval filling ($F(1,9) = 0.36$, $p > .20$) or interval duration ($F(2,18) = 0.66$, $p > .20$). There was, however, a significant interaction between the two ($F(2,18) = 6.31$, $p < .01$). Figure 2 shows that click location was markedly more accurate in 6 second filled intervals than in any other combination of duration and filling.

Insert Figure 2 about here

There was a significant interaction between interval filling and click position ($F(4,36) = 15.22$, $p < .001$), and a three-way interaction between filling, duration, and click position ($F(8,72) = 4.63$, $p < .001$). Table 3 lists the direction and magnitude in tenths of a second of the mean errors to the 30 basic intervals.

Insert Table 3 about here

From Table 3 it is clear that although there was an asymmetrical central tendency in filled intervals, it was much more pronounced in empty intervals. Furthermore, inspection of Table 3 demonstrates that duration had little effect on either the magnitude or the asymmetry of the central tendency in empty intervals but it had a marked effect on on filled intervals. There is a pronounced difference between 2 and 4 second filled intervals on the one hand and 6 second filled intervals on the other. Responses to 6 second filled intervals had an almost symmetrical central tendency, clicks at positions 4 and 5 were perceived as far to the left as clicks at positions 2 and 1 were perceived to the right. The 2 and 4 second intervals showed a persistent right bias that changed very little from click 1 to click 3 and did not become a left bias until click 5.

A significant sessions main effect ($F(2,18) = 4.96$, $p < .025$), showed a marked increase in the magnitude of the overall right bias from day 1 to day 2 with no further increase shown for day 3. A significant two-way interaction between sessions and click position ($F(8,72) = 3.73$, $p < .005$), showed a marked increase in the magnitude of right bias at click positions 1, 2, and 3 from session 1 to session 2 but no change in the magnitude of the left bias at click positions 4 and 5. From the significant three-way interaction between sessions, click positions and durations ($F(16,144) = 3.06$, $p < .001$), it appears that although an increase in the magnitude of the right bias occurred for all three durations from session 1 to session 2, the most dramatic change was by the 6 second intervals. During the first session, the 6 second intervals showed a small right bias at click position 1, no bias at click 2, and a left bias at all other click positions. By the second session they had developed a right bias at click positions 1, 2, and 3 comparable in magnitude to that shown by the other two durations.

The sessions factor also entered into an interaction with interval filling ($F(2,18) = 4.63$, $p < .025$), and a four-way interaction with filling, duration, and click position ($F(16,144) = 2.07$, $p < .025$).

Inspection of the data suggested that a major factor in the significance of the two interactions was a large and inexplicable shift in the magnitude and direction of the error at click position 1 in 4 second filled intervals during session 3. At all click positions other than the first, error magnitude and direction were comparable to the biases shown by the other five combinations of duration and filling.

Proportion of total errors to the right (Pe,r). Again the ANOVA was a four factor complete repeated measures design. The data were subjected to an Arcsin $\sqrt{x}$ transformation to assure homogeneity of variance. Table 4 presents the analysis of variance summary table for the Pe,r data.

Insert Table 4 about here

Click position had a significant effect on the Pe,r ($F(4,36) = 8.34$, $p < .001$). Figure 3 illustrates the decrease in Pe,r with later click positions and the shift to a left bias for click position 5. Thus only for the very last click position were a majority of the clicks perceived as occurring earlier than they objectively did. Comparison of Figure 3 to Figure 1b shows that the asymmetry of the biases is much more marked when the magnitude of the errors is ignored.

Insert Figure 3 about here

Reber and Anderson (1970) also used Pe,r as a response measure and, although the actual values are not directly comparable due to scoring differences, the pattern of a right bias shifting to a left bias to the right of the central position, is identical.

As with the first response measure, there was no main effect for interval filling ($F(1,9) = .785$, p = n.s.). There was, however, a significant duration main effect ($F(2,18) = 5.94$, $p < .025$). The and 4 second intervals with Pe,r's of .627 and .616 respectively, differed markedly from 6 second intervals with a Pe,r of .541. The significant duration by filling interaction ($F(2,18) = 24.32$, $p < .001$), showed that the decrease in Pe,r of the 6 second intervals was solely attributable to the filled 6 second intervals. The empty 6 second intervals had a Pe,r comparable in magnitude to those of the 2 and 4 second empty intervals.

In contrast to the first response measure, Pe,r showed a significant duration by click position interaction ($F(8,72) = 3.96$, $p < .001$). Figure 4 shows the decrease in Pe,r across click positions for the different durations. Clearly the central tendency decreased as the duration increased.

Insert Figure 4 about here

The filling by click position interaction ($F(4,36) = 15.88$, $p < .001$), is similar in appearance to the same interaction with the magnitude and direction response (Table 3). Table 5 shows the Pe,r for the 30 basic intervals. It is apparent from Table 5 that there was

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Insert Table 5 about here

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a much stronger central tendency in empty intervals. Filled intervals, although showing less right bias in the first two click positions, maintained the right bias at a relatively high level for later click positions. At click position 4, fully .572 of the errors to filled intervals were to the right of the actual click position. The three-way filling by duration by click position interaction ($F(8,72) = 10.32$, $p < .001$), shows that it is the 2 and 4 second filled intervals which maintain a strong right bias at later click positions, 6 second filled intervals showed a steady decrease in Pe,r from click position 1 to click position 5. From Table 5 it is clear that the biases around the central click position were highly asymmetrical for all combinations of filling and duration except 6 second filled intervals. Not only were the variations in Pe,r across click positions relatively small for 6 second filled intervals, they were also symmetrical with respect to the centre of the interval.

The proportion of errors to the right increased across sessions ($F(2,18) = 5.50$, $p < .025$) from .538 in session 1 to .606 in session 2 and .641 in session 3. The increase in Pe,r continued during the third session but it was not significantly different from the Pe,r of session 2 ($p > .10$, Duncan's Multiple Range Test).

There were two significant interactions with the sessions effect; sessions by filling ($F(2,18) = 4.27$, $p < .05$), and sessions by click position ($F(8,72) = 2.34$, $p < .05$). The sessions by filling interaction indicates that the increase in Pe,r across sessions was greater for empty than for filled intervals. Possibly interval filling dampens whatever process is responsible for the sessions effect just as it apparently dampened the central tendency. The sessions by click positions interaction shows the sessions effect to be nonexistent at click position 5. The magnitude response measure also indicated that the sessions effect was negligible at later click positions but there seems no ready explanation as to why this should be so.

Subliminal control condition. For the subliminal data the 55 millimeter response lines were divided into eleven 5 millimeter sections and responses were scored on the basis of the section in which they occurred. Figure 5 shows the total number of responses in each section.

Insert Figure 5 about here

As expected, responses showed a strong central tendency. The mean of the distribution is 6.28 reflecting a slight tendency to respond more often in the second half of the interval. An analysis of variance showed no effect for the duration, filling, or session factors. These results indicate that, for all of the conditions of the present experiment, a subject uncertain of the location of the click will tend to respond toward the centre of the intervals.

Responses to post questionnaires

The first two questions(Appendix B) pertained to the perceived distribution of the clicks. The clicks were perceived to be evenly distributed by five of the experimental subjects and to be concentrated toward the middle of the intervals by the other five subjects. Three of the subliminal subjects perceived the nonexistent clicks to be evenly distributed and two perceived them as concentrated in the second half of the intervals.

Question 3 explored the perceived duration of the click. It was considered by four experimental subjects to last an appreciable length of time, one subject suggesting a duration of .5 seconds. The subliminal subjects all perceived the click as instantaneous.

Question 4 explored response strategies. The subliminal subjects responded with "intuition," "guesswork," and "don't know." Eight of the experimental subjects consciously compared the time before the click to the time after the click, the other two compared clicks across intervals and one of these stated that she had a tendency to "balance" the distribution. Five of the subjects who compared durations before and after the click relied upon counting; three made the interesting observation that they counted until the click occurred but often either neglected or forgot to continue counting after the click.

Discussion

The pattern of response errors is clearly similar to those reported by Bever and Fodor (1965) for linguistic messages and to those reported by Reber and Anderson (1970) for both linguistic and nonlinguistic messages. The overall Pe,r of .595 in the present study is considerably larger than the .511 for linguistic messages and .527 for nonlinguistic messages reported by Reber and Anderson. It seems reasonable that structure could have a restraining effect upon the magnitude of the error but just how it could affect the direction of the error is unclear. It is thought to be much more probable that the greater Pe,r in the present experiment resulted from the greater number of trials. The Pe,r of .538 during the first session is close to the values reported in the other studies. In this connection it is worth mentioning the significant increase in right bias across sessions. A similar effect was reported by Fodor and Bever (1965) and by Reber and Anderson (1970) for linguistic messages but not for nonlinguistic ones.

Reber and Anderson, however, did report a nonsignificant increase in Pe,r across the 180 trials of their experiment. The discrepancy, then, is again attributed to the greater number of trials in the present experiment.

The subjects' introspective reports of their strategies supported the idea of click location as a task requiring judgements of relative duration. As an investigation of temporal location, then, the experiment showed the effects of interval filling, interval duration, click position, and number of testing sessions, on the time-error. Overall, there was a positive time-error which became stronger across sessions. Figure 6 shows the development of positive time-error in the six combinations of duration and filling across sessions. Only in 6 second filled intervals during session I was there a negative time-error.

Insert Figure 6 about here

In general, empty intervals of all durations produced positive time-errors at the first three click positions and negative time-errors at the last two. The 2 and 4 second filled intervals produced positive time-errors for the first four click positions and a negative time-error only at click position 5. In contrast, the 6 second filled interval produced an overall positive time-error only at the first two click positions and a negative time-error at the last three.

The general impression received from the data is of two response biases, a central tendency and a right bias, the effect of which confound each other. The occurrence of a central tendency is common in duration judgements (Fraisse, 1963; Gilliland and Humphreys, 1943), and in comparative duration judgements (Turchioe, 1948). Fraisse explained it as resulting from subjects developing a subjective average value and then minimizing deviations from it. It follows that the less sure a subject is of the actual location of a click, the closer the response will be to the average value. In the present context, it is reasoned that the apparent lessening of the central tendency in filled intervals results from the white noise keeping the subject's attention on the interval and thus lessening uncertainty about the location of the click.

The right bias is somewhat more difficult to explain. It is not certain how much explanatory power may be attributed to the slight right bias observed in the subliminal response distribution, but it is thought to be very little. The two subjects who, for an unknown reason, thought the majority of the nonexistent clicks were in the second half of the intervals, were probably responsible for this bias.

Reber and Anderson (1970) attempted to explain the right bias that appeared in their studies with a Neo-Titchenerian (Neo-T) prior entry hypothesis. The Neo-T hypothesis is based upon three assumptions: 1) the perceptual process is a single channel operation with only one channel attended to at any one time (Broadbent, 1958); 2) Ss will initially attend to the channel with the most novel auditory input (Cantor, 1967); 3) inputs in the attended channel are perceived as occurring earlier in time than contiguous inputs in the non-attended channel (Titchener, 1909: Law of Prior Entry).

With this hypothesis, the right bias is the time required to switch channels from the message to the click. A problem arises, however, when the message is a period of silence. If the silence is presumed to occupy a perceptual channel in a fashion similar to an auditory message, it is necessary to postulate channel switching at the onset and offset of the message as well as just when the click occurs.

For example, consider an empty interval and a channel switching time of .5 seconds. Before the starting tone, silence is occupying the subject's perceptual channel, when the tone occurs a switch in channels is required and the tone is perceived as occurring .5 seconds later than it actually did. There is a subsequent switch back to silence but it does not alter the time relationships. When the click occurs, there is another switch required and the click is perceived .5 seconds late. There is another switch back to silence and then a final switch when the offset tone occurs so it too is perceived .5 seconds late. The end result is that there is no change in the relative position of the click with respect to the endpoints of the interval.

A rather different explanation of directional biases is based upon Frankenhaeuser's (1959) hypothesis that the subjective duration of an interval is a function of the amount of mental content associated with that interval. A directional bias, then, is the result of a disproportionate amount of mental content associated with the duration between the click and one of the limits of the interval. Both the instructions and the nature of the task emphasize the importance of the click. Therefore, before the click the subject is attending, anticipating, listening intently, and often counting. When the click occurs, the level of this cognitive activity decreases (note the subjects who often stopped counting when the click occurred) and as a result there is less mental content after the click. The significant sessions effect suggests that this is a strategy that the subject either develops with experience or comes to prefer from a number of alternatives.

Responses to 6 second filled intervals consistently differed from responses to the other five combinations of duration and filling. In contrast to responses to the other five types of interval, which showed a strong overall right bias, responses to the 6 second filled intervals were symmetrically attracted toward the centre of the interval. In effect, this means that the 6 second filled intervals were anomalous because the right bias was much weaker for them than for the other types of interval. On the basis of the Frankenhaeuser hypothesis, the weakening of the right bias implies that for the 6 sec. filled intervals there was an atypical amount of mental content associated with the post-click duration. A possible explanation of the increased post-click mental content in 6 second filled intervals is that they are perceived as longer in total duration than 6 second empty intervals. Schumann (1893) reported a feeling of intensified expectation when the terminus of an interval was delayed. Such expectation would tend to inflate the post-click duration and thus lower the overall right bias. It should be noted that the hypothesized difference in perceived duration is contrary to the conclusion of Wallace and Rabin (1960) that there is no difference between duration estimates to filled and unfilled intervals.

Experiment II was designed primarily to test a prediction from the Frankenhaeuser hypothesis. Its general validity as an explanation of duration experience was not in question but previous results did not indicate whether it would be applicable to the short durations of the present experiment. Subsidiary investigations were of possible alternative response strategies and of possible differences in perceived duration between filled and empty intervals.

Experiment II

The primary purpose of this experiment was to test the hypothesis that the right bias reported in Experiment I resulted from subjects devoting a relatively greater amount of cognitive activity to the period preceding the click. It was reasoned that if a high level of cognitive activity produces a greater subjective duration than a lower level, then the perceived duration of an interval should be a function of the proportion of the interval that was devoted to the higher level of cognitive activity. The basic prediction then, was that if a right bias ensued, duration estimates for intervals with clicks at position 5 would be significantly greater than the estimates for intervals with clicks at position 1. Clearly there should be a more or less linear increase across all click positions but because the durations used were short and the variance of the duration estimates was expected to be large, a significant difference was predicted only between the extreme click positions.

There were two subsidiary predictions based on an analysis of possible response strategies available to a subject. Of the strategies to be discussed below, it is assumed that a single subject may use them all at different times.

The strategies are:

1) The S attends at a uniform high level throughout an interval, resulting in approximately accurate click location.

2) The S anticipates and attends before the click then waits relatively passively for the interval to end. This strategy results in an overall error to the right of the actual click position.

3) The S waits relatively passively for the click then actively

attends for the end of the interval. This strategy results in an overall error to the left of the actual click position.

Use of strategies 2 and 3 will result in errors because, with both, the relative duration of some part of an interval will be underestimated due to lack of attention and the consequent drop in mental content. The first subsidiary prediction, then, is that intervals in which the responses show a marked left or right bias will be judged to be of less duration than intervals of objectively equal length in which the clicks are located more or less accurately.

The second subsidiary prediction has three parts:

1) If a subject uses strategy 1, responses will be correct and there will be no difference in perceived duration as a function of click positions.

2) If strategy 2 is used, responses will show a right bias and the magnitude of duration estimates will increase across the five click positions.

3) If strategy 3 is used, responses will show a left bias and the magnitude of duration estimates will decrease across the five click positions.

There is, of course, a fourth possible strategy in which a subject pays little attention throughout an interval. Inattention should lead to uncertainty about the actual location of the click and thus produce a strong central tendency for location responses. How inattention will affect duration estimates, however, is uncertain. There are two possibilities. The first is that duration estimates will be low, commensurate with the low amount of mental content hypothesized to accompany low attention. The second is that the subject will respond with an average duration value, that is, show a central tendency for duration estimates. In either case, there is no reason to expect strategy 4 to be used with one combination of filling, duration, and click position more often than with any other, so its overall effect should be random.

The possibility was considered that asking for a duration estimate of the total interval would sensitize subjects toward paying attention throughout the entire interval. Thus an increase in the use of strategy I was expected and concomitant with such an increase, it was expected that the overall right bias would be less than in Experiment I.

The third subsidiary prediction was that 6 second filled intervals would be judged significantly longer than 6 second empty intervals.

Method

Subjects. 10 male and 10 female graduates and undergraduates at the University of British Columbia were recruited from those available during the intersessional period. Each S was paid $2.00 for taking part in the $1\frac{1}{2}$ hour experiment. Ages ranged from 18 to 29 years.

Materials. The intervals used in this experiment were the same ones as were used in Experiment I. For this experiment, however, only the first four blocks of trials were placed on the tape for a total of 240 intervals; eight replications each of the basic 30. The time between intervals was increased to 16 seconds to accommodate the added task of duration estimation. The tape was played on a Sony 630 stereophonic tape player.

Response booklets were 12 pages long with 20 pairs of response lines on a page. The first response line, for the click location, was 60 millimeters long with only the end points marked. The response line for the duration estimate was beside the first and was 20 millimeters long (Appendix C).

Procedure. Subjects were tested in groups of one to four. They were seated at desks in a quiet room. The first part of the instructions describing the click location task were essentially the same as in Experiment I.

The instructions continued:

> After you have located the click by marking the horizontal line I want you to give me a very subjective estimate of how long the total interval seemed to be. Make your estimate to the nearest tenth of a second and write it on the line provided. Examples might be 3.4 or 1.2.

In order to moderate the expected lessening of the right bias because of sensitization to the whole interval, the primary importance of the click location task was emphasized. Subjects were asked to first locate and mark the position of the click and then to "think back" to make their duration estimate. It was further emphasized that the accuracy of their duration estimate was unimportant to their task and that they were not to worry about it.

As in Experiment I, subjects listened to 10 intervals before actually beginning the experiment.

At the conclusion of the 240 trials, subjects were given a post-questionnaire (Appendix D) investigating response strategies and the relative amount of attention they devoted to the two tasks.

Results

Each of the 20 subjects made eight location responses and eight duration estimates to each of the 30 basic intervals.

Click location was scored on the same two measures of magnitude of error in 10ths of a second and proportion of total errors to the right

(Pe,r).

Magnitude of error. The ANOVA was a three-factor complete repeated measures design. Table 6 presents the analysis of variance summary table for the magnitude of error in 10ths of a second.

Insert Table 6 about here

There was a significant main effect for interval filling ($F(1,19) = 8.38$, $p < .01$). The mean errors were .113 seconds to the right (that is, late in time) for empty intervals and .200 seconds to the right for filled intervals. The duration main effect was nonsignificant ($F(2,38) = 1.88$, $p > .10$), but duration entered into a significant interaction with interval filling ($F(2,38) = 7.37$, $p < .01$). The errors for the 2, 4, and 6 second empty intervals and for the 6 second filled intervals were all very similar in magnitude with values of .091, .133, .113, and .140 seconds respectively. The 2 and 4 second filled intervals, however, had much larger errors of .215 and .246 seconds respectively. Comparison of the shape of this interaction with the same interaction in Experiment I (Figure 2) shows that while the shapes of the curves have not changed, their position with respect to each other has. In Experiment I the 2 and 4 second filled intervals and the three empty intervals all had errors of similar magnitude, and it was the 6 second filled interval that stood out with an exceptionally small overall error. In the present experiment the errors are larger for all six types of interval but the increase is considerably greater for the filled intervals so that now the 2 and 4 second filled intervals have exceptionally large errors.

The click position main effect was significant ($F(4,76) = 13.74$, $p < .001$), showing a linear decrease in the magnitude of the error from click position 1 to click position 5 but in contrast to Experiment 1, there was no real shift in the direction of the error. At click position 5 the mean error was .002 seconds to the left, at all other click positions it was strongly to the right. In Experiment 1, the shift to a left bias occurred between click positions 3 and 4.

Click position entered in significant interactions with interval filling ($F(4,76) = 3.05$, $p < .05$), and with interval duration ($F(8,152) = 4.96$, $p < .001$). Figure 7 shows the effect on the magnitude and direction of error of a) the click position by interval filling interaction and b) the click position by interval duration interaction.

Insert Figure 7 about here

It is clear that the linear decrease in the magnitude of the right error across click positions is less for filled intervals than for empty ones (Figure 7a). This result is very similar to that observed in Experiment 1. From Figure 7b it is apparent that the slope of the decrease in right error across click positions is less as the interval duration increases. For the 6 second intervals there is little or no decrease in the magnitude of the right error across the last three click positions.

There was a significant three-way interaction between filling, duration, and click position ($F(8,152) = 284$, $p < .01$). Table 7 lists the direction and magnitude in 10ths of a second of the mean errors to the 30 basic intervals.

Insert Table 7 about here

Inspection of Table 7 demonstrates that the difference between the 2 and 4 second filled intervals and the 2 and 4 second empty intervals was restricted to the last three click positions. This result is very similar to what was observed in Experiment 1, the 2 and 4 second filled intervals maintained the right bias. However, in the present experiment, the two 6 second intervals also maintained a right bias; it was only the 2 and 4 second empty intervals that showed an actual central tendency.

Pe,r. The ANOVA was a three-factor complete repeated measures design. Table 8 presents the analysis of variance summary table for the Pe,r data.

Insert Table 8 about here

The main effects and interactions of the filling, duration, and click position factors each have essentially the same form and level of significance with this response measure as with the magnitude measure. An exception is the significant duration effect ($F(2,38) = 6.26$, $p < .01$), showing the 2 and 4 second intervals with Pe,r's of .682 and .689 respectively, differing from the 6 second intervals with a Pe,r of .622. Although the Pe,r's are higher, the difference between the 2 and 4 second intervals on the one hand and the 6 second intervals on the other, is identical to the difference observed in Experiment 1.

The major difference between the two response measures is that Pe,r not decrease across click positions to the same extent as the magnitude of the errors. Table 9 lists the Pe,r for the 30 basic intervals.

Insert Table 9 about here

The entries in Table 9 are the means for the significant filling by duration by click position interaction ($F(8,152) = 2.80$, $p < .01$). From Table 9 it is clear that the 2 second empty interval was the only one to show a left bias at any click position. The 4 second filled interval showed very little drop in Pe,r across click positions and both types of 6 second intervals showed a slight increase in right bias at later click positions. The comparison of these results with the result from the same response measure in Experiment I (Table 5), indicates that the central tendency was much weaker in the present experiment, its effects were strong and only with the 2 and 4 second empty intervals.

Duration. The means of the eight duration estimates made by each subject to each of the 30 basic intervals were the data for a three factor, complete repeated measures analysis of variance. Table 10 presents the analysis of variance summary table for the duration estimate.

Insert Table 10 about here

The major prediction of the present experiment was that there would be a significant increase in the magnitude of the duration estimates between click position I and click position 5. The click position main effect, however, was nonsignificant ($F(4,76) = 2.09$, $p < .10$). Figure 8 illustrates the effect of click position on the magnitude of the duration estimate.

Insert Figure 8 about here

It is clear from Figure 8 that although the duration estimates were larger at click position 5, there was no linear increase from click position 1 to click position 5. The only significant difference was between click position 5 and click position 3 ($p < .05$; Duncan's Multiple Range Test).

There were significant main effects for filling ($F(1,19) = 4.44$, $p < .05$), and duration ($F(2,38) = 86.22$, $p < .001$). The significant filling by duration interaction ($F(2,38) = 5.99$, $p < .01$), shows that both the 4 and 6 second filled intervals were judged to be longer than the corresponding empty intervals by the approximately equal amounts of .19 and .23 seconds respectively. This result supports the prediction that the 6 second filled intervals would be judged longer than 6 second empty intervals. However, the atypically weak right bias in 6 second filled intervals that the difference in perceived duration was to explain, did not occur in the present experiment. In contrast to the results of Experiment 1, the 6 second intervals of both types were almost identical on both response measures in the present experiment.

The nonsignificant effect of click position on the magnitude of duration estimates, in spite of the strong overall right bias shown by the click location responses, suggested that any effect of error direction on duration estimates was a very weak one. Therefore, in order to give the predicted effect of error direction on duration estimates the greatest possible chance to appear, click location responses were not counted as errors unless they deviated markedly from the correct click position. The click location responses were categorized as ERROR LEFT, CORRECT, or ERROR RIGHT. For 2 second intervals the CORRECT category extended 6 millimeters to either side of the actual click position so that any response that did not deviate from the correct click position by more than 6 millimeters was classed as a correct response. The CORRECT category was 3 millimeters each side of the actual click position for 4 second intervals and 2 millimeters each side for 6 second intervals.

In order to make the duration estimates comparable across durations and between subjects, they were converted to z-scores. For each subject, z-scores were calculated for the 80 duration estimates of each of the three durations. Thus, for each subject, there were three sets of duration estimate z-scores. Each duration z-score was assigned to the same category as its associated click location response.

The duration z-score-click location response pairs were still differentiated on the basis of the actual position of the click to which they were made. The result was a 3 (categories) by 5 (click positions) matrix for each subject. The median duration z-score was taken as the representative value for each cell of the matrix. The values for each subject were plotted across the five click positions separately for each category. Figure 9 shows the duration estimate z-scores averaged across subjects at each click position separately for each of three categories of click location response: ERROR LEFT, CORRECT, and ERROR RIGHT.

Insert Figure 9 about here

Figure 9 shows that when errors were to the left there was a tendency for duration estimates to decrease from click position I to click position 4. When the errors were to the right, however, the duration estimates did not show any increase across click positions. Furthermore, there was no apparent difference between duration estimates when click location responses were correct and when they were errors to the right.

The overall means for the three categories were calculated to test the final subsidiary hypothesis that duration estimates would be greatest when the clicks were correctly located. As was expected from the previous result (Figure 9), duration estimates were of the same magnitude for both accurate click location responses and errors to the right.

Post-questionnaire. To question I, investigating click location strategies, thirteen of the twenty subjects stated that they compared the durations before and after the click. Nine subjects used counting strategies, five counted right through and remembered the number where the click fell and four started a new count when the click occurred. One subject rotated her foot and remembered the point in the rotation where the click fell. Other strategies were: holding breath, putting finger down to mark click, two subjects mentioned closing their eyes and visualizing the interval as space.

Question 2 investigated duration response strategies. Seven subjects based their duration estimate on the total count of the interval. It is probable that the counting method entails comparison between intervals. Three subjects stated that they derived their estimate by comparison with previous intervals. The other ten subjects "guessed."

Question 3 investigated the attention devoted to the two tasks.

Thirteen subjects devoted more attention to click location. Five said that they considered the tasks to be of equal importance and one said that he paid more attention to the duration from start to click than from click to finish.

To question 4, seven subjects responded that click location became easier as trials progressed and four found durations easier to judge as trials progressed.

To question 5, ten subjects reported that both click location and duration estimation were easier with white noise; four found both tasks easier with empty intervals; four others reported clicks easier to locate in empty intervals but found duration estimates easier with white noise; two subjects found no difference between fillings for either task.

Discussion

It is clear that the predictions based upon the Frankenhaeuser hypothesis were not supported. The major prediction of a difference between the duration estimates at click positions 5 and 1 was in the right direction and close to significance ($p < .10$). Other aspects of the data, however, suggest that the difference may be safely accepted as a chance occurrence, and not construed as weak support for a differential mental content explanation of response biases. In the first place, duration estimates to clicks at positions 2, 3, and 4 were less than or equal to the estimates at position 1. Although their relative magnitudes with respect to click positions 1 and 5 were not predicted, on the basis of the hypothesis they would be expected to have magnitudes intermediate between those for clicks 1 and 5. Second, the increase in the magnitude of duration estimates across click positions should have been greatest when only those responses with a marked right error were counted. As Figure 9 illustrates, there were no large differences between click positions even for the data most likely to show them.

The third piece of evidence counter to the hypothesis was the overall effect on response biases of asking subjects to make duration estimates. If the right bias of Experiment I resulted from subjects paying greater attention to the period before the click, directing their attention toward the total interval, as was done in Experiment II, should have led to a decrease in the overall right bias. The overall magnitude of the right error was .156 seconds for Experiment II and .075 seconds for Experiment I. Experiment II had an overall Pe,r of .665 compared to a Pe,r of .595 for Experiment I. Clearly, instead of showing the expected decrease in right bias, Experiment II showed a marked increase compared to Experiment I.

Figure 10 shows the average perceived click positions for all 30 basic intervals for Experiment I (above the line) and Experiment II (below the line). It illustrates the stronger right bias of the Experiment II responses.

Insert Figure 10 about here

Figure 10 also demonstrates the discrepancy between the patterns of responses to the longer intervals in the two experiments. The average responses to the 6 second intervals in Experiment II show an apparent constant deviation from the actual click position regardless of where it is in the interval. It is reasoned that the longer time between trials (16 vs. 6 seconds) and the interpolated activity of duration estimation, lessened the comparison of click locations across trials and thus considerably weakened the central tendency. If this reasoning is correct, the right bias in its unconfounded form is an error of constant magnitude between the objective and the subjective positions of the click.

It is possible to explain such a constant error by hypothesizing a delay between the occurrence and the perception of the click. Reber and Anderson's (1970) Neo-Titchenerian hypothesis proposed just such a delay and attributed it to the time required to switch perceptual channels. However, in addition to the reservations about a channel switching hypothesis mentioned earlier, there is reason to suspect that it cannot adequately account for a constant error. In the development of their hypothesis, Reber and Anderson mention that as an interval progresses, the occurrence of the click becomes increasingly more probable. They account for the apparent left bias present at later click positions in their data by suggesting that as the probability of the click increases, subjects switch their attention to the click channel spontaneously and thus when the click occurs, it is perceived earlier than the accompanying primary message. Even if pre-click channel switching is discounted, channel switching should not produce a constant error. Mowrer (1940) observed that, if an event occurs when it is highly probable, reaction time is less than if the event occurs at a time when it is less probable. A channel switching hypothesis, therefore, would predict a decrease in switching time and a consequent decrease in the magnitude of the error for clicks at later positions in an interval. In Experiment II, the decrease across click positions should occur in the longest intervals but be negligible in shorter ones.

An alternate possibility is that, rather than the click being perceived later in time, the portion of the interval following the click is underestimated by a constant amount. The post-click duration would be underestimated if the click was perceived to occupy an appreciable duration which was not counted as part of either the pre- or post-click durations, or was perceived as part of the pre-click duration. In Experiment I, four of the ten subjects reported that the click lasted an appreciable length of time. Furthermore, something analogous to Gastaut's (1949) cortical potential could delay the perceived onset of the post-click duration without a subject necessarily being consciously aware of it.

Unfortunately, a hypothesis involving a click of perceptible duration or an enduring cortical potential would be unable to account for the occurrence of a right bias or positive time-error when two durations to be compared are separated by more than a few tenths of a second. It may be that the time-error when two intervals have a common limit is qualitatively different from the time-error when two intervals are separated by a third interval. As Plutchik and Schwartz (1968) concluded, the time-error is probably not an unitary phenomenon.

In conclusion, it has been shown that individuals locate a click in an interval of time by comparing the duration between the click and the limits of the interval. Accuracy of comparison is apparently affected by two response biases, a central tendency and a right bias. The central tendency is greatest when there is opportunity for comparison between intervals. Whether comparison is facilitated or not, short intervals show a stronger central tendency than longer intervals and empty intervals show a stronger central tendency than filled intervals. An explanation or the right bias based upon differential amounts of mental content before and after the click was not supported by the data. Finally, for 6 second intervals at least, the right bias has the appearance of a constant error.

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Table I

Possible Click Positions for Each of Three Durations

Click Position	2 sec.	4 sec.	6 sec.
1	.33 sec.	.67 sec.	1.00 sec.
2	.67 "	1.33 "	2.00 "
3	1.00 "	2.00 "	3.00 "
4	1.33 "	2.67 "	4.00 "
5	1.67 "	3.33 "	5.00 "

Table 2

Analysis of Variance Summary Table: Magnitude of Error, Experiment I

Source	df	Mean Square	Error Term	F	Prob.
Mean	1	517.3081	P	1.8276	
P	9	283.0564			
Sessions	2	71.9110	SP	4.9640	<.025
SP	18	14.4864			
Filling	1	1.3489	FP	0.3594	>.20
FP	9	3.7529			
Duration	2	21.8515	DP	0.6635	>.20
DP	18	32.9323			
Click	4	896.7576	CP	12.7250	<.001
CP	36	70.4722			
S x F	2	6.6284	SFP	4.6298	<.025
SFP	18	1.4317			
S x D	4	9.8406	SDP	2.2645	<.10
SDP	36	4.3455			
F x D	2	15.3608	FDP	6.3111	<.01
FDP	18	2.4339			
S x C	8	27.0120	SCP	3.7326	<.005
SCP	72	7.2367			
F x C	4	69.6467	FCP	15.2172	<.001
FCP	36	4.5768			
D x C	8	5.0115	DCP	0.6175	>.20
DCP	72	8.1156			
S x F x D	4	1.4944	SFDP	0.6529	>.20
SFDP	36	2.2889			
S x F x C	8	2.5936	SFCP	1.1773	>.20
SFCP	72	2.2023			
S x D x C	16	7.4853	SDCP	3.0557	<.001
SDCP	144	2.4496			
M x D x C	8	10.1859	MDCP	4.6344	<.001
MDCP	72	2.1979			
S x F x D x C	16	4.5649	SMDCP	2.0730	<.025

Table 3

Direction and Magnitude in 10ths of a Second of the Mean

Errors to the 30 Basic Intervals

Experiment I

Filling	Duration	Click Position				
		1	2	3	4	5
Empty	2 sec.	3.994	2.732	0.316	-1.281	-2.315
	4 sec.	4.579	2.965	1.166	-1.479	-2.604
	6 sec.	4.122	2.494	1.090	-1.396	-2.610
Filled	2 sec.	2.675	1.794	1.638	0.194	-1.262
	4 sec.	1.668	2.749	1.462	0.543	-1.515
	6 sec.	2.748	1.592	0.269	-1.527	-2.236

Table 4

Analysis of Variance Summary Table: Pe,r

Experiment I

Source	df	Mean Square	Error Term	F	Prob.
Mean	1	2973.685	P	213.393	
P	9	13.935			
Sessions	2	6.058	SP	5.500	<.025
SP	18	1.101			
Filling	1	0.278	FP	0.785	>.20
FP	9	0.354			
Duration	2	5.680	DP	5.937	<.025
DP	18	0.956			
Click	4	32.051	CP	8.341	<.001
CP	36	3.842			
S x F	2	0.483	SFP	4.274	<.05
SFP	18	0.113			
S x D	4	0.259	SDP	0.940	>.20
SDP	36	0.275			
F x D	2	3.386	FDP	24.322	<.001
FDP	18	0.139			
S x C	8	0.968	SCP	2.337	<.05
SCP	72	0.414			
F x C	4	5.088	FCP	15.877	<.001
FCP	36	0.320			
D x C	8	2.121	DCP	3.958	<.001
DCP	72	0.536			
S x F x D	4	0.204	SFDP	1.195	>.10
SFDP	36	0.170			
S x F x C	8	0.149	SFCP	0.856	>.20
SFCP	72	0.174			
S x D x C	16	0.084	SDCP	0.420	>.20
SDCP	144	0.199			
F x D x C	8	1.517	FDCP	10.320	<.001
FDCP	72	0.147			
S x F x D x C	16	0.138	SFDCP	0.999	>.20
SFDCP	144	0.138			

Table 5

Pe,r for the 30 Basic Intervals

Experiment I

Filling	Duration	Click Position				
		1	2	3	4	5
Empty	2 sec.	.899	.931	.487	.354	.265
	4 sec.	.831	.781	.578	.478	.359
	6 sec.	.729	.643	.544	.480	.496
Filled	2 sec.	.803	.741	.719	.630	.439
	4 sec.	.695	.732	.600	.646	.463
	6 sec.	.606	.591	.464	.440	.415

Table 6

Analysis of Variance Summary Table: Magnitude of Error

Experiment II

Source	df	Mean Square	Error Term	F	Prob.
Mean	1	1469.349	P	26.181	
P	19	56.123			
Filling	1	115.676	FP	8.384	<.01
FP	19	13.797			
Duration	2	20.222	DP	1.882	>.10
DP	38	10.746			
Click	4	165.984	CP	13.736	<.001
CP	76	12.084			
F x D	2	14.022	FDP	7.366	<.01
FDP	38	1.903			
F x C	4	13.624	FCP	3.048	<.05
FCP	76	4.471			
D x C	8	19.230	DCP	4.965	<.001
DCP	152	3.873			
F x D x C	8	6.879	FDCP	2.844	<.01
FDCP	152	2.419			

Table 7

Direction and Magnitude in 10ths of a Second of the Mean

Errors to the 30 Basic Intervals

Experiment II

Filling	Duration	Click Position				
		1	2	3	4	5
Empty	2 sec.	3.53	2.78	0.33	-0.36	-1.72
	4 sec.	3.32	2.40	1.62	0.09	-0.75
	6 sec.	2.28	0.91	1.23	0.64	0.59
Filled	2 sec.	2.86	3.32	2.99	1.55	0.02
	4 sec.	3.30	2.97	3.18	2.14	0.71
	6 sec.	2.42	1.72	0.57	1.28	1.02

Table 8

Analysis of Variance Summary Table: Pe,r

Experiment II

Source	df	Mean Square	Error Term	F	Prob.
Mean	1	265.119	P	497.320	
P	19	0.533			
Filling	1	.604	FP	9.044	<.01
FP	19	.067			
Duration	2	.271	DP	6.255	<.01
DP	38	.043			
Click	4	.798	CP	6.102	<.001
CP	76	.131			
F x D	2	.245	FDP	11.631	<.001
FDP	38	.021			
F x C	4	.160	FCP	3.671	<.01
FCP	76	.044			
D x C	8	.389	DCP	8.625	<.001
DCP	152	.045			
F x D x C	8	.081	FDCP	2.802	<.01
FDCP	152	.029			

Table 9

Pe,r for the 30 Basic Intervals

Experiment II

Filling	Duration	Click Position				
		1	2	3	4	5
Empty	2 sec.	.864	.846	.575	.470	.319
	4 sec.	.805	.720	.692	.572	.508
	6 sec.	.682	.541	.607	.633	.662
Filled	2 sec.	.796	.853	.834	.725	.539
	4 sec.	.797	.702	.738	.728	.637
	6 sec.	.647	.604	.557	.659	.633

Table 10

Analysis of Variance Summary Table: Duration Estimates

Experiment II

Source	df	Mean Square	Error Term	F	Prob.
Mean	1	658176.8	P	121.508	
P	19	5416.711			
Filling	1	289.815	FP	4.441	<.05
FP	19	65.263			
Duration	2	35036.34	DP	86.215	<.001
DP	38	406.383			
Click	4	59.797	CP	2.086	<.10
CP	76	28.665			
F x D	2	86.469	FDP	5.989	<.01
FDP	38	14.438			
F x C	4	20.502	FCP	2.027	>.10
FCP	76	10.115			
D x C	8	13.649	DCP	0.817	>.20
DCP	152	16.707			
F x D x C	8	11.249	FDCP	1.576	>.10
FDCP	152	7.137			

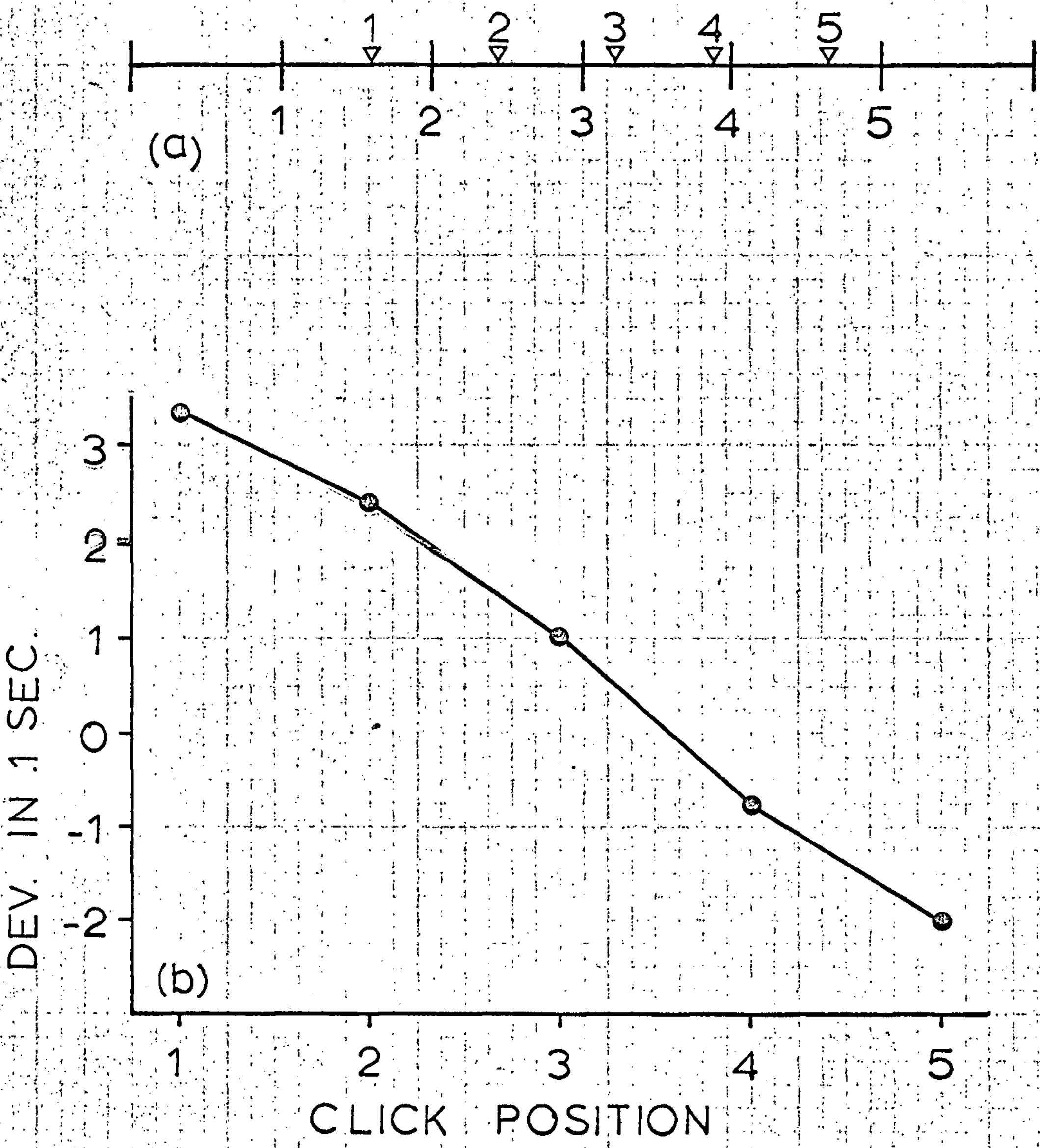

Figure 1. Effect of click position on location of the click. (a) Average perceived click position in relation to actual click position. (b) Magnitude of error in 10ths of a second.

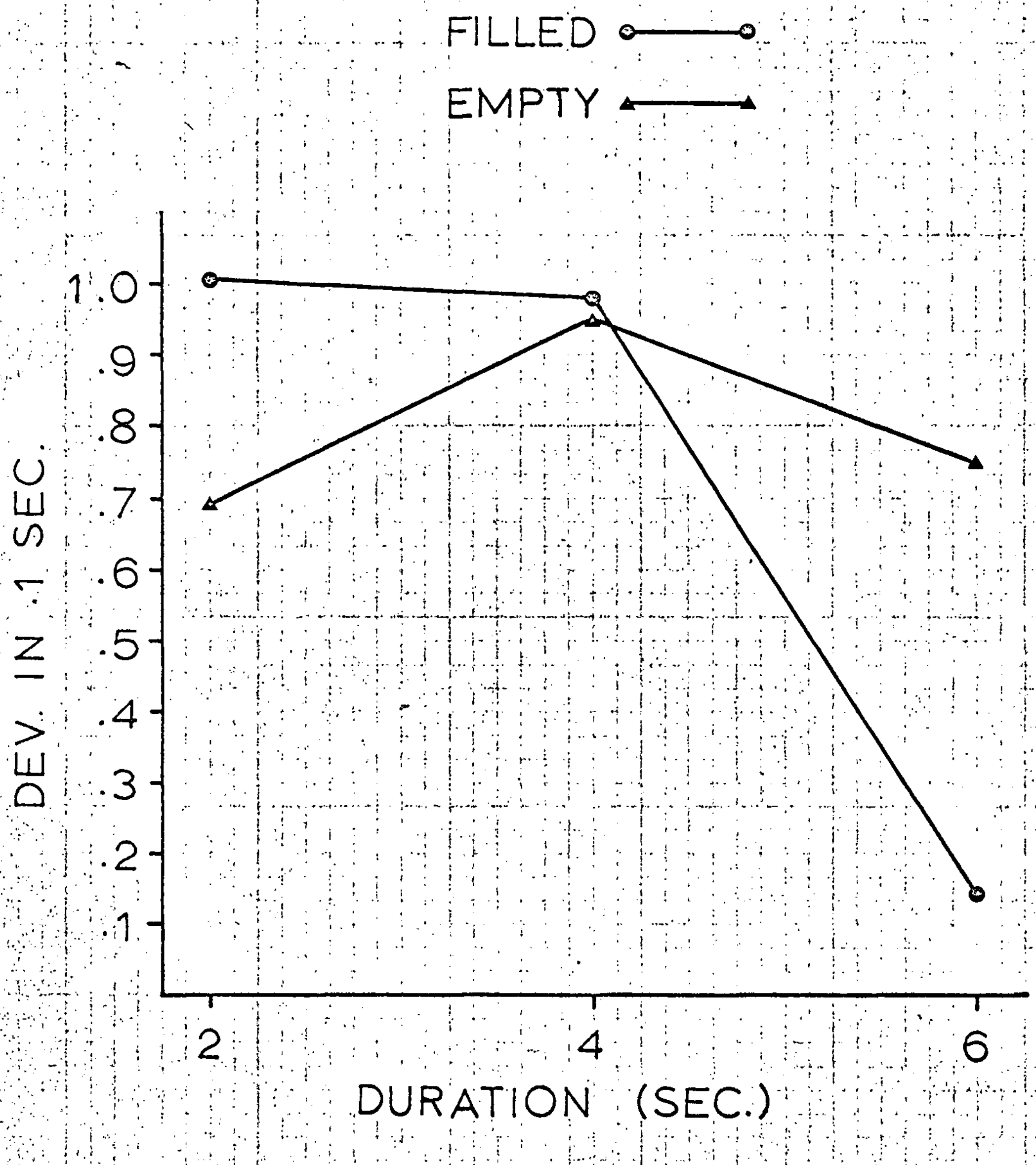

Figure 2. Filling x duration interaction.

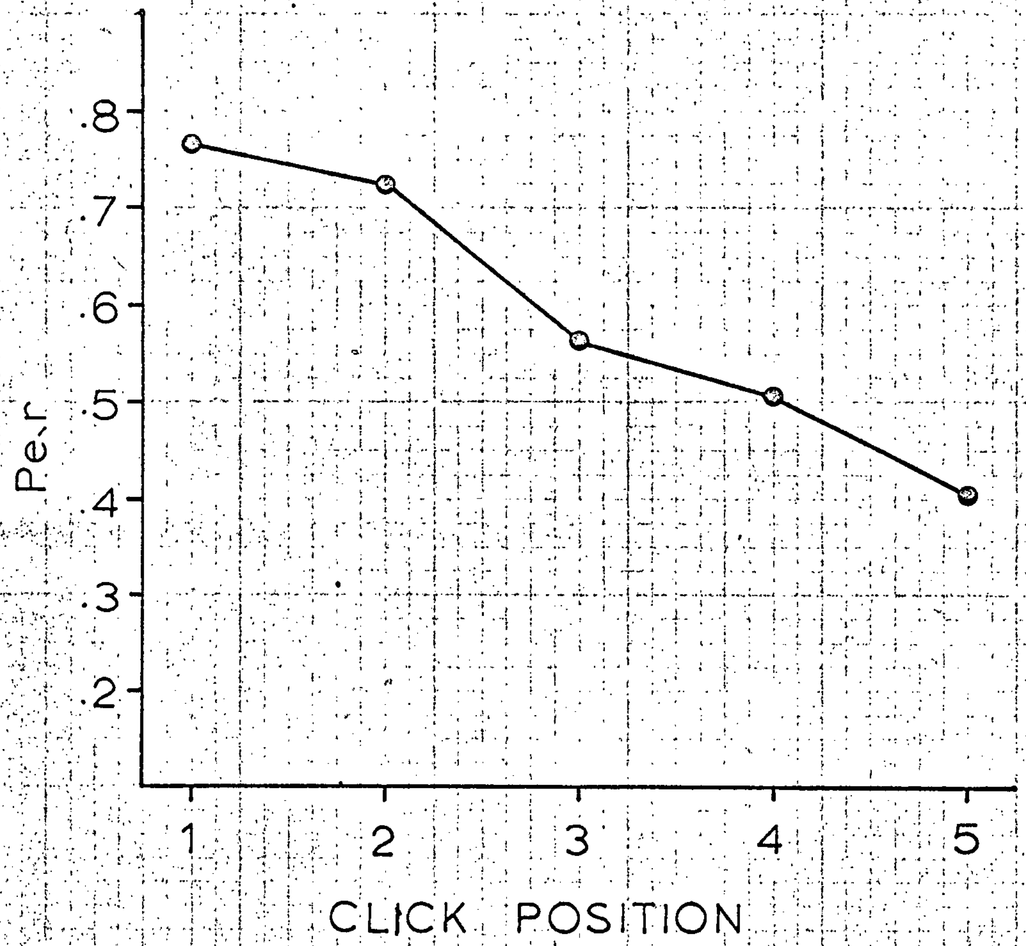

Figure 3. Effect of click position on proportion of errors to the right (Pe,r).

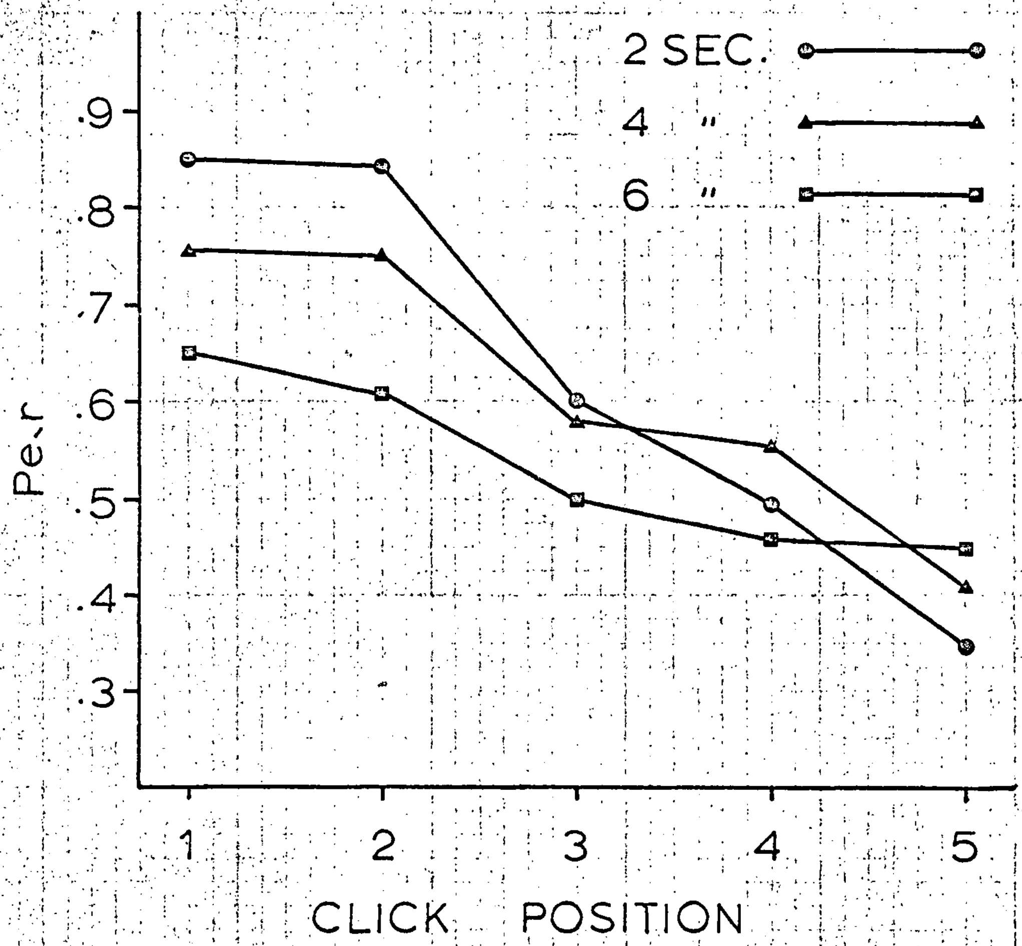

Figure 4. Decrease in Pe,r across click positions for three durations.

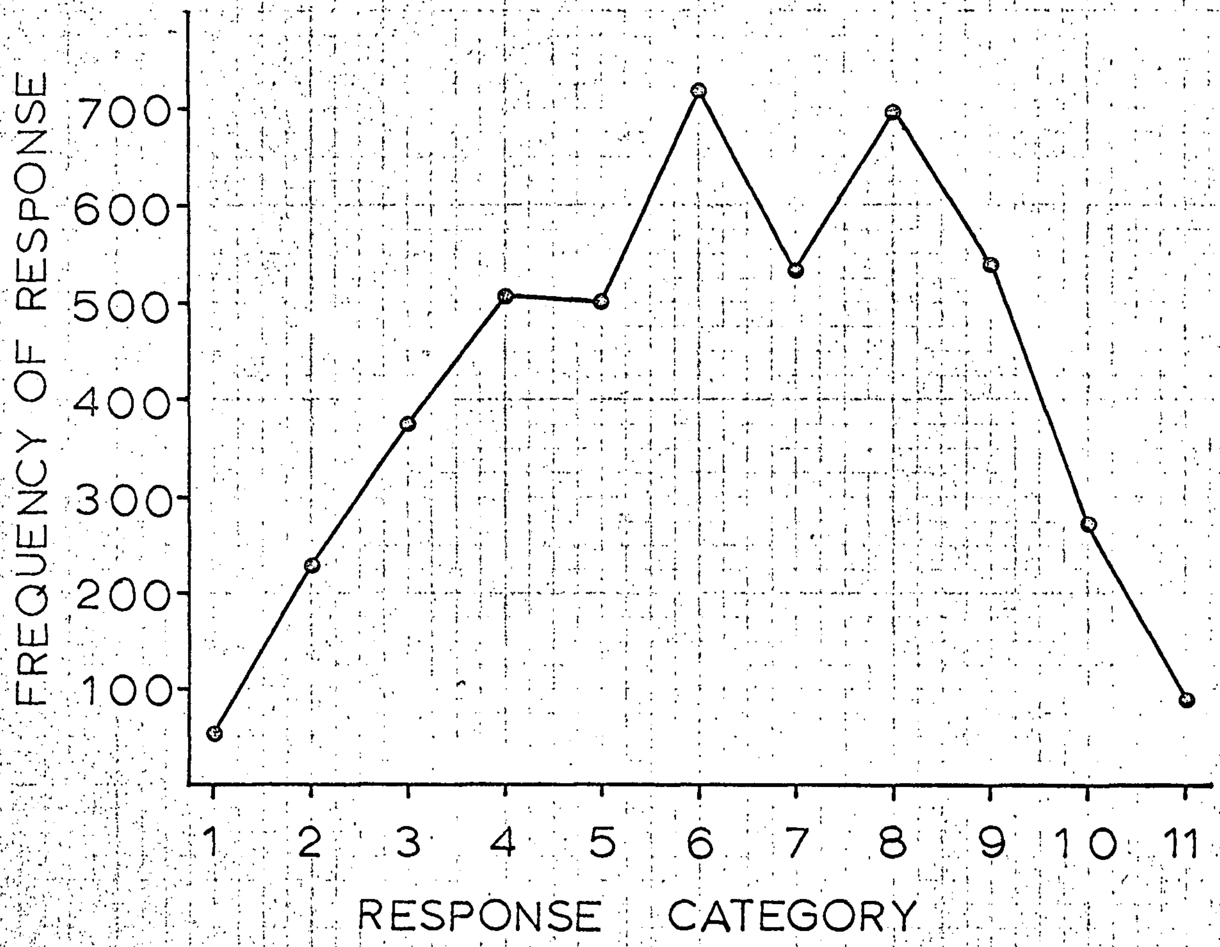

Figure 5. Response tendency of "subliminal" subjects.

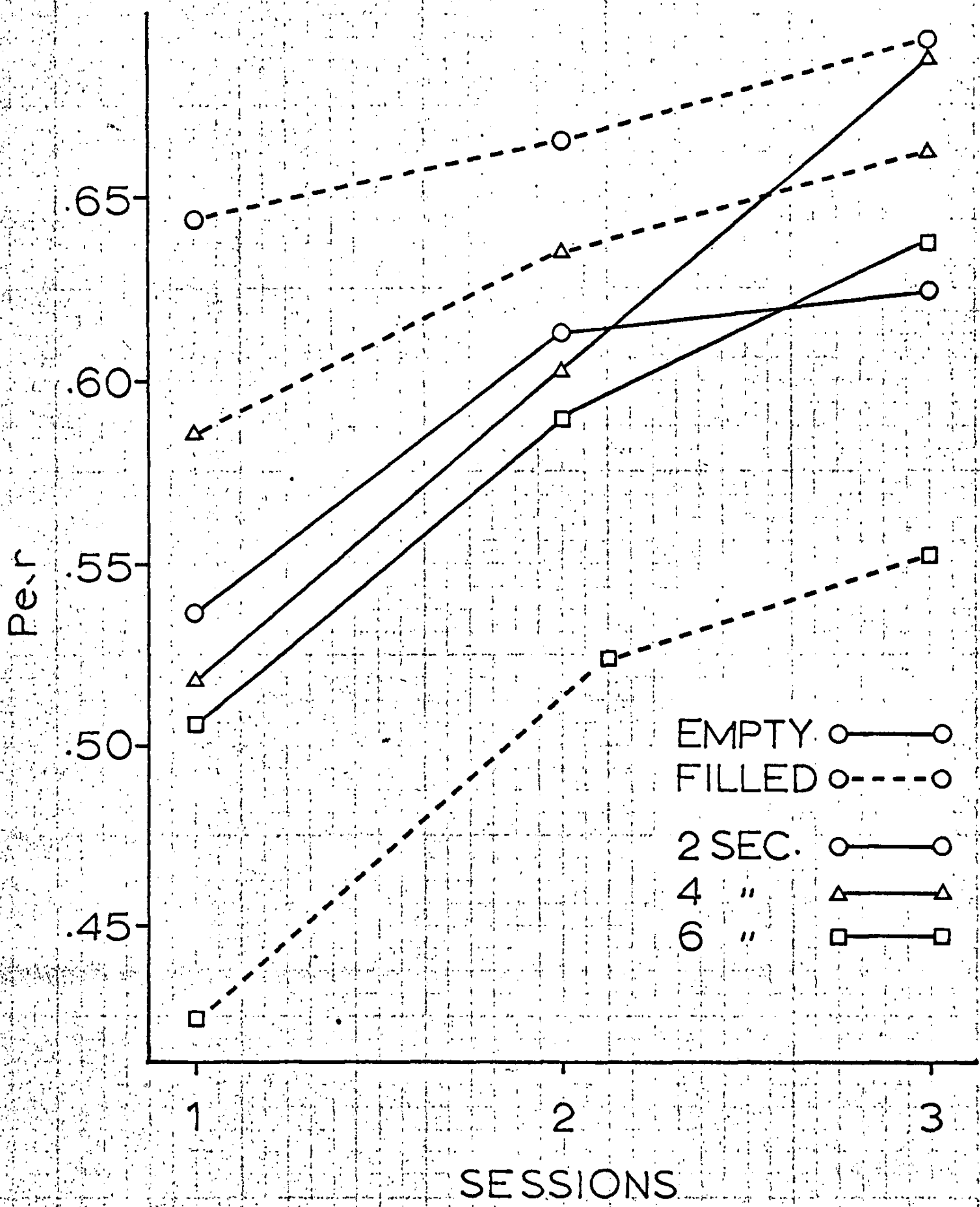

Figure 6. Development of positive time-error across sessions.

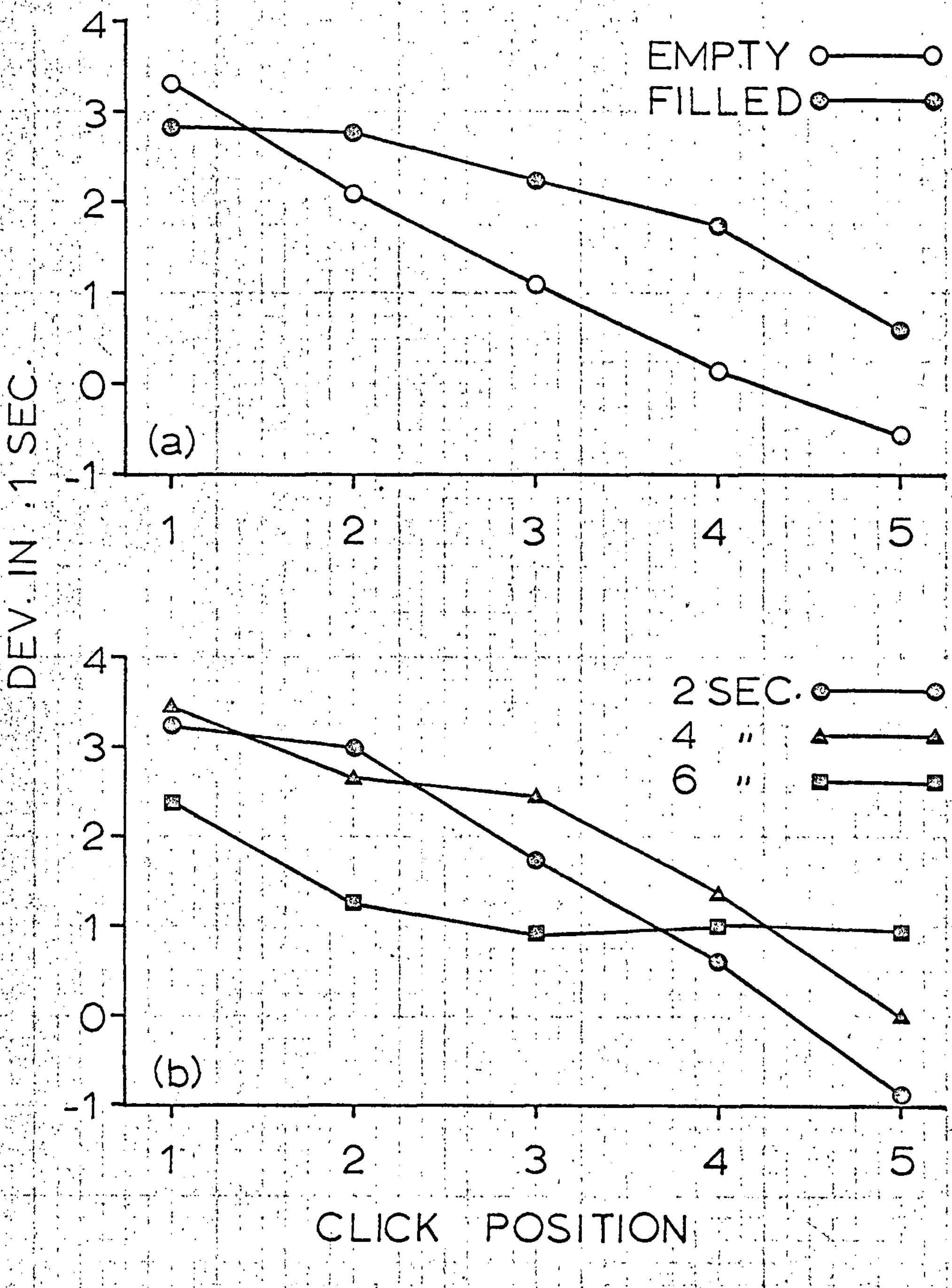

Figure 7. Magnitude of error. (a) Filling by click positions; (b) Duration by click positions.

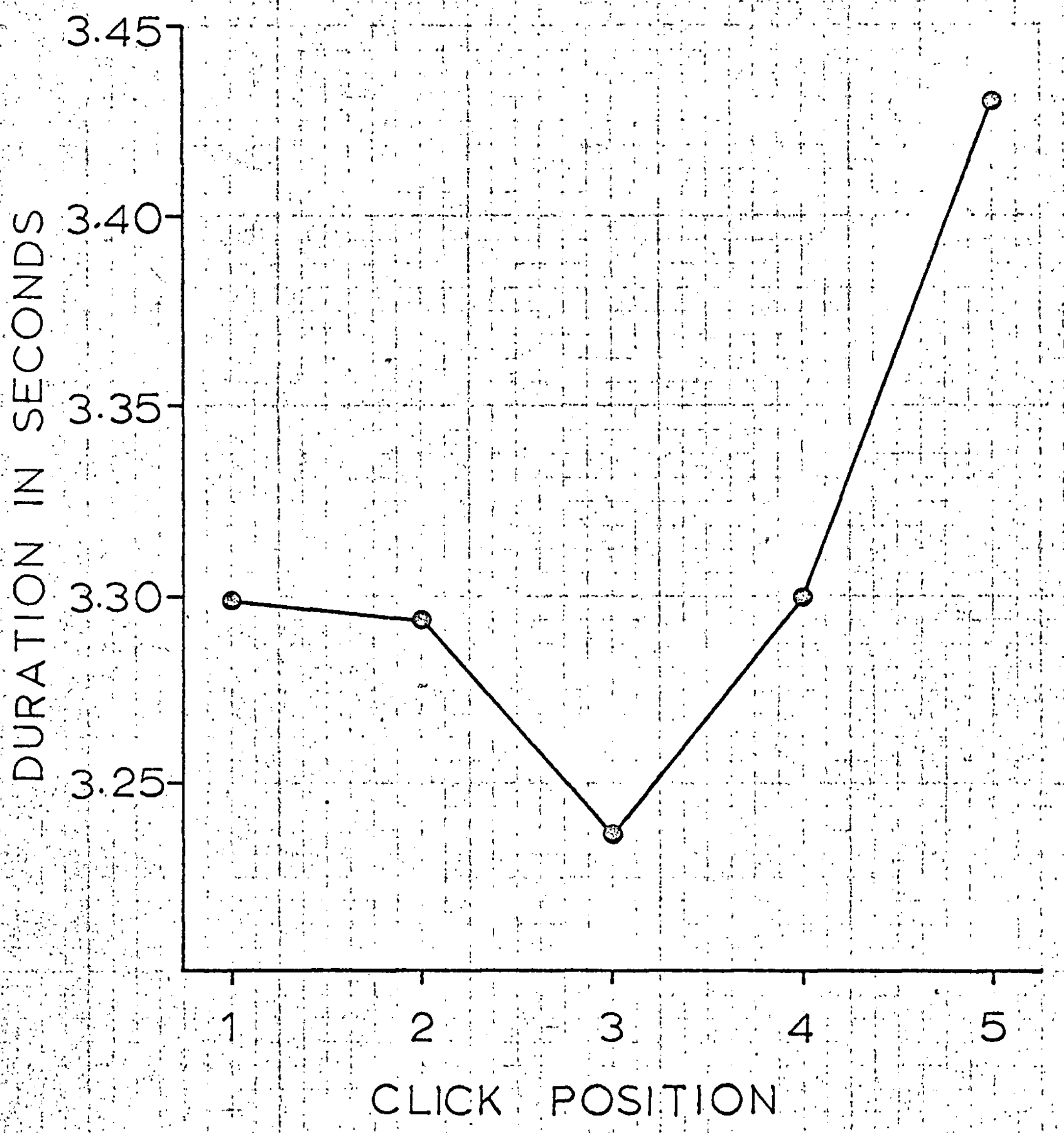

Figure 8. Effect of click position on magnitude of duration estimates.

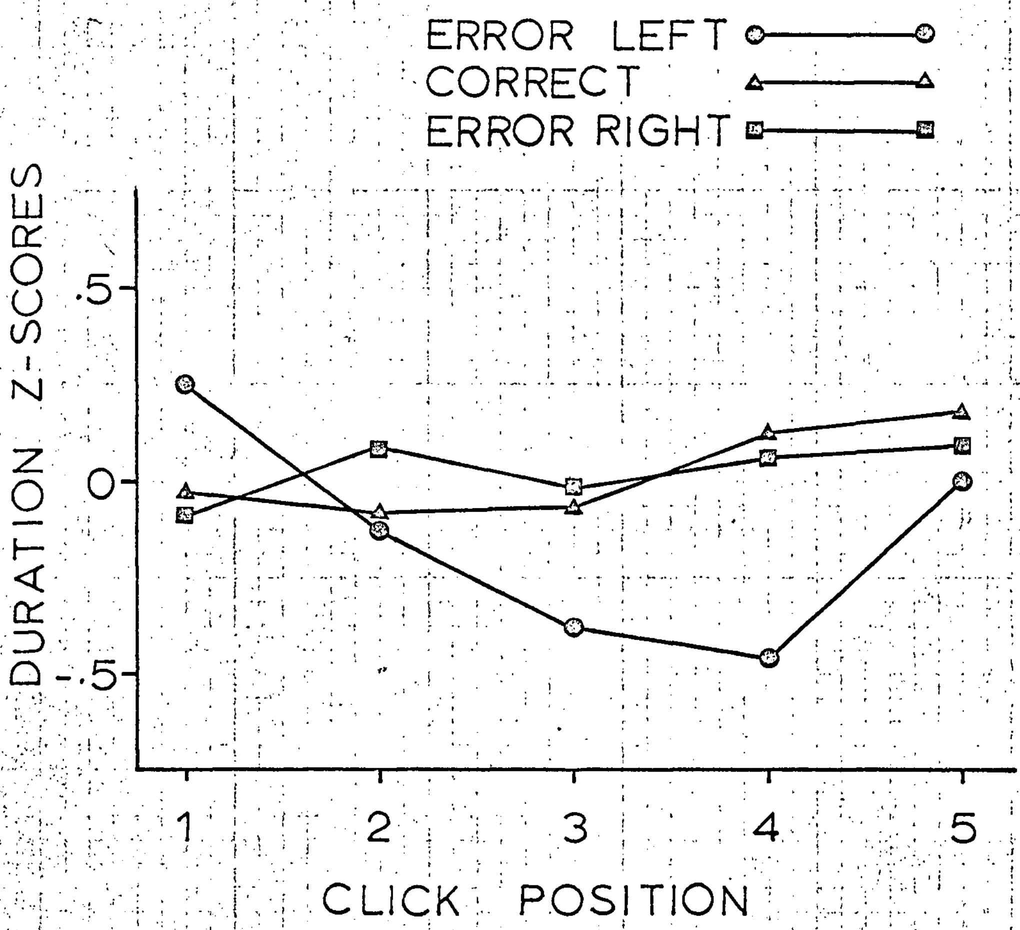

Figure 9. Duration estimate z-scores averaged across subjects at each click position for each of three categories of click location response.

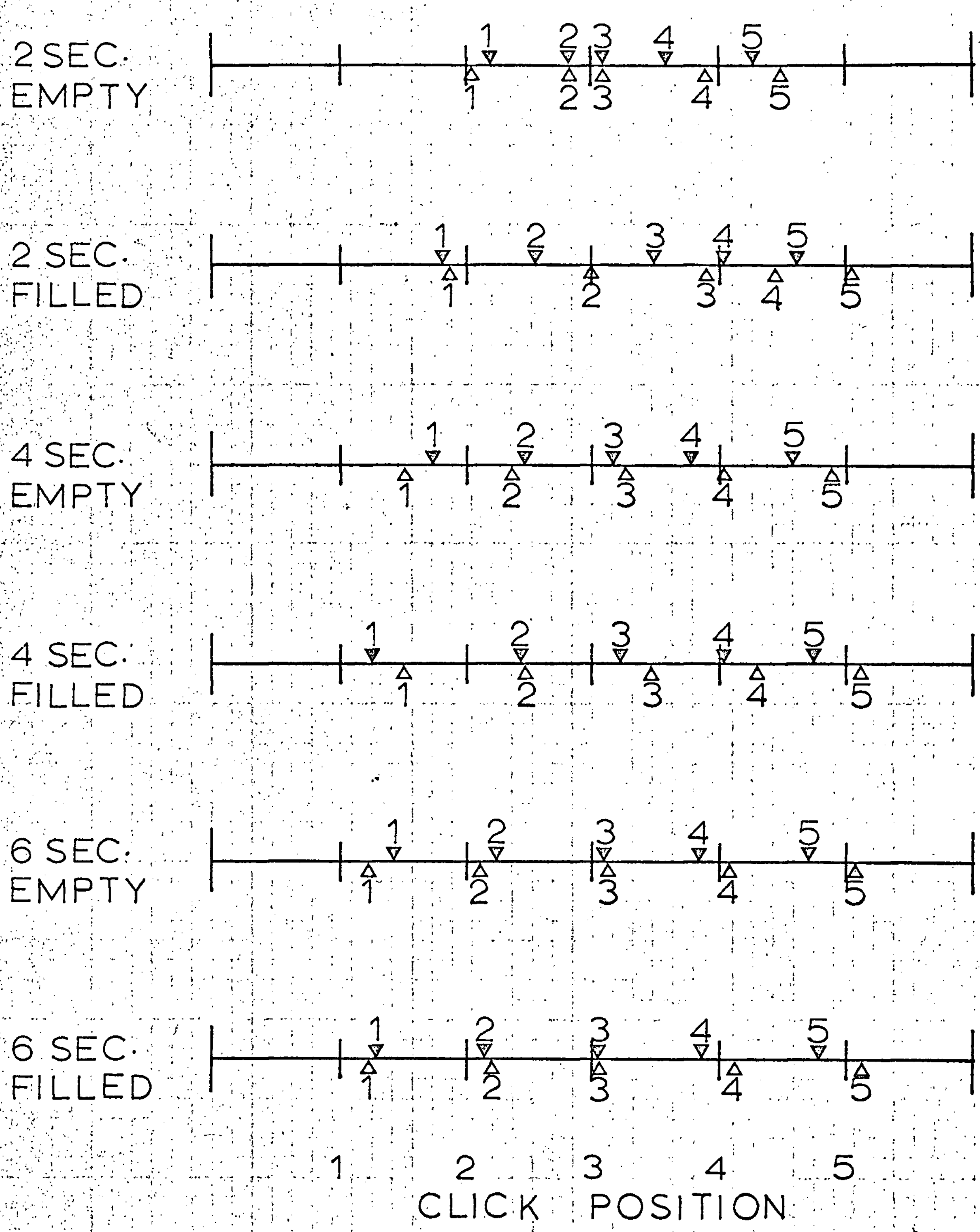

Figure 10. Average perceived click positions for 30 basic intervals. Experiment I, above the response line; Experiment II, below the response line. (Response line 2x actual length.)

Appendix A

Response Sheet (Condensed): Experiment I

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Appendix B

Post Questionnaire: Experiment I

1) On the average, were the clicks evenly distributed throughout the intervals or did they seem to occur more in some positions than in others?

2) If you do not think that the clicks were evenly distributed, please indicate on the following lines: 1) the area or areas that seemed to have a higher than average density of clicks; and 2) the area or areas that had a lower than average density of clicks if it seems to you that such areas also occurred. Please indicate the location and extent of each area by drawing two vertical lines and shading between them.

   1) High Density ____________________

   2) Low Density ____________________

3) Was the click instantaneous or did it seem to last an appreciable length of time? Given that the line below represents an interval of 5 seconds in length, mark off the length of time that seems to you to be equivalent to the duration of the click. A single vertical line will mean that you perceive the clicks to have been instantaneous.

____

4) Please tell me if you have any ideas as to how you determined the positions of the clicks. (Elaborate as much as possible.)

Appendix C

Response Sheet (Condensed): Experiment II

	Location Of The Click Within The Interval.	Total Interval To Nearest .1 Sec.
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Appendix D

Post Questionnaire: Experiment II

1) Describe, in as much detail as possible, how you determined the click location.
2) Describe, in as much detail as possible, how you estimated the duration of the interval.
3) Did you devote more attention to one task than to the other? If so, which?
4) a) Did locating the click become easier as time progressed? If it did, can you explain why?

   b) Did estimating the duration become easier as time progressed? If it did, can you explain why?
5) a) Was it easier to locate the clicks in the white noise or in the silent intervals? Why?

   b) Was it easier to estimate the duration in the white noise or in the silent intervals? Why?