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TEMPORAL NUMEROSITY AND THE PSYCHOLOGICAL MOMENT: AN EVALUATION

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TEMPORAL NUMEROSITY AND THE PSYCHOLOGICAL MOMENT: AN EVALUATION

CHAPTER I

INTRODUCTION

The question of the minimum time separation required for the human organism to perceive discrete events as separate has intrigued students of brain functioning and behavior for many years. A series of studies has recently purported to demonstrate a maximum "perceptual rate" which limits the rate at which new stimuli can be perceived and which is essentially independent of sensory modality and stimulus characteristics. The present study examines several phenomena purported to demonstrate a maximum "perceptual rate" and proposes another explanation which appears more adequate to account for the observed phenomena.

<u>Temporal acuity as an indicator of brain functioning</u>. Investigators interested in the examination of basic perceptual and information processing properties of the human organism have long been impressed by the sensitivity of tests of "temporal acuity" in reflecting changes in functioning of the central nervous system. Broadly defined, "temporal

acuity" refers to the ability to perceive the discreteness of temporally distributed stimulus pulses (Geldard, 1953). Battersby, Wagman, Karp, and Bender state that "it is significant that the more sensitive of the special testing methods have used time as the independent variable" (1960, p. 24). Much of the work which has led investigators to this conclusion has involved patients with cerebral damage, and most of the work in this general area has been in the determination of flicker-fusion thresholds in the visual modality. The general finding of studies of temporal acuity in subjects in which the central nervous system is functioning at less than optimal levels is that these subjects are less discriminating, i.e. they are less able to perceive the discreteness of the stimulus elements, requiring a greater time separation between the pulses or a lower frequency in order for the intermittent nature of the stimulus pattern to be appreciated (Landis, 1954; Parsons & Huse, 1958; Simonson & Brozek, 1952). Deficits in temporal acuity have been demonstrated in other sensory modalities also. Halstead (1959) and Chapman, Symmes, and Halstead (1955) found deficits in the auditory modality in brain-damaged subjects using an auditory "flutter" technique, while Green, Reese, Pegues, and Elliott (1961) found that patients with intracranial disease required a greater time separation between two cutaneous stimuli than did normal subjects or patients with sensory loss due to peripheral nerve or cord lesions. Ax and Colley (1955) investigated temporal acuity in brain-damaged and control subjects in three sensory modalities, vision, audition, and touch. Using a variable frequency stimulus source they presented a flashing light to the visual system, audible clicks to the auditory system, and both electric shocks and mechanical impulses to the tactual receptors of the finger tip. The method-of-limits technique was used with both ascending and descending trials. Significantly lower flicker-fusion thresholds were obtained for the brain-damaged subjects particularly when calculated from the values of the descending trials. On the basis of their sample they were unable to conclude whether temporal acuity is a generalized function of the brain as a whole or specific to each sensory modality. However, the majority of studies of temporal acuity as measured by the subject's response to an intermittent stimulus have concluded that some sort of "resolving power" of the central nervous system is being measured (Granger, 1960; Halstead, 1947; Landis, 1954; Simonson & Brozek, 1952). Although there is agreement that something very basic about the functioning of the nervous system is being tapped by studies of temporal acuity, the manner in which the nervous system responds to or "follows" a repetitive stimulus is the subject of considerable speculation. An important question in this connection is: how rapidly can the brain recover from a previous stimulation and respond to another stimulus? Stated conversely, what is the minimum time separation at which the nervous system can respond to two or more stimuli? A closely related question concerns the point at which the nervous system ceases to respond to each and every stimulus in a train of pulses.

Some characteristics of "temporal acuity." While it is known that values of "temporal acuity" are dependent on the nature of the stimulus and the particular modality under investigation, several investigators in recent years have presented data which they consider to lend strong support to the hypothesis that "there is some temporal process in the central nervous system that limits and orders the perceptual events of the major sense modalities" (White & Cheatham, 1959, p. 444). These studies have apparently demonstrated an upper limit to the rate at which stimuli can be perceived ("perceptual rate"), finding this rate to be about one pulse or stimulus per 100 milliseconds (Cheatham & White, 1952; Cheatham & White, 1954; Lichtenstein, 1961; Lichtenstein, White, Siegfried, & Harter, 1963; White, 1963; White & Cheatham, 1959; White & Lichtenstein, 1963). That is, regardless of the stimulation rate, there appears to be a constant upper limit to the perceptual rate (number of stimuli that can be perceived as discrete per unit time), corresponding to about 10 pulses per second. This value was found to be relatively independent of the frequency of the stimulus, retinal location, and sensory modality, inasmuch as essentially similar results were obtained for the auditory and tactual modalities.

Studies of "perceptual rate" have been relatively limited and have stemmed from the observation that the rate of a flickering or repetitive stimulus is usually significantly underestimated. In 1937 LeGrand found that a light of a certain intensity flickering at a rate of 42 cycles per second (cps.) appears to be flickering around the rate of 7 per second when presented to a point 15 degrees from the fovea. Studies by Bartley (1958) of "residual flicker" (the last vestige of flicker before the light appears fused) illustrated that the subjective flicker rate differed from objective flash rate and that the flicker rate near the CFF is about the same regardless of flash rate and intensity. Although he estimated 20 cps. to be the upper limit of the subjective flicker, he speculated that with better methods of assessing the subjective flicker rate, the maximum rate would probably be found to be closer to 10 cycles per second.

In the studies of perceptual rate by White (1963), the subjects were presented with short trains of successive stimuli, at various rates, and asked to report the number of stimuli perceived ("temporal numerosity") in each stimulus train. When the perceived number of pulses was plotted as a function of presentation time, it was seen that subjects "underestimated" the number of pulses in a specific manner. It was found that there was an upper limit to the number of pulses reported per unit time such that one additional pulse was perceived per approximately 100 milliseconds of presentation time. The results were felt to reflect a perceptual rate of about 10 pulses per second. More specifically, they distinguished two segments of their curves, with the transition point between the two about 300 msec. after initiation of the stimulation. The slope of the first part of the curve yielded a rate of about 12 - 13 pulses per second, while that for the second part of the curve corresponded to 6 - 7 pulses per sec. The perceptual rate (slopes) for the second part of the curve were found to be essentially constant regardless of the sensory modality (audition, vision, touch), or retinal location stimulated and were consistent over a wide range of variation in the intensity and frequency of the stimulus source. The similarity of the results for three modalities, including the change in slope around 300 msec. after the beginning of stimulation led the authors to conclude that two central processes were operating to determine the maximum rate at which perceived units could be added and that there was a consistent point in time which marked the transition between the two processes. The degree of consistency of their results is impressive, especially in their observation that certain number-rate combinations showed no variability at all: "For example, all the subjects always reported having seen 2 flashes whenever 5 flashes at 30/ second were presented to them, and they always reported having seen 3 flashes whenever 10 flashes at 30/ second were presented"

(White, 1962, p. 19).

Since the work of White and his co-workers is central to the present study, the following quotation is presented which adequately summarizes the experimental techniques and findings of the "numerosity" studies of these investigators:

> . . . a train of from 1 to 15 flashes at a 25 fps [flashes per second] rate was presented to the observer. For each number of flashes presented in any given train, the observer was to count the number of flashes he perceived in that train. Ten judgments per observer were made for each number presented, under each of the many conditions of the experiment. Thus, for each condition, number of flashes perceived was plotted as a function of number of flashes presented. Number of flashes perceived could also be plotted as a function of elapsed time to present those flashes. Generally, perceived number of flashes versus elapsed time in the flash train is a function that has two linear legs, which differ in slope. The first leg applies to trains of up to seven flashes, or 240 msec. of presentation time. It was shown that initial slope depends upon light onset transient effects. Thereafter the slope settles down to represent the "steady state" number flashes perceived per unit time, i.e., the <u>count rate</u>. A typical slope in this stable, second leg of the numerosity function is one perceived flash for every 180 msec. of elapsed presentation time beyond 240 msec., or a count rate of about 5.6 perceived fps of real time (Lichtenstein <u>et al</u>., 1963, p. 528).

<u>Intrinsic time systems</u>. As noted previously, White and his colleagues have considered the results of their studies to be evidence for a basic time unit of the central nervous system which limits the rate at which new information can be processed. This idea is not a new one, but has existed in one form or other for many years. A long known observation in research with living organisms is that thresholds for a

given stimulus impinging on a cell or receptor show a characteristic fluctuation over time measured from the initiation of the stimulus. With continuous stimulation neurons are found to have cyclic patterns of activity and refractoriness (Bartley, 1959; Osgood, 1953). A more difficult task, but one which has been facilitated in recent years by advances in instrumentation, is that of demonstrating that more molar systems of an organism are characterized by intrinsic activity-rest cycles, with cyclic variations in sensitivity. White's monograph (1963) contains an extensive review of the concept expressed by a number of writers that there are natural time units which are a function of the organism itself, possibly related to rhythms seen in the electroencephalograph. If there is indeed a maximum rate at which new information can be perceived, the time period of one cycle or unit can be considered to be the basic time unit for the organism. This notion is consistent with recent neurophysiological speculations which suggest that the brain must use some sort of scanning or time sampling process to reduce the amount of data it must handle (Ellingson, 1956; Lindsley, 1952). The idea of discrete time units seems to have been originally expressed by Bergson, who argued that psychological time must consist of successive discrete units like frames of motion pictures (Bergson, 1913). Since then, the intrinsic electrical rhythms of the brain have been cited by many authors to be a basic reflection of this cyclic activity. That there is a relation between some electrical rhythms of the brain, particularly the alpha rhythm, and behavior has been demonstrated, for example by Callaway (1962), who found a relationship between phase of the alpha rhythm and reaction time, and by Surwillo (1963) who demonstrated a relation between alpha frequency and reaction time. Stroud (1948), reviewing the literature for evidence of natural time units or cyclic processes in perception and behavior noted that the length of such units has been reported to range from about 50 to 200 milliseconds, with the most frequently reported value being around 100 msec. He referred to the basic time unit as the "moment," a term which has been retained in most of the current literature in the area.

Perceptual rate and the "psychological moment." White and his co-workers consider their data to support this concept of a "psychological moment" and its corollary: that there exists a maximum perceptual rate and that temporally separate events occurring within the time span of a moment should not be perceived as separate. In apparent confirmation of this latter point, a study by Lichtenstein (1961) is relevant. He presented his subjects with an array of 4 lights, one at each corner of a small (about 2^{o} visual angle) diamond configuration, in such a manner that they flashed sequentially. It was the task of the subject to increase the rate of flash presentation up to the point at which all lights appeared to be flashing simultaneously. He found that to produce the impression of simultaneity, the rate or time period required to present each cycle of four flashes remained relatively constant regardless of the within-cycle temporal pattern used. The mean time per cycle at "simultaneity" was 125 msec., with a mean variance of only 8 msec. "Moment theory would predict, as the data show, that temporal relationships <u>within</u> the 125 msec. cycle time (moment) would not be discernable, whereas a particular flash, on successive repetitions is in successive 'moments' and hence would be appreciated as pulsating" (Lichtenstein, 1961, p. 59). Further apparent confirmation of White's conclusion of a maximum perceptual rate comes from a study by Forsyth and Chapanis (1958) in which they investigated the ability of the human observer to count repeated light flashes as a function of their number, rate of presentation and retinal location stimulated. The study was not oriented toward a theory of perceptual rate or psychological moment, and the primary analysis was in terms of the number of flashes reported as a function of number presented under various experimental conditions. When, however, they re-plotted the data as a function of length of time of presentation, results were obtained which were in agreement with data of White and his co-workers. For example, Forsyth and Chapanis found their curves to be essentially parallel for all conditions, indicating similar "perceptual rates" of 6 cps. for presentation times greater than 300 milliseconds.

Is there indeed a universal number which represents the maximum rate of assimilation of new stimuli and which is independent of sensory modality and stimulus quality, or are there complicating factors which are not adequately accounted for by concepts of psychological moment and "perceptual rate"? That there are complicating factors will be discussed in the following sections.

Temporal acuity: general considerations. In an attempt to evaluate the recent research on temporal discrimination as manifested by perceptual rate and the hypothetical psychological moment, it is necessary to examine certain aspects of temporal acuity or discrimination which are often overlooked. Hirsh and Sherrick (1961) and Lichtenstein (1963) have pointed out that the values obtained for temporal acuity are dependent on the nature of the task imposed on the subject. To assess the meaning and implications of studies of perceptual rate, therefore, it would be important to keep in mind the range of time values to which the human observer can respond, depending on the nature of the task. Hirsh and Sherrick discuss several broad classes of responses which depend on some form of temporal discrimination: 1. detection of changes in qualitative characteristics of sounds perceived as single, as in pitch, timbre, and apparent location; 2. detection of changes from singleness to discrete stimuli (as in the transition between fusion and "flicker"); 3. detection of changes from merely two stimuli to two perceptually different stimuli; 4. specifying the order of occurrence of two perceptually different stimuli. Considering the auditory modality for example, Hirsh and Sherrick point out that human observers can make a differential response to interaural time differences of only a few microseconds. In this type of task the subject is required to make estimates of the apparent location of a sound source in space. A higher order task is that of the judgment of simple successiveness, in which the subject must differentiate between the perception of one stimulus and more than one. Hirsh and Sherrick report minimum values of about 2 msec. separation between two stimuli for the detection of successiveness as opposed to simultaneity. A third type of task, one that seems to be of a higher degree of complexity, is that of the identification of temporal order, i.e., identification of which of two distinguishable stimuli comes first. The above authors found that a separation of around 20 msec. is necessary for a subject to attain 75% accuracy. In addition, it is well known that, in the visual system, temporal acuity as measured by the flicker-fusion technique is significantly affected by variations in a multitude of factors including size of target, portion of retina stimulated, state of dark adaptation, intensity of light, etc. (Simonson & Brozek, 1952; White & Lichtenstein, 1963). In light of the numerous factors which affect traditional measures of temporal acuity, many of which relate to characteristics of the different sensory modalities, it is indeed interesting to examine further the evidence of White and his colleagues for a central mechanism of perception, independent of sensory modality, which limits the rate at which new stimuli can be perceived, thereby yielding relatively invariant values of "perceptual rate."

<u>Evaluation of the numerosity studies as evidence for a psychological moment</u>. The hypothesis of a maximum perceptual rate implies that the rates of stimuli flickering at various subfusional frequencies above this rate could not be differentiated from one another. That is, if the visual system cannot respond to more than about ten flashes per second, there would be no reason why a stimulus flashing at the rate of 15 cps. should appear slower than one flashing at 25 cps. Common observation, however, suggests that these frequencies can be differentiated. In a similar manner, the raw data as reported by White (1963) do not appear to support the hypothesis of a maximum perceptual rate. If, according to the moment hypothesis, new stimuli can be perceived only at the rate of about one every 100 msec., how is it that the mean responses to increasing numbers of stimuli flashing at the rate of 25 cps. (one every 40 msec.) become increasingly larger? That is, the mean estimate of a flash train of 7 pulses is larger than that to a train of 6 pulses although the larger train is only 40 msec. longer than the shorter. In other words, adding a new stimulus only 40 milliseconds after the one preceding it can cause a difference in the

subject's response.

Another question which may be raised about the time values of the psychological moment is the wide variation in values attributed to it by the authors of current studies using the concept. For example, studies by White and Cheatham (1959) find the maximum value of their curves to suggest 80 milliseconds as the time value for the moment. White (1963) points out that the period of the alpha rhythm (approximately 100 msec.) is possibly related to the psychological moment. Lichtenstein (1961) cited the value of 125 msec., obtained in the study of the phenomenon of "simultaneity," as a reflection of the time value of the moment. Furthermore, a later publication by Lichtenstein (1963) states that a "typical slope" of the stable part of the curves in White's study is one perceived flash for every 180 msec. of elapsed presentation time, or a count rate of about 5.6 perceived flashes per second. Although it is reasonable to attribute a range of values between 80 and 125 msec. to those central processes responsible for the alpha rhythm, the value of 180 msec. appears excessively large to be attributed to these same processes. The investigators, however, do not specifically explain or discuss possible reasons for this variation in values cited for the moment.

Further criticism can be directed toward Lichtenstein's "simultaneity" experiment, described above, on the basis of preliminary observations made by the present investigator. Using equipment essentially similar to that used by Lichtenstein, preliminary results were obtained which tentatively replicated those of Lichtenstein. However, it was further observed that the time value obtained for one cycle of lights at "simultaneity" was to a considerable extent a function of the number of lights used, when trials presenting 2 and 8 lights were given in addition to the 4 light condition. This finding is not consistent with the moment hypothesis advanced by Lichtenstein in his discussion of the results. That is, if the condition which results in the illusion of simultaneity is that in which a number of separate lights turn on all within the time period of a moment (125 msec. as stated by Lichtenstein), the number of lights involved in the presentation should not influence the value of the frequency at which simultaneity is obtained.

Another phenomenon with which the moment hypothesis does not adequately deal is that of changes in "apparent rate" as a function of retinal location. The phenomenon, described by a number of investigators including Pieron (1952) and Lichtenstein et al. (1963) is that a light flashing at a fixed frequency appears to be flickering more slowly when viewed in the periphery than in the central visual field. This has been documented by Lichtenstein et al. (1963) who found subjects to equate a 25 cps. light with a 10.5 cps. auditory signal when the light was observed at the fovea, but when the same light was seen at a 70 degree visual angle the auditory signal that was subjectively equal in rate was only about 3.5 cps. A "paradox" and a problem for the moment theorists is that the "numerosity" or perceptual rate studies of White resulted in data indicating that the "perceptual rate" as discussed above was essentially unchanged by variations in retinal location. Comparing the two sets of data, Lichtenstein <u>et</u> <u>al</u>. noted,

> On computation of the counting rate, that is, the number of flashes perceived and counted per unit time following onset transients, it was discovered that, while apparent rate of perceived flashes had differed so drastically between the far periphery and the fovea, the counts of flashes perceived at those loci were, surprisingly enough, approximately the same. Given, for example, 15 flashes at the 25 fps. rate, it is paradoxical that one should see about the same number of flashes during foveal observations where stimuli are perceived to come at such a fast rate as one sees when observing peripherally where the apparent flash rate is so low (Lichtenstein <u>et</u> <u>al</u>., 1963, pp. 523-524).

The authors are forced to radically modify their thinking about the psychological moment. Instead of positing one scan or sampling rate of the nervous system, they were required to postulate the operation of a number of different scan rates in order to account for the so-called paradox. By so doing, they considerably weaken their position that the moment reflects a basic neurophysiological mechanism. For example, they can no longer point to the ten per second alpha rhythm and the research on its behavioral correlates as convincing evidence for a sampling rate (and psychological moment) of about this frequency. The theorizing they do advance to explain the "paradox" involves postulating gradients of time perception across the retina, which reflect different sampling rates. Their reasoning is that since "rate" is the resultant of number divided by time, and since perceived number does not change, it is perceived time that must change.

The question arises whether or not a more parsimonious explanation can be advanced to account for the data which have been cited in support of a psychological moment hypothesis, one which does not necessarily have to postulate any new processes. A more parsimonious explanation would hopefully be able to account for not only the consistency of findings across modalities but also be able to resolve the "paradoxical" findings of Lichtenstein _et_ _al_. (1961).

White and his colleagues, in their studies of the psychological moment, have referred to studies by Garner (1951) and by Forsyth and Chapanis (1958) as essentially supporting their own findings, although these latter studies were conducted with a very different orientation. These studies concern themselves with an investigation of the parameters governing the speed and accuracy with which the human subject can count temporally distributed stimuli. Garner, for example, presented from 1 to 20 flashes of light at five frequencies, two duty cycles, and two intensities to five subjects whose task it was to count as accurately as possible the total number of flashes. Forsyth and Chapanis presented an essentially similar task and varied retinal location, number of pulses, and frequency of flashes. Garner found that counting very low numbers of pulses can be accurate at rates as high as 12 per second. At numbers above 5 or 6 however, counting accuracy decreases with rates of 6 or more per second. He found no significant difference in counting accuracy as a function of either intensity or duration (clicks _vs._ "beeps") of the stimulus pulses. These studies did not purport to be dealing with perceptual phenomena--they dealt with counting ability, or some ability at a higher or more complex level than merely the appreciation of discreteness. As such, a general characteristic of the findings of these studies is that variations in many stimulus parameters which typically affect the results of perceptual studies do not affect counting ability. That is, within broad limits, it does not seem to matter what the physical characteristics of the stimuli to be counted are; as long as they are perceptible as discrete, they can be counted with comparable speed and accuracy regardless of sensory modality. A rapid or long train of pulses is underestimated, to be sure, but this observation does not necessarily imply that the discrepancy between the actual number of pulses presented and the subject's count of the pulses is the direct result of a failure to perceive the pulses. In light of all of the above considerations the question can be raised whether White and the other investigators of the psychological moment are measuring some basic aspect of perception, neurophysiological functioning, and temporal discrimination, or whether they are measuring the speed at which their subjects can count. Indeed, in several places, Lichtenstein (1963) discusses "counting rate" but equates this with perceptual rate, since he frequently used the phrase "perceived and counted."

For further neuropsychological and perceptual research in this area, it is important to clarify the meanings and implications of these studies purporting to deal with temporal discrimination and to differentiate between basic perceptual processes and higher level functions. It appears, for example, that an explanation in terms of counting speed would adequately resolve Lichtenstein's "paradox," since, on the basis of Forsyth and Chapins' findings (1958), it is not surprising that one should count peripherally presented lights as accurately as foveally presented lights. In support of a counting model, several informal observations were made by the present author which strongly suggest that people counting to themselves as rapidly as possible can count at a maximum rate of 6 to 10 counts per second, a value similar to the range of "perceptual rates" found in White's studies. If counting rate is an important or limiting factor in the "perceptual rate" and "numerosity" studies, it should be possible to demonstrate that subjects who are asked to count to themselves while a steady signal light is displayed for various time periods comparable to those involved in White's presentation of a flickering light will produce "count rate" curves essentially identical to the "perceptual rate" curves of the studies of White *et al*. Such a demonstration is a primary goal of the present study.

CHAPTER II

STATEMENT OF THE PROBLEM

The maximum rate at which a person can perceive the discreteness of a repetitive stimulus is generally thought to reflect basic properties of brain functioning and information processing. Studies have appeared recently in the literature of perceptual research which have purported to demonstrate the existence of a time unit, referred to as the psychological moment, which is supposedly closely related to basic processes of the central nervous system and which limits the rate at which new stimuli can be perceived as discrete. This maximum "perceptual rate" has been derived from an analysis of data, referred to as "temporal numerosity," obtained by having subjects count the number of pulses perceived in a brief train of stimuli.

In the previous section a number of questions were raised about the interpretation of these studies. Specifically, it was questioned whether the results of studies such as those of White (1963) and Lichtenstein (1961) in fact reflect a basic time unit affecting perception, or whether these results could be explained in non-perceptual terms. It was seen that values of "temporal acuity" are dependent on the nature of the perceptual task, and under certain circumstances the nervous system can react to time intervals of only a few microseconds. Hirsh and Sherrick (1961) have indicated that the order of occurrence of two perceptually different stimuli can be reported when they are separated by about 20 milliseconds, and the literature on flicker perception (Landis, 1954) illustrates that under certain conditions a single light flashing on and off at a frequency of 40 cps. (25 milliseconds) can be seen as flickering or consisting of discrete pulses. These two latter illustrations involve time values far shorter than the value of the hypothetical psychological moment, and the suggestion was made that the "numerosity" phenomenon is not a simple perceptual one but probably involves higher level cognitive processes such as counting. If this is the case, then a question is raised about the utility of a psychological moment concept based on these "numerosity" results in explaining basic functioning of the brain.

The purpose of the present study is to examine the results of several studies purporting to reflect a basic aspect of brain functioning and to suggest an alternative explanation in non-perceptual terms. In this connection, a study involving several tasks will be conducted with the following goals:

1. To replicate the major findings of two studies which have been cited as illustrating the perceptual

consequences of the psychological moment: a. White's visual numerosity curves, and b. Lichtenstein's "simultaneity" phenomenon.

2. To devise a task to permit the explanation of the results of White and of the preceding experiment (1a) in non-perceptual terms, rather than using the psychological moment concept. An attempt will be made to demonstrate that the subject's response in such a situation is determined primarily by the speed at which he can count events, rather than by the rapidity with which he can perceive them. In this experiment, a "mock" numerosity study will be conducted. Instead of presenting subjects with trains of stimuli varying in number presented, the subject will be presented a steady light, the length of the "on" period corresponding to the various lengths of time which were required to present the discrete stimuli in experiment 1a and in White's study. The subjects will be asked to count to themselves as rapidly as possible while the light is on, and to report the number reached at the point the light is turned off. If <u>counting</u> speed is the important determinant of the subject's response as a function of presentation time, the curves in this experiment should closely parallel those of experiment 1a (and of White's studies). Results of this experiment will also indicate the ability of the subject to estimate the relative durations of the stimuli--durations which vary in steps smaller than the values cited for the psychological moment.

3. To extend the range of the Lichtenstein "simultaneity" experiment (and experiment 1b above) to ascertain the generality of the conclusions of Lichtenstein and White concerning the relation of the simultaneity illusion to a psychological moment. In addition to the use of 4 stimuli as in the earlier study, 2 and also 8 lights will be used. Preliminary observations suggest that the frequency at which the lights appear to be flashing simultaneously depends primarily on the number of lights in the array, the results therefore not explainable solely in terms of the moment concept.

4. To compare the "numerosity" and "simultaneity" phenomena with a more traditional measure of temporal acuity, the CFF (critical flicker frequency). The latter measure has been extensively investigated in relation to central nervous system functioning and is considered to be a rather straightforward perceptual task. If, as we suspect, the "numerosity" task is primarily a higher order task such as counting, and if the "simultaneity" illusion is primarily a perceptual phenomenon, we would expect a higher degree of relationship between a subject's values for the CFF and the "simultaneity" threshold than between CFF and the "numerosity" or psychological moment values.

CHAPTER III

METHOD

Procedure. The four experimental tasks were administered in the following order:

1. CFF determination
2. "Temporal numerosity" task
3. "Mock" numerosity task (counting), counterbalanced for order with 2.
4. Simultaneity experiment.

Experimentation was conducted in an air-conditioned room free from distracting noises. The room lighting was subdued, with illumination on the viewing surfaces as indicated below. The subject was given about 5 minutes to become accustomed to the experimental surroundings while he answered questions as to his name, age, etc. The subject rested his chin in a standard chin-rest while viewing the stimuli. A short rest period (5 minutes) was provided between conditions 2, 3, and 4.

1. CFF. The subject was presented an example of a steady light and of a flickering light (10 cps.) and was told that the light would initially appear steady and that he was

to depress his response button as soon as the light appeared to flicker. After one practice trial, ten determinations of the CFF were made, using a modification of the method of limits with descending trials (from high to low frequency) only. Descending trials were chosen in order to duplicate previous techniques with similar equipment (Parsons & Gottlieb, 1960; Parsons & Huse, 1958) which found this technique to yield thresholds with less variability than the ascending-descending technique. Thresholds were recorded in cycles per second and the mean of the 10 thresholds obtained. This task was the first in order for all subjects, since it is a relatively simple one and served to acquaint the subjects with the equipment and the general appearance of a flickering light.

2. Temporal numerosity. Procedures essentially similar to those of White (1963) were followed with the exceptions of the modifications and improvements described in the section describing the equipment. Subjects were presented with trains of light, flashing at 25 cps., which varied in the number of flashes presented, and the subjects instructed to count to the best of their ability the number of flashes they saw. Number of flashes presented were either 2, 3, 4, 5, 6, 7, 9, 11, 13, or 15, and ten presentations of each number of flashes were given, resulting in a total of 100 trials. The order of presentation of the different numbers was randomized in blocks of ten, such that all ten numbers

occurred once in each group.

3. "Mock" numerosity study. This condition preceded the numerosity study in half of the subjects to control for order effects. In this experiment the conditions were comparable to those of the "numerosity" study with the exception of the stimulus light, which instead of presenting discrete flashes to the subject, was a steady light, the duration or "on" times of which were exactly comparable to the stimulus presentation times in the "numerosity" study. The subject was instructed to count to himself, as rapidly as possible, for the length of time that the light was on, and to report the number he had reached when the light was turned off. The time durations are multiples of 40 msec. (the reciprocal of 25 cps.) by factors of 2, 3, 4, 5, 6, 7, 9, 11, 13 and 15 and were randomized in the same fashion as the discrete pulses were in the "numerosity" study. The durations of the stimulus light are, therefore: 80, 120, 160, 200, 240, 280, 360, 440, 520, and 600 milliseconds.

4. "Simultaneity" task. The equipment for this task is somewhat different from the original study, but differs in a manner which should not affect the results if Lichtenstein's reasoning is followed. The stimulus configuration consisted of either 2 lights (at 90° and 270° on the circumference of the circle), 4 lights (at 0°, 90°, 180°, and 270°) or 8 lights (with the addition of lights at 45°, 135°, 225°, and 315°). The circle subtended $1^{\circ}30'$ visual angle as in

Lichtenstein's study, with the subject fixating central binocular vision on a spot at the center of the circle.

The procedure of obtaining "simultaneity" thresholds followed that used by Lichtenstein. Ascending trials were run, with the lights flashing around the circumference at a slow rate, gradually increasing in frequency. The subjects were instructed, with examples, about the apparent movement phenomenon, and reminded that this was not the effect in which we were interested, and told to press the response key when all lights appeared to be flashing "on" simultaneously, with no evidence of time differences among any of the flashing lights. The subjects were reminded that each individual light might be flashing with respect to itself, but that as soon as no time differences between the onset of any of the lights could be discerned, he should press his response key. Ten trials for each condition (2, 4 and 8 lights) were administered. The order of administration of the three conditions was randomized, but the ten trials in one condition were completed before beginning a new condition. The starting frequency of the stimuli was randomly varied from points considerably below the point of simultaneity in order to avoid the possibility of a temporal response set.

Subjects. Since we are studying behavior which supposedly reflects basic neurophysiological processes, or at least represents basic cognitive functions, an attempt was made to use normal, comparatively intelligent, and cooperative individuals as subjects. Subjects consisted of ten "normal" young men, drawn from volunteer medical students at the University of Oklahoma School of Medicine. Their ages ranged from 21 through 25 years. The low variability of the data obtained in pilot studies and that reported in the literature suggested that ten subjects would be sufficient, and indeed a considerably greater number than that employed in the studies of White and the other investigators of "temporal numerosity."

Apparatus. The basic apparatus employed in the various parts of the study consisted of an electronic device which caused a light source (a Sylvania R1131C glow modulator tube) to flash with a square wave form at frequencies and intensities which could be precisely controlled. The duty-cycle of the flashes was 1:1. The light output of the tube was diffused by a piece of translucent plastic, and the intensity of the resulting stimulus patch was controlled at 3.5 foot-candles. The stimulus patch was a circle about 15 mm. in diameter, and when viewed at a distance of 330 mm. it subtended 1.96 degrees visual angle. The surface surrounding the stimulus light was flush with the surface of the plastic diffuser and was painted a dull black. The intensity of reflected light from this surface was 2.5 foot-candles. These conditions were chosen because they duplicate dimensions used in standard visual field perimetry examinations and allow comparison of the CFF thresholds obtained in this study with those of other studies of CFF. Incorporated into the electronic control unit is a pre-set counter which enabled the experimenter to determine exactly how many flashes will be presented. As an additional check, the number of flashes presented was displayed by a digital readout. The control devise incorporates several refinements over the equipment used in White's studies. It is noiseless in operation, obviating the necessity of a masking sound; furthermore, exactly the desired number of pulses can be presented, whereas White's equipment would sometimes produce one more or less than the desired number. Finally, the device can be made to produce the steady light required for the "mock" numerosity study, and the unit has a timer with which the experimenter can accurately determine the duration of the stimulus presentation.

For the investigation of the simultaneity phenomenon, the electronic control unit was connected to a device which could cause any one of eight neon tubes (NE-2) to flash sequentially. These small lamps were mounted on a board in a circle 4.5 centimeters in diameter, which when viewed at a distance of 172 cm. subtended a visual angle of $1^{\circ}30'$, the visual angle used in Lichtenstein's study. The device could be adjusted to flash either 2, 4 or 8 lights sequentially in any pattern. By "sequential" the following is meant: The first pulse from the control unit turns light 1 on; the second pulse turns light 2 on and light 1 off, etc. The frequency of the impulses when the subject pushes his response key is read directly from the digital readout.

Analysis of Data. The data obtained in studies of "temporal numerosity" which led certain investigators to hypothesize the existence of a psychological moment are in the form of the slopes of the curves, indicating number of flashes "perceived" per unit time. The curves of mean responses obtained from the numerosity study were compared with those obtained from the "mock" numerosity task, the abscissas or time axes being comparable. In addition to a visual inspection of the curves, the main form of analysis used in White's study (1963), the regression equations for the lines, were obtained and the regression coefficients compared, a procedure employed by Forsyth and Chapanis (1958).

For the simultaneity phenomenon, the time period of interest is the time, in milliseconds, required for one "cycle" or revolution of the flashing lights in the circle. This time is easily obtained by dividing the frequency of the pulses at the point where the subject reports the simultaneity phenomenon by the number of lights used in that condition, and calculating the reciprocal. The mean time values for the 3 conditions (2, 4 and 8 lights) were calculated for all subjects. Correlation coefficients were calculated for the following combinations of measures: CFF and simultaneity (with 4 lights); CFF and the regression coefficient for "numerosity"; CFF and regression coefficient for the "mock" numerosity regression coefficient. In addition, a number of other aspects of the data were examined, such as a comparison of the elevation of the numerosity and "mock numerosity" curves, and also the relation between the "simultaneity" threshold using 4 lights with those using 2 and 8 lights.

CHAPTER IV

RESULTS

<u>Numerosity and counting</u>. With regard to experimental goals 1a and 2, i.e., those of replicating the visual numerosity curves of White and of presenting evidence that these functions might be explained in non-perceptual terms, the mean responses for the 10 subjects for both the numerosity and the counting parts of the study are presented in Table 1 and Figure 1. (Data for each subject on all experimental variables are given in Appendices A and B.) It can be seen that the two curves appear highly similar both in slope and in

Table 1

Mean Responses to Numerosity and Counting Tasks as a Function of Number of Flashes (Numerosity) or Presentation Time (Counting)

Number of flashes	Numerosity	Counting	(Presentation Time, msec.)
2	1.0	1.6	80
3	1.3	1.9	120
4	2.2	2.3	160
5	2.9	2.9	200
6	3.4	3.2	240
7	3.8	3.8	280
9	4.5	4.1	360
11	5.3	4.9	440
13	5.7	5.3	520
15	6.5	5.8	600

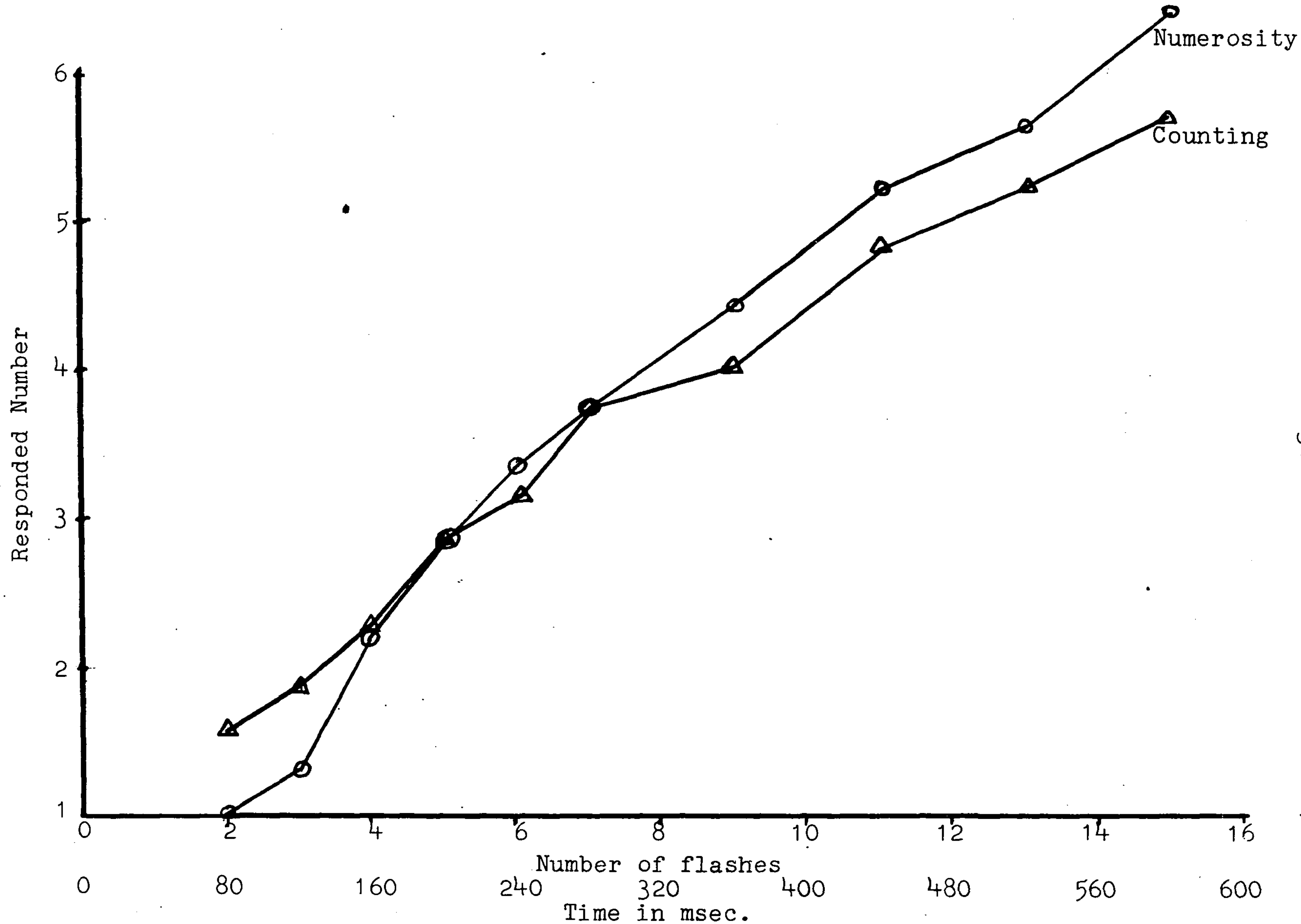

Fig. 1. Comparison of numerosity and counting functions

overall level. Linear regression coefficients were calculated for all subjects for both conditions, and are presented in Table 2. The slopes of the two curves were compared by examining the differences between the two regression coefficients for each subject and calculating *t* tests for the

Table 2

Regression Coefficients for Numerosity and Counting Tasks

Subject Number	Numerosity	Counting
1	.613	.410
2	.360	.252
3	.417	.332
4	.450	.329
5	.337	.295
6	.466	.414
7	.297	.315
8	.253	.303
9	.757	.333
10	.205	.390

difference scores. The obtained value of *t* was 1.65, *df*=9, which is not significant at the .05 level, indicating that the observed differences in the slopes of the two functions can be reasonably attributed to chance variation. The mean responses for the numerosity and counting tasks were nearly identical: 3.64 for the numerosity task, and 3.59 for counting. The difference between the two means is not significant (t=.19 df=9, $p>.05$). Calculating values of the moment based on the slopes of these curves, the value derived from the numerosity curve is 96 msec., while that for counting is 122 msec., both values well within the range cited in the studies of White and his associates (White, 1963; White & Cheatham, 1959; White & Lichtenstein, 1963). "Perceptual" rate calculated as the reciprocal of the moment values is 10.4 flashes per second for the visual numerosity curve while that for counting rate is 8.2 per second.

Further evidence for the comparability of the curves of this study to those published previously can be seen in Figure 2, in which data from White and Cheatham (1959) and also from White (1963) are plotted along with the present curves. The curve of the White and Cheatham study was derived using a flash rate of 30 cps., but since it is plotted along a time base (abscissa) it is comparable to the other curves. From the comparison of these two sets of data, it can be seen that the "numerosity" and the counting rate curves of the present study fall well within the range of slopes purported to represent perceptual rate.

Evidence that increments in the numerosity response are reliably associated with increments in the counting response at comparable stimulus presentation times is seen from the fact that the average correlation between numerosity and counting response for the ten subjects is .98, with the lowest correlation being .96.

A question raised earlier concerned the ability of an individual to discriminate increments either in number of flashes or stimulus duration smaller than the minimum value cited by the investigators of the moment concept, a value of

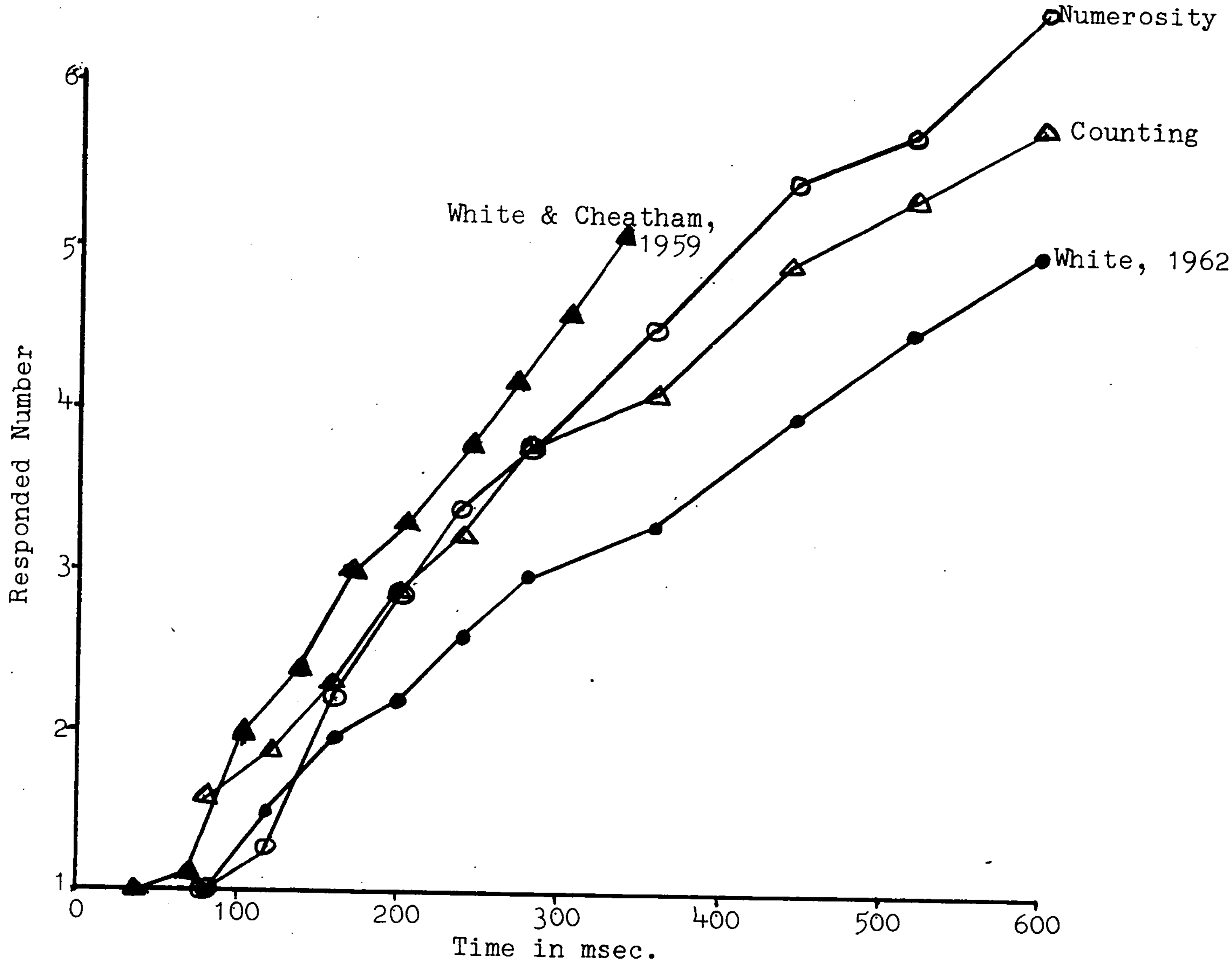

Fig. 2. Comparison of numerosity and counting with previously published numerosity functions

about 80 msec. To this end, the increments of the mean responses to 4, 5, 6, and 7 flashes in the numerosity condition, and to the steady-light counting counterparts (160, 200, 240, and 280 msec.) were analyzed by *t* tests (see Table 3). These points were chosen since they represent increments of one flash in the numerosity task, and in both the

Table 3

t Tests Between Responses to Increments in Presentation Time (msec.)

Comparison	*t*	
	Numerosity	Counting
160 *vs*. 200	5.41**	9.80**
200 *vs*. 240	5.59**	2.82*
240 *vs*. 280	4.32**	7.55**

*$p < .05$, *df*=9

**$p < .01$, *df*=9

numerosity and counting tasks represent time increments of only 40 msec. The differences in response to two and three flashes were not included in this analysis in order to avoid confounding the possible effects of other phenomena, such as the initial fusion effect. All increments, both in numerosity and counting, were significant beyond the .01 level indicating that, within the range analyzed, increments of only one flash or of 40 msec. presentation time result in significant increments in the subjects' responses.

Simultaneity. With regard to aims 1b and 3 in

Chapter II, the results of the simultaneity tasks are presented in Table 4. It can be seen that the values for the moment, which in this instance represent the time value for one cycle or revolution of lights at simultaneity, range from 117 msec. (2 lights), 157 msec. (4 lights), to 164 msec. for 8 lights, or 8.6, 6.4, and 6.1 cycles or revolutions per second respectively. It will be recalled that the value obtained by Lichtenstein (1961) was 125 msec. using 4 lights.

Table 4

Mean Values for Simultaneity Illusion
Under Three Conditions

Condition	Time Each Cycle (msec.)	Freq. Each Cycle (cps.)	Time Between Adjacent Flashes (msec.)
Sim-2	117	8.6	58
Sim-4	157	6.4	39
Sim-8	164	6.1	20

Tables 5 and 6 present intercorrelations among all the major measures of the present study. Both product-moment and rank-order correlations are presented inasmuch as one subject (#9) responded in such a deviant fashion on the CFF and simultaneity tasks as to produce some correlations which may be misleading. It is apparent from the rank-order correlations that there are significant intercorrelations among the three simultaneity tasks, but that there are no significant correlations between the simultaneity thresholds and any of the other measures used in this study. This

Table 5

Product-Moment Correlations Among Major Variables

Variable	Sim 2	Sim 4	Sim 8	CFF	Regression Coefficient	
					Numerosity	Counting
Neon CFF	-.03	-.81**	-.77**	.68*	-.52	-.07
Sim 2		.50	.57*	-.08	-.22	-.17
Sim 4			.93	-.35	.43	-.10
Sim 8				-.31	.21	-.14
CFF					-.48	.01
Numerosity Regression Coefficient						.20

*$p < .05$

**$p < .01$

Table 6

Rank-Order Correlations Among Major Variables

Variable	Sim 2	Sim 4	Sim 8	CFF	Regression Coefficient	
					Numerosity	Counting
Neon CFF	.04	-.48	-.52	.18	-.04	-.26
Sim 2		.61*	.62*	-.03	-.26	-.03
Sim 4			.79*	-.25	-.21	-.21
Sim 8				-.25	-.38	-.12
CFF					-.20	-.20
Numerosity Regression Coefficient						.30

*$p < .05$

**$p < .01$

observation is of interest in light of White's interpretation of the simultaneity threshold as another measure of the psychological moment. Similarly, Table 7 illustrates a significant difference between the means of the simultaneity threshold between the two-light condition (Sim-2) and both the four- and eight-light conditions (Sim-4, Sim-8), and a non-significant difference between the Sim-4 and Sim-8 conditions.

Table 7

t Tests Between Means of Three Simultaneity Conditions

Comparison	*t*	*p*
Sim-2--Sim-4	2.96	$<.02$
Sim-2--Sim-8	4.44	$<.01$
Sim-4--Sim-8	1.16	$>.20$ n. s.

Critical flicker frequency. In Table 8 data are presented relevant to aim 4. Values are given for the CFF for all subjects under two conditions. The first CFF value cited

Table 8

Values for CFF (cps.) Under Two Conditions

Subject Number	CFF	Neon CFF
1	49.2	30.8
2	46.8	31.6
3	44.7	31.4
4	45.7	32.9
5	43.9	31.6
6	44.2	34.7
7	45.6	30.0
8	47.8	33.7
9	38.1	23.5
10	45.4	29.5

is that as determined by the procedure and equipment discussed in Chapter III. The values for the "Neon CFF" were obtained using ten ascending trials with one of the lamps of the simultaneity device, for the purpose of obtaining an additional measure of CFF under conditions comparable to those of the simultaneity tasks. It can be seen that by rank-order technique, neither CFF measure is significantly correlated with any other measure. However, the Neon CFF has higher correlations than the standard CFF. While the application of the product-moment correlation reveals that the Neon CFF is significantly correlated with the Sim-4 and Sim-8 conditions and also with the standard CFF measure, these correlations are inflated due to one extreme subject (#9), and must be cautiously interpreted. In general, however, they are consistent with the rank-order correlations.

In summary, the results relevant to the experimental goals are:

1. Replication of White's numerosity curves and Lichtenstein's simultaneity phenomenon was obtained.

2. Instructions to the subject to count during specified time intervals, in the absence of the perception of discrete perceptual events, resulted in slopes and mean responses highly similar to those obtained by White in temporal numerosity studies, purportedly representing a maximum rate of perceiving. Further analyses indicated significant response increments between, and therefore differential

response to, increments in stimulus duration considerably smaller than the value cited as representing the basic time unit of the nervous system.

3. Lichtenstein's simultaneity phenomenon gave rise to consistent values for four and eight lights, but not for two lights.

4. The critical flicker frequency, a more traditional measure of temporal acuity, was not related in any clear fashion to the numerosity or simultaneity phenomena.

CHAPTER V

DISCUSSION

Numerosity, counting, and the psychological moment. The results of the present study indicate that replication of the principal findings of the studies of visual "numerosity" discussed in earlier sections of this paper was accomplished. That behavior characteristic of human observers in general has been measured is seen from the fact that the replication involved a group of ten untrained subjects, whereas the majority of studies published concerning this problem have used two or three trained observers, often the authors themselves. However, the results of this study raise questions concerning the nature of the mechanism which gives rise to the numerosity curves. The logic followed by White and by Lichtenstein states that temporal numerosity functions derived from a subject's response as to the number of flashes "seen" reflects a maximum perceptual rate which is determined by neurophysiological processes possibly related to the alpha rhythm. The alternative interpretation, advanced in the present study, is that the temporal numerosity curves primarily reflect counting speed rather than perceptual discrimination. (The determinants of counting speed may be of a basic neurophysiological nature but more likely involves higher level neuromuscular and cognitive processes.)

The overall slope of the numerosity function indicates a "perceptual rate" of 10.4 flashes per second. The striking finding is that when subjects were asked to count to themselves during specified time intervals, the curves relating number counted to counting time were highly similar to those of the so-called numerosity or perceptual rate studies. The slope of this latter curve indicated a counting rate of 8.2 per second. It will be recalled that there were no significant differences in the two curves, either in slope or in level (mean response). In effect, then, a presumably perceptual phenomenon has been duplicated by a task in which no external perceptual events were counted. This is especially interesting inasmuch as the request to count "as fast as possible" is relatively unstructured and may imply different rates to different individuals, depending on such factors as activity level and motivation to cooperate. It should be noted that the subjects were young, intelligent volunteers who were presumably interested in cooperating and who therefore did probably count as rapidly as possible. The results appear to indicate that what is being measured in the "perceptual rate" or numerosity studies is maximum counting speed, and not a basic perceptual phenomenon. When individuals are asked to count or even to estimate the number of a group of rapidly sequential events, there appears to be an implicit or explicit sequential <u>counting</u> which can attain a maximum rate of only about 8 counts per second regardless of perceptual discriminative ability. That perceptual discrimination is not limited to only one additional perceived event every 96 msec. (the reciprocal of 10.4 flashes per second) was seen in the significant increments in mean response when the responses to 4, 5, 6, and 7 flashes were compared. If additional stimuli can be <u>perceived</u> at the rate of only one additional flash every 96 milliseconds, subjects would have been unable to differentiate, for example, between 6 and 7 flashes, which differed by only 40 msec. (i.e., the 7th flash of a light flashing at 25 cps. is separated from the 6th flash by only 40 milliseconds). It is apparent that we are dealing primarily with a response variable, counting rate, rather than with a basic perceptual rate.

If the "numerosity" results are considered in the framework of the studies published on counting rate, a number of the questions which were raised earlier are clarified. First, the present results are consistent with those obtained by Forsyth and Chapanis (1958) who obtained count rates of about 6 per second. Second, since these studies of counting (Foryth & Chapanis, 1958; Garner, 1951) suggest that count rate is relatively consistent despite rather wide variations in stimulus characteristics and retinal location, an explanation is offered for the apparent rate paradox as well as for the striking consistency of the "numerosity" function across sensory modalities. The observation that a flickering light of a given frequency appears to be flashing more slowly when viewed in the peripheral field of vision than when viewed directly has been noted for years, as mentioned by Lichtenstein _et al_. (1963), but the latter study found that while apparent rate differed drastically between the periphery and fovea, "the counts of those flashes perceived at those loci were, surprisingly enough, the same" (Lichtenstein _et al_., 1963, pp. 523-524). As discussed in a previous section of this paper, they reasoned that since perceptual rate is a result of number of reported flashes per unit time, and since reported number does not change as a function of retinal displacement, it is perceived time which must change. They state,

> We therefore offer the following hypothesis which, if true, would resolve the apparent rate-count rate paradox. It is that _perceived elapsed time or perceived time between perceived flashes_ over short real time intervals and under stimulus conditions of this and White's experiment _increases across the retina_, i.e., under conditions of these experiments, a given short interval containing flashes closely spaced in physical time _appears longer at the periphery than it does at the fovea_ (Lichtenstein _et al_., 1963, p. 532).

The above hypothesis is considerably more complex and less consistent with known neurophysiological phenomena than their original line of thought which postulated only one basic scanning or time sampling rate. Whereas, in their previous speculations about the nature of the psychological moment they were able to base much of their arguments on the extensive literature of the relation of cyclic brain activity to behavior, there is no comparable literature on the existence of a continuum of scanning mechanisms such as they propose. The fact that their new line of reasoning is limited to the visual system further limits the generality of their conclusions.

A resolution of the apparent rate paradox is comparatively straightforward when approached from the framework of a counting rather than a perceptual model. Since it appears that counting rate is the limiting factor of the subject's response, and since this rate is considerably slower than either the objective rate or the "apparent rate" as measured at retinal displacements up to 30°, the maximum retinal displacement used in White's study (1963), it is not at all surprising that "the higher apparent flash rate at the fovea does <u>not</u> manifest itself in a correspondingly greater number of flashes per second <u>counted</u> [sic] there" (Lichtenstein <u>et al</u>., 1963, p. 529).

An analysis of the response increments between 2 and 3 flashes, as compared to the mean increments in counting for 80 and 120 msec. illustrates a characteristic of the visual system also found by White (1963) and not directly related to the numerosity results. The increment in the counting response was significant ($\underline{t}=4.3$, $\underline{df}=9$, $\underline{p} < .005$) while the numerosity increment barely reached significance at the

.05 level (t=1.9). This resulted from the "initial fusion" phenomenon, reported by White (1963): although a light flickering at 25 cps. is seen by normal persons as flickering, if presented with only two flashes of light subjects almost invariably report only one. For example, of 100 responses to the two flashes in the numerosity condition, 98 were "1" and 2 were "2." Under the comparable time interval (80 msec.) in the counting experiment, there were 50 responses of "1," 36 of "2," and 14 of "3." Similarly, with three flashes, there were 74 responses of "1," but only 32 responses of "1" under the parallel counting task. The initial fusion phenomenon appears to be a sensory characteristic of the visual system, thought by White to be related to the scotopic B-wave seen in the electroretinogram. The reason for the higher degree of significance of the count increments over the numerosity increments between the 80 and 120 msec. presentation times is that there were a greater number of responses of "1" to the three flash presentation, while most of the counting responses were greater than one.

<u>Simultaneity, CFF, and the psychological moment</u>. The simultaneity phenomenon was included in the present study because it represents a phenomenon which has been frequently cited by investigators of the psychological moment as another reflection of the operation of a scanning or sampling mechanism which limits the rate at which new stimuli can be perceived as discrete. The fact that the results can not

reasonably be attributed to counting ability provided additional impetus to investigate the phenomenon further. Following Lichtenstein's reasoning, the illusion of simultaneity can be thought of as a breakdown of a form of temporal acuity, i.e., an inability to detect the time of onset of one light as compared to any other light in the array. In Lichtenstein's study, the time value for one revolution of lights in the stimulus configuration at the point the simultaneity illusion was reached was about 125 milliseconds, a value he felt to represent the psychological moment, the assumed basic time unit of the nervous system within which the temporal order of events is not discernable. The time value for one cycle of lights under the four light condition in the present study was 157 msec. This value is reasonably close to Lichtenstein's value of 125 msec. considering differences in equipment and the fact that his subjects were allowed to control the presentation rate themselves.

To review the interpretation of the values obtained in this type of experiment, it was reasoned (Lichtenstein, 1961) that the illusion of simultaneity occurred when all of the lights in the array were turned on within a time interval equal to or less than the psychological moment. When, in his experiment, the whole array of lights was seen as pulsating simultaneously, each light was flashing only about 8 cps. (or every 125 msec.); successive flashes of any one light, therefore, came in different moments. In the present experiment, the comparable value was 6.4 cps., or 157 msec. between the onset of flashes of any one light.

The results of the present study indicate a significant correlation and nonsignificant differences in means between the four light and eight light conditions. However, the fact that the two light condition is not correlated with either the four or eight light condition and that none of the conditions is significantly correlated with the numerosity slopes suggests that these techniques are measuring different processes. Furthermore, the lack of correlation between any of these measures and CFF, a traditional index of perceptual-temporal discrimination raises additional doubts that numerosity is a perceptual phenomenon and poses questions for interpretation of the simultaneity illusion.

The predictions concerning the simultaneity illusion were not supported by the data of this experiment. On the hypothesis that the simultaneity illusion was a perceptual phenomenon related to temporal discrimination or resolving power, the prediction was made that there should be higher correlations between the simultaneity thresholds and CFF than between simultaneity and the slopes of the numerosity curves. Tables 5 and 6 suggest that this might be the case, but the direction of the correlations is opposite to the predicted direction. That is, high CFF thresholds ("good" temporal discrimination) tend to be associated with low thresholds for simultaneity ("poor" temporal discrimination). No simple explanation for this negative correlation can be offered at this point. The simultaneity phenomenon produces a convincing subjective illusion, characteristic of many perceptual phenomena, as illustrated by an anecdotal example: the electronics consultant who designed the device believed that it was malfunctioning and flashing the lights simultaneously rather than sequentially until he could prove otherwise by means of his oscilloscope.

Despite a lack of data from this study which could be readily interpreted as reflecting a basic characteristic of perceptual processes, certain evidence suggests that the simultaneity phenomenon may be measuring a form of temporal acuity and may be a more productive area of further study of the temporal characteristics of perception than the numerosity technique. It is to be noted, for example that the values for frequency of revolution of the lights at simultaneity, as seen in Table 4 appears to be reaching an asymptotic value around 6 per second as the number of lights in the array increases. Adding lights reduces the time interval between any two adjacent lights that can be detected as non-simultaneous, primarily by increasing cues of apparent movement (Hirsh & Sherrick, 1961). The interval between the onset of any adjacent lights in the eight light condition in the present study was 20 milliseconds. An interesting question for future research concerns a more exact specification of the time intervals which lead a subject to perceive non-simultaneity. In the eight light condition for example, the question arises of whether it is the 20 millisecond time interval between adjacent lights or is it the maximum time interval possible between any 2 lights, which in this example would equal 20 x 7 or 140 msec., which produces the non-simultaneous effect. (This value represents the discrepancy in onset times between any one light initiating a cycle and the last light in the cycle.) The problem lends itself to some fairly straightforward empirical tests. The results would have to be reconciled with those of Hirsh (1959) and Hirsh & Sherrick (1961) who found an interval of 2 milliseconds sufficient for judgments of non-simultaneity, but that 20 msec. time separation between two stimuli was necessary for judgments of temporal order to attain a criterion of 75% accuracy.

The lack of evidence in the present study for correlation of numerosity slopes with a more traditional measure of temporal discrimination, the CFF, finds corroboration in a study by Page (1957). Page used essentially the same technique for obtaining numerosity curves as in the present study and compared the results with CFF thresholds. He found no consistent relationship between the two measures for three observers. Page's results in addition provide further evidence suggestive to the present investigator that the numerosity curves could more easily be explained in terms other than perceptual ones. He found, as nearly all investigators of flicker perception have found, that CFF is dependent on the light-dark ratio (LDR; more technically known as "duty-cycle") of the stimulus light; i.e. that small changes in LDR result in changes in CFF. However, he found that LDR had little if any influence on the determination of perceived number. Page made no attempt to explain this lack of influence of an important stimulus variable upon the subjects' response. In terms of the discussion in a previous section of this paper, duty-cycle (or LDR) can be added to the list of variables which have little effect on counting ability. As long as duty-cycle is not so great as to result in fusion of the light, "perceived" flashes can be counted with comparable accuracy over a wide range of duty-cycles.

Summary and conclusions of discussion. In this study questions have been raised about the interpretation of temporal numerosity responses as representing a basic time unit of the nervous system which influences perception. It was demonstrated that data highly similar to the numerosity results could be obtained by ascertaining how rapidly subjects could count to themselves in the absence of a pulsating stimulus. The explanation of the numerosity results on the basis of counting behavior is more parsimonious in that it explains a greater amount of data without postulating new mechanisms (such as gradients of time perception across the retina). The question might be raised as to whether or not counting speed is merely another reflection of the same neurophysiologically determined moment that determines perceptual rate. That the maximum rate at which an individual can count is also probably centrally determined is not disputed. However, it has been demonstrated that subjects were in fact able to make differential responses to small differences in number of stimuli presented and that these differential responses would not have been predicted on the basis of the logic followed by the moment theorists. An interesting study for the future would be to provide subjects with more categories with which to label their responses, perhaps by informing them as to the range of number of stimuli to be presented, including examples of each. Since the data of the present study suggests that differential response to small stimulus differences can be made, by the proper instructions it may be possible to improve a subject's "perceptual" accuracy by promoting a greater degree of correspondence between objective number and the label assigned to it by the subject.

In any event, it seems evident that the simultaneity illusion is less dependent on response variables. Whether or not an explanation of the results is most parsimoniously accomplished by invoking the moment hypothesis is questionable. Further research into different measures of temporal acuity will probably lead to explanations of the simultaneity results in terms of classifying the task at the proper level of a hierarchy of perceptual-temporal discriminations discussed by Hirsh and Sherrick (1961). It will be recalled that they concerned themselves primarily with temporal relations between two stimuli, finding that increasing time separation is required depending on whether the task is to differentiate simultaneity from successiveness or to specify temporal order. Simultaneity involving more than two stimuli as in the present study probably involves additional variables to be considered, such as the fact that the phenomenon is constantly repetitive. In this situation, as implied earlier, there are varying degrees of non-simultaneity. It remains for future work to identify the critical time values in this situation.

This study has replicated the major findings of two lines of research which have supposedly illustrated the existence of a psychological moment which limits the rate at which stimuli can be perceived. A modification of the first research technique, that of assessing "temporal numerosity" or the number of stimuli presumably perceived in a short train of stimuli, has illustrated that the results can be explained in terms of counting speed and that perceptual discrimination is finer than that predicted from a moment hypothesis. With regard to the second line of research, that of the perception of simultaneity, the present study found no correlation between simultaneity and numerosity values for ten subjects as would be expected if both techniques were measuring the same perceptual process. Furthermore no relation was found between simultaneity thresholds and flicker-fusion thresholds, a relationship which would have been expected if the simultaneity threshold were measuring a basic aspect of temporal acuity. As predicted, no correlation was found between CFF and numerosity values, further evidence raising doubt as to the perceptual nature of the numerosity task. The results of simultaneity values using additional numbers of lights in the stimulus array were somewhat more consistent with the results of the original study than anticipated. Considering the results of the numerosity and counting studies however, it is concluded that future work with this technique should yield explanations more consistent with existing information on temporal discrimination without the necessity of invoking a concept such as the psychological moment.

CHAPTER VI

SUMMARY

The maximum rate at which a person can perceive the discreteness of a repetitive stimulus is generally thought to reflect basic properties of brain functioning and information processing. Studies have appeared recently in the literature of perceptual research which have purported to demonstrate the existence of a time unit, referred to as the "psychological moment," which is supposedly closely related to basic processes of the central nervous system and which limits the rate at which new stimuli can be perceived as discrete. This maximum "perceptual rate" has been derived from an analysis of data, referred to as "temporal numerosity," obtained by having subjects count the number of pulses perceived in a brief train of stimuli. The results have been interpreted as reflecting a maximum perceptual rate of about 6 to 10 new stimuli per second, or a "psychological moment" of about 100 to 166 milliseconds.

A number of questions were raised about the interpretation of these studies. Specifically, it was questioned whether the results of studies such as those of White (1963) and Lichtenstein (1961) in fact reflect a basic time unit affecting perception or whether these results could be explained in more parsimonious, perhaps non-perceptual, terms. To this end, an experiment was conducted with the following goals:

1. To replicate the major findings of two studies which have been cited as illustrating the perceptual consequences of the "psychological moment": a. White's visual numerosity curves, and b. Lichtenstein's "simultaneity" phenomenon.

2. To devise a procedure to permit the explanation of the numerosity date in terms of a non-perceptual behavior, counting speed. In this connection, a "mock" numerosity procedure was followed. Instead of presenting the subjects trains of varying numbers of flashes, the subjects were presented a steady light, the duration of which corresponded to the various lengths of time which were required to present the discrete stimuli in the numerosity study. The subjects were asked to count as rapidly as possible while the light was on, and to report the number reached when the light was turned off. It was predicted that if the numerosity response represented primarily counting, the numerosity and counting curves would be similar.

3. To extend the range of stimuli of the Lichtenstein "simultaneity" experiment to ascertain the generality of the conclusions of Lichtenstein and White concerning the relation of the simultaneity illusion to a "psychological

moment."

4. To compare the numerosity and simultaneity phenomena with a more traditional measure of temporal acuity, the CFF (critical flicker frequency). It was predicted that there would be a higher degree of relationship between CFF and simultaneity values than between CFF and numerosity.

The subjects were 10 normal young male volunteers between the ages of 21 and 25. The experimental procedure was as follows:

1. Ten determinations of central binocular CFF.

2. <u>Temporal numerosity</u>. Subjects were presented with trains of light, flashing at 25 cps., and instructed to count the number of flashes they saw. They were presented either 2, 3, 4, 5, 6, 7, 9, 11, 13, 15 flashes, with 10 presentations of each number, in a random order.

3. "<u>Counting</u>" <u>or</u> "<u>mock</u>" <u>numerosity</u>. Conditions were identical to the numerosity procedure with the exception that the subjects were instructed to count to themselves as rapidly as possible while a steady signal light was on, and to report the number reached when the light went off. The durations of this light were exactly comparable to the stimulus presentation times in the numerosity study. To control for possible order effects, procedure 3 was counterbalanced with procedure 2, alternate subjects receiving condition 3 preceding condition 2.

4. "<u>Simultaneity</u>." Subjects viewed a configuration

of lights which flashed sequentially and the rate increased until they reported that all of the lights appeared to be flashing simultaneously, i.e., when they could no longer discern any time differences between the onset of one light and that of any other light in the array. Three conditions were used, utilizing two, four, and eight lights. Ten trials were given under each condition, one condition being administered before presenting another, the order of conditions for each subject being randomized.

5. An additional CFF determination was made at the end of the study, using one of the lights of the simultaneity device rather than the standard CFF device.

Replication of the numerosity and simultaneity studies was accomplished. The results of the counting procedure produced data highly similar to those of the numerosity task and illustrated that the numerosity results can be explained in terms of counting speed and that perceptual discrimination is finer than that predicted from a "moment" hypothesis. No correlation was found between simultaneity and numerosity values for the ten subjects as would have been expected if both techniques were measuring the same perceptual process. Furthermore, no relation was found between simultaneity thresholds and flicker-fusion thresholds, a relationship which would have been expected if the simultaneity threshold were measuring a basic aspect of temporal acuity. As predicted, no correlation was found between CFF and numerosity values, further evidence raising doubt as to the perceptual nature of the numerosity task. The results of simultaneity thresholds using additional numbers of light in the stimulus array were more consistent with the results of the original study than anticipated. It was concluded that further work with this technique should yield explanations more consistent with existing information on temporal discrimination without the necessity of invoking a concept as the psychological moment.

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APPENDIX A

Mean Numerosity and Counting Responses for Each of 10 Subjects

Presentation Time (msec.)	Subject 1		Subject 2		Subject 3		Subject 4		Subject 5	
	N[a]	C[b]	N	C	N	C	N	C	N	C
80	1.0	2.4	1.0	1.3	1.0	2.3	1.0	1.0	1.0	1.1
120	2.5	2.9	1.1	1.5	1.1	2.8	1.0	1.6	1.1	1.3
160	3.8	3.2	2.5	1.7	1.8	3.0	1.6	1.7	2.0	1.8
200	4.5	3.6	3.3	2.3	3.1	3.8	2.7	2.4	2.6	2.5
240	5.3	3.9	3.9	2.8	3.3	3.8	3.7	2.4	3.0	2.5
280	5.9	4.9	4.1	3.5	4.1	4.5	3.7	2.6	3.2	3.1
360	6.8	5.5	4.5	3.3	4.5	4.8	4.6	3.2	3.8	3.4
440	8.1	6.6	5.0	3.9	5.3	5.7	5.4	3.8	4.2	4.0
520	8.6	6.9	5.4	4.1	5.6	6.0	6.1	3.4	4.7	4.5
600	9.6	7.5	5.8	4.5	6.3	6.7	6.4	4.6	5.6	4.9

[a]Numerosity response

[b]Counting response

APPENDIX A. Continued

Presentation Time (msec.)	Subject 6		Subject 7		Subject 8		Subject 9		Subject 10	
	N	C	N	C	N	C	N	C	N	C
80	1.0	1.0	1.0	1.7	1.0	1.0	1.0	2.5	1.2	2.0
120	1.0	1.0	1.6	2.0	1.1	1.4	1.1	2.5	1.5	2.2
160	1.8	1.6	2.1	2.3	1.8	1.8	2.1	3.2	2.0	2.4
200	2.8	2.3	2.3	2.5	1.9	2.2	3.3	3.8	2.3	3.1
240	3.1	2.6	3.1	3.4	2.3	2.8	3.8	3.7	2.4	4.1
280	3.6	3.5	3.3	3.8	2.7	3.2	4.5	4.1	2.5	4.7
360	4.7	4.2	3.7	4.4	3.1	3.7	6.1	4.8	2.9	4.7
440	5.5	4.9	4.2	4.8	3.6	4.1	7.9	5.3	3.4	5.7
520	5.7	5.6	4.5	5.6	4.0	4.4	8.9	6.3	3.5	6.6
600	7.0	5.9	5.1	5.6	4.1	5.0	10.5	6.5	4.1	6.6

APPENDIX B

Mean Simultaneity Thresholds (cps.) for Each of 10 Subjects Under 3 Conditions

Subject #	Sim-2	Sim-4	Sim-8
1	6.31	4.31	4.27
2	8.79	5.17	5.53
3	6.98	6.12	5.63
4	7.71	5.06	5.91
5	6.45	4.96	4.59
6	9.07	4.66	4.74
7	11.29	9.68	8.66
8	12.13	6.02	5.69
9	9.71	12.67	9.54
10	7.86	5.12	6.59