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The discrimination of auditory and visual number

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THE DISCRIMINATION OF AUDITORY AND VISUAL NUMBER

by

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THE DISCRIMINATION OF AUDITORY AND VISUAL NUMBER[1]

SECTION ONE

INTRODUCTION

Situations often arise in which a person is asked to judge how many objects there are in a group of objects. There is the familiar case of the contest where the task is to judge the number of jellybeans in a large jar. If the beans could be taken out of the jar one by one, the exact number of beans could be determined by counting them. However, the rules of the contest prevent this, and therefore the number of beans in the jar must be estimated and an approximate answer given.

If everyone who entered the contest were allowed to count the jellybeans there would be little or no difference among the answers given. Counting determines the numerosity of the beans. Numerosity has been defined by Stevens[2] in the following manner:

> "....in order to specify the numerosity of any group we have merely to pair successively each object in the group with a numeral from the numeral-series. This operation we call counting."

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[1]The study was conducted under the guidance of Doctor Ira J. Hirsh at Central Institute for the Deaf.

[2]Stevens, S. S., On the problem of scales for the measurement of psychological magnitudes, J. Unified Sci., 9, 1936, p.95.

When an estimate rather than an exact count of the number of beans is required the answers of different contestants may be quite different and will depend on individual ability to judge the size of the beans and the capacity of the jar. Estimating determines the numerousness of the beans. Numerousness has been defined by Kaufman *et al.*[3] as

> "that property of a group of objects which we can discriminate, without counting, under instruction to judge how many objects the group contains."

Thus there are two different properties of the group of beans that can be determined when a person is asked to judge how many beans are in the jar. He can tell how many beans there are by counting them and determine the numerosity of the beans. Or he can estimate the number and give the numerousness of the beans.

In experimental studies on the discrimination of number subjects have often been asked to report the number of objects in a group of objects. Kaufman *et al.*[4] asked their subjects to judge the number of dots when groups of dots (alike in size but random in distribution) were exposed on a screen for 1/5 second. This exposure was too brief for subjects to count and they had to estimate the number of dots they had seen. They thereby determined the numerousness of the groups of dots. The results gave evidence for two

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[3]Kaufman, E. L., M. W. Lord, T. W. Reese, and J. Volkmann, The discrimination of visual number, Amer. J. Psychol., 62, 1949, p. 498.

[4]Kaufman *et al.*, Ibid, pp. 498-525.

different ways in which visual number is discriminated under conditions of simultaneous presentation. Discrimination of from one to six dots was faster, more accurate, and accompanied by more confidence than was the discrimination of more than six dots. Taves[5] had obtained similar results under similar experimental conditions and proposed that two different kinds of reports might exist, one kind for presented numbers of six and below and another kind for larger numbers. Kaufman _et al._[6] have proposed that the process of determining the numerousness of groups of visual stimuli with six or fewer stimuli be called _subitizing_ to differentiate this kind of report from estimates of larger groups.

In other experiments subjects have been asked to judge the number of stimuli in a group when flashes of light were presented successively either in the same place or in different places along the same horizontal plane. In one such study[7] some of the presentation rates were as fast as 50 flashes per second (fps). Cheatham and White[8] also used

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[5]Taves, E. H., Two mechanisms for the perception of visual numerousness, _Arch. Psychol._, 37, 1941, 1-47.

[6]Kaufman _et al._, _op. cit._, p. 520

[7]Psychophysical Research Summary Report 1946-1952. Psychophysical Research Unit, Mount Holyoke College. NAVEXOS P-1104, Technical report SPECDEVCEN 131-1-5, 1953, 96-104.

[8]Cheatham, P. G. and C. T. White, Temporal numerosity: I. Perceived number as a function of flash number and rate. _J. Exper. Psychol._, 44, 1952, 447-451.

flashes of light at fast rates (10, 15, 22.5, and 30 fps). In audition Garner[9] has worked with successive stimuli (series of 1000 cps tone pulses) at different rates including rates of 10 and 12 pulses per second (pps). When stimuli come successively at fast rates, either auditorily or visually, it is difficult to identify the individual stimuli of the group. A subject must estimate how many he sees or hears and when he does he is again reporting the numerousness of the stimulus group. This time, however, it is under conditions of successive presentation.

Slower presentation rates were used in the Mount Holyoke study on successive visual number[10] (as low as 2 fps) and by Garner[11] (the lowest was 4 pps). Also Taubman[12,13] used rates from 1.8 to 5.4 fps in a study on successive visual number and rates from 5.7 to 8.9 pps in a similar auditory study. At slow rates the stimuli are relatively far apart and there is time available to identify them one by one. Subjects are able to count and thereby to determine the

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[9] Garner, W. R., The accuracy of counting repeated short tones, J. Exper. Psychol., 41, 1951, 310-316.

[10] Psychophysical Research Summary Report, op. cit., p. 100.

[11] Garner, op. cit., p. 310.

[12] Taubman, R. E., Studies in judged number: I. The judgment of auditory number, J. Gen. Psychol., 43, 1950, 167-194.

[13] Taubman, R. E., Studies in judged number: II. The judgment of visual number, J. Gen. Psychol., 43, 1950, 195-219.

numerosity of successive stimuli. A report of numerosity is also obtained when a group of stimuli are presented simultaneously and exposed for a long enough time for subjects to count the number in the group. Subjects can be instructed for accuracy to assure that they will count.

When the stimuli are presented successively the rates at which subjects will give accurate reports of numerosity depend on the limiting interval between two stimuli. This interval (A) must be shared by the stimulus reaction time (B) and the time necessary to emit the verbal response (C). The maximum presentation rate at which counting will occur accurately is that rate at which A=B + C. At higher rates errors will occur.

This discussion has been an attempt to differentiate numerousness and numerosity. The former is determined by the process of estimating, the latter is determined by the process of counting. Examples of these two processes have been taken from experiments on both auditory and visual discrimination of number. There is lacking in the literature on the discrimination of number, however, any direct comparisons of auditory and visual numerosity and auditory and visual numerousness.

SECTION TWO

STATEMENT OF THE PROBLEM

No experiment has compared directly the discrimination of auditory and visual number. Taubman in his experiments with successive stimuli[14,15] used the same group of subjects for his visual and his auditory measurements, but none of the rates of presentation in the two studies overlapped.

Taubman's results show that subjects give reports of the numerosity of a group of successive stimuli at low rates of presentation in both vision and audition (subjects will count). But counting of visual stimuli breaks down at a lower rate than counting of auditory stimuli. Subjects were making less than 50% correct responses for visual series containing more than three flashes at a stimulus rate of 5.46 fps. In contrast all subjects were making 100% correct responses for all auditory stimulus series at a presentation rate of 5.7 pps. Garner's auditory data[16] and the visual data from Mount Holyoke[17] agree well with Taubman's data.

This experiment was designed to compare directly the discrimination of successive visual number and successive auditory number using the same stimulus durations and presentation rates for both kinds of stimuli.

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[14] Taubman, R. E., Studies in judged number: I. The judgment of auditory number, J. Gen. Psychol., 43, 1950, p.174.

[15] Taubman, R. E., Studies in judged number: II. The judgment of visual number, J. Gen. Psychol., 43, 1950, p. 196.

[16] Garner, op. cit., p.311.

[17] Psychophysical Research Summary Report, op. cit., p.101.

SECTION THREE

EXPERIMENTAL CONDITIONS

__Stimuli__. Square electrical pulses from a Tektronix pulse generator activated both the auditory and visual circuits (see Figure 1). The duration of the electrical pulse was held constant at one millisecond and the interval between pulses was varied to change the rate at which the pulses were presented.

The number of pulses in a series was controlled by a binary counter-relay circuit. The counter registered up to 128 counts by a system of neon lights and recorded multiples of 128 counts on a mechanical counter controlled by relay 2. In the resting position relay 2 was closed, relay 1 was open, and switch 1 was open. To put a predetermined series of pulses through the circuit switch 1 was momentarily closed which let enough current through the circuit from the 6 volt battery to close relay 1. With relays 1 and 2 closed the circuit from the generator to the transducer was complete and pulses went through the circuit and were recorded by the counter. The counter was first set to let only the desired number of pulses through. The lights of the counter were lit so that the count they registered plus the number of pulses in the desired series totalled 128. When switch 1 was closed the counter would continue recording counts from the point at which it was set until the last pulse in the series (by this method always the 128th count) opened relay 2 and

BLOCK DIAGRAM OF APPARATUS

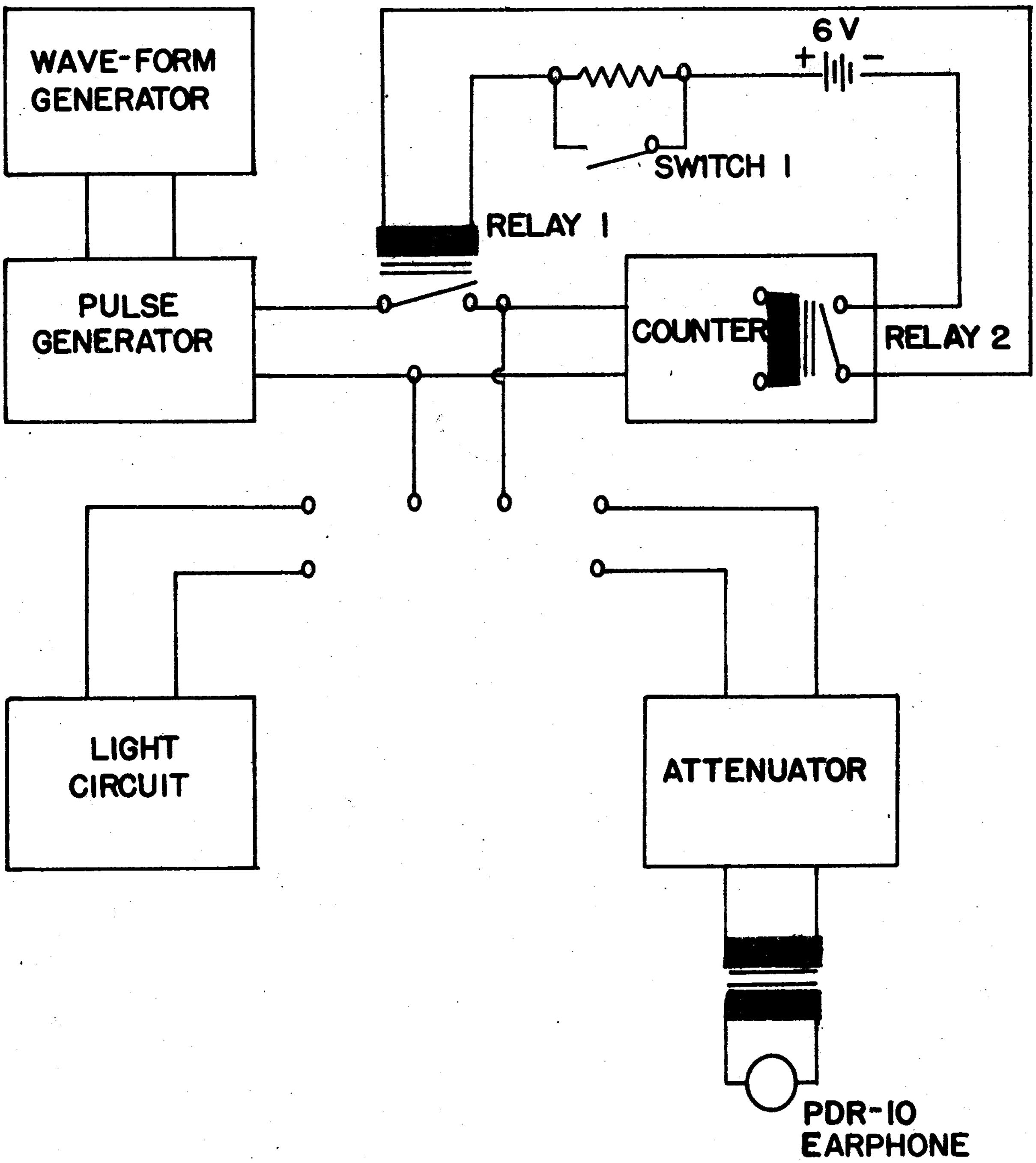
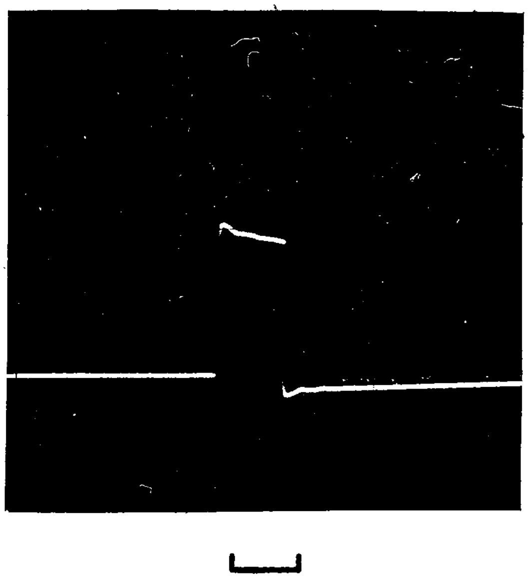


Figure 1

the pulses were stopped.

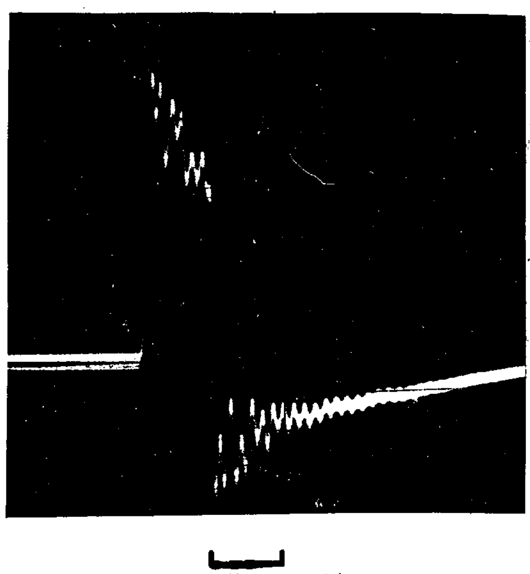
The peak voltage of the pulse from the generator was 40 volts. In the auditory transducer circuit the pulses were led first to an attenuator and then to an impedance-matching transformer before reaching the PDR-10 earphone. Pulses were delivered to the subject monaurally. The shape of the electrical pulse as it reached the earphone is seen in Figure 2. The actual peak voltage delivered to the earphone was 0.13 volts corresponding to a peak pressure of 110.7 db re 0.0002 microbar delivered at the entrance to the ear canal. The shape of the acoustic pulse, which remained the same for all presentation rates, is shown in Figure 3. The acoustic pulse retains the essential square characteristics of the electrical pulse. In addition the earphone responds at a resonant frequency after the on and the off parts of the pulse causing the oscillatory effects seen in Figure 3.

To produce the flashes of light the electrical signal from the pulse generator was fed to the light circuit diagrammed in Figure 4. The light output of the R1131C (a Sylvania glow modulator tube) was recorded by a photoelectric cell and is shown in Figure 5. The square characteristics of the pulse are lost in the light output. However, the light flash maintains the same shape at all repetition rates and the light output also drops to zero between pulses at all repetition rates (see Figure 6).



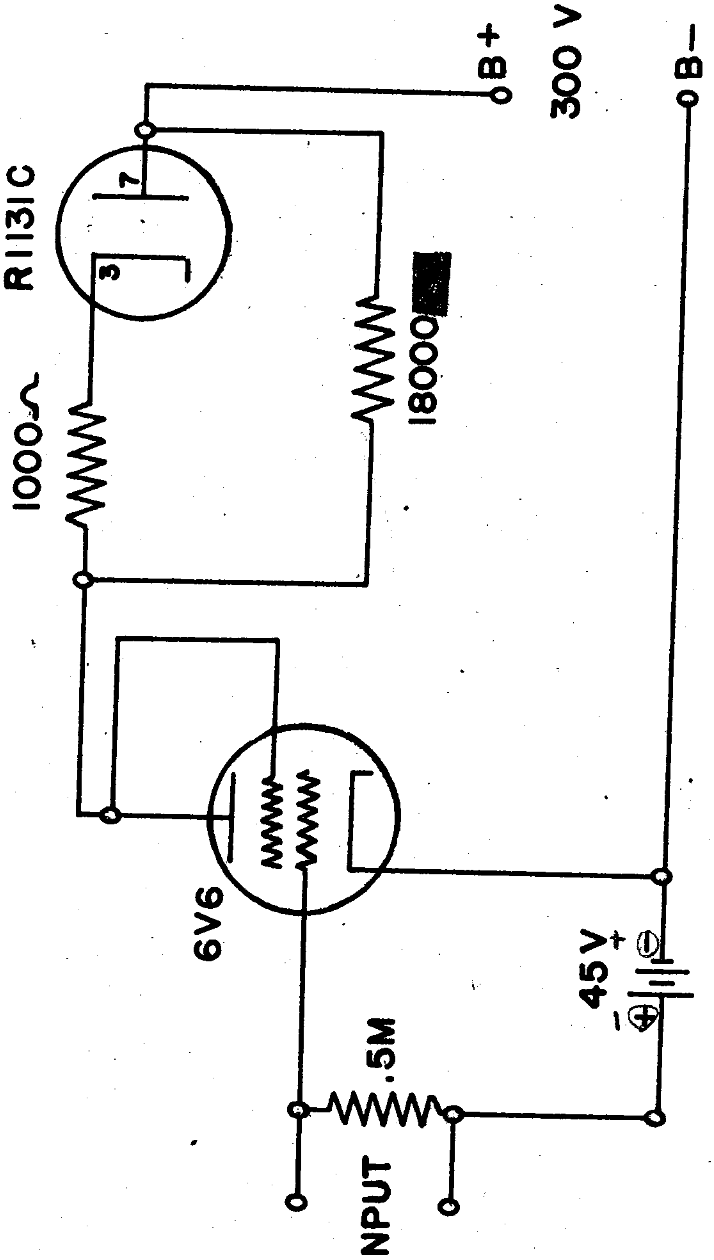
1.0 MSEC.

Figure 2. Shape of the electrical pulse fed to the earphone.



1.0 MSEC.

Figure 3. Acoustic pulse from the earphone (see discussion in text)



LIGHT CIRCUIT

Figure 4

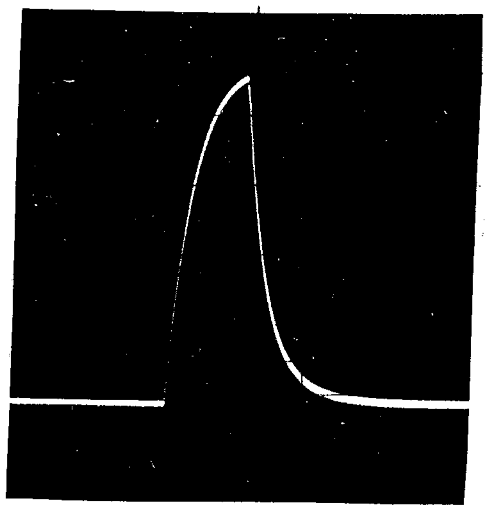


Figure 5. Light output from the R1131C(Sylvania Glow Modulator Tube) for a square electrical pulse input as recorded by a photoelectric cell.

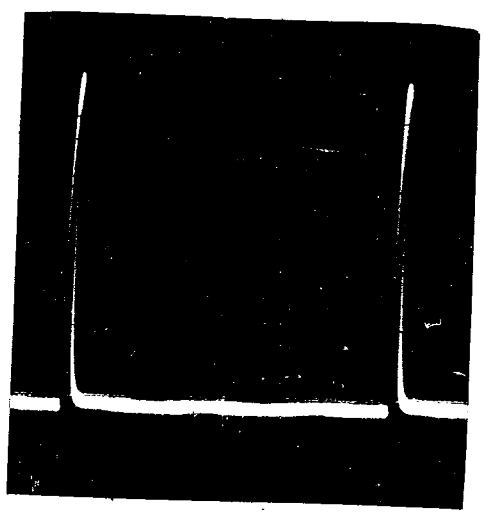


Figure 6. Successive light flashes from the R1131C as recorded by a photoelectric cell to show that the light output dropped to zero between flashes.

The light flashes were presented at eye level through a hole 5/8 inch in diameter drilled in a large piece of plywood. The hole was covered with a piece of sanded plexiglass to diffuse the light evenly. Indirect, low level room lighting was obtained by reflecting the light of a 100 watt incandescent bulb from the ceiling of the room. The plywood surface facing the subject was painted a medium grey and the circle of the light flash was actually centered in the middle of a three inch square piece of white cardboard.

The subject sat ten feet away and viewed the light binocularly. The brightness of the light at the position of the subject was 3.8 apparent foot candles as measured by a MacBeth illuminometer. At a three foot distance the brightness of the light was 6.5 apparent foot candles, of the white square was 2.7 foot candles, and of the grey background was .98 foot candles.

<u>Subjects</u>. Subjects were five young adults of the Institute staff, four males and one female. Three had had experience as subjects in psycho-acoustic experiments but none had ever served in an experiment on the discrimination of successive number.

<u>Procedure</u>. Auditory and visual stimuli were presented at seven different rates, 4.0, 5.0, 6.25, 7.69, 10.0, 12.5, and 15.87 pulses per second. Series varying in length from 2 to 32 stimuli were used at each of the seven rates. A preliminary study had shown that accuracy was 100 per cent at rates lower than 4.0 pps and for any series which

contained only one pulse. The series increased by ones from 2 to 20, then by twos from 20 to 28, and the longest series contained 32 pulses. All series and all rates were randomized, each series at each rate appearing three times in the experimental program.

Subjects came for six one-hour sessions, all occurring within a period of two weeks. At each session both auditory and visual stimulus series were given. If a subject was given the auditory stimuli first at the first session then he was given the visual stimuli first at the second session, and so on. Different randomizations were used for each subject.

A rest period was given between the two different kinds of stimulus series. An auditory warning signal was used to signal the presentation of a visual series while a red light signaled the presentation of an auditory series.

Instructions. Subjects were simply asked to report how many auditory pulses or flashes of light there were in each series presented to them. No instructions were given as to grouping of counts or as to the top number of stimuli in the experiment. They were told that some series would be very short and others much longer; that some series would be slow enough to count easily, and others would come so fast they could not be counted.

SECTION FOUR

RESULTS

Reported number has been plotted as a function of presented number for each presentation rate (see Figures 7 to 13). Auditory and visual results for a given rate have been presented together to compare the two kinds of responses. Each point is a mean of 15 responses, five subjects giving three responses each. The solid line with a slope of 1 indicates where all the points would fall if subjects were accurate all of the time.

Figure 7 shows the results for the slowest rate. At this rate subjects give very accurate auditory reports for all stimulus series. Visual reports are not quite so accurate. Series of two or three flashes are reported without error but reports for longer series are in error by one or two counts. Error increases as the length of the series increases.

Figure 8 shows results when the rate is increased to 5 pps. Auditory reports are still very accurate, but occasional errors by some subjects give some means slightly less than the presented number. At a rate of 5 fps visual accuracy is definitely impaired. Subjects report two and three flash series accurately, miss one or two flashes for other series up to ten, and miss as many as five or six in the longer series.

At stimulus rates of 6.25, 7.69, and 10.0 pps auditory

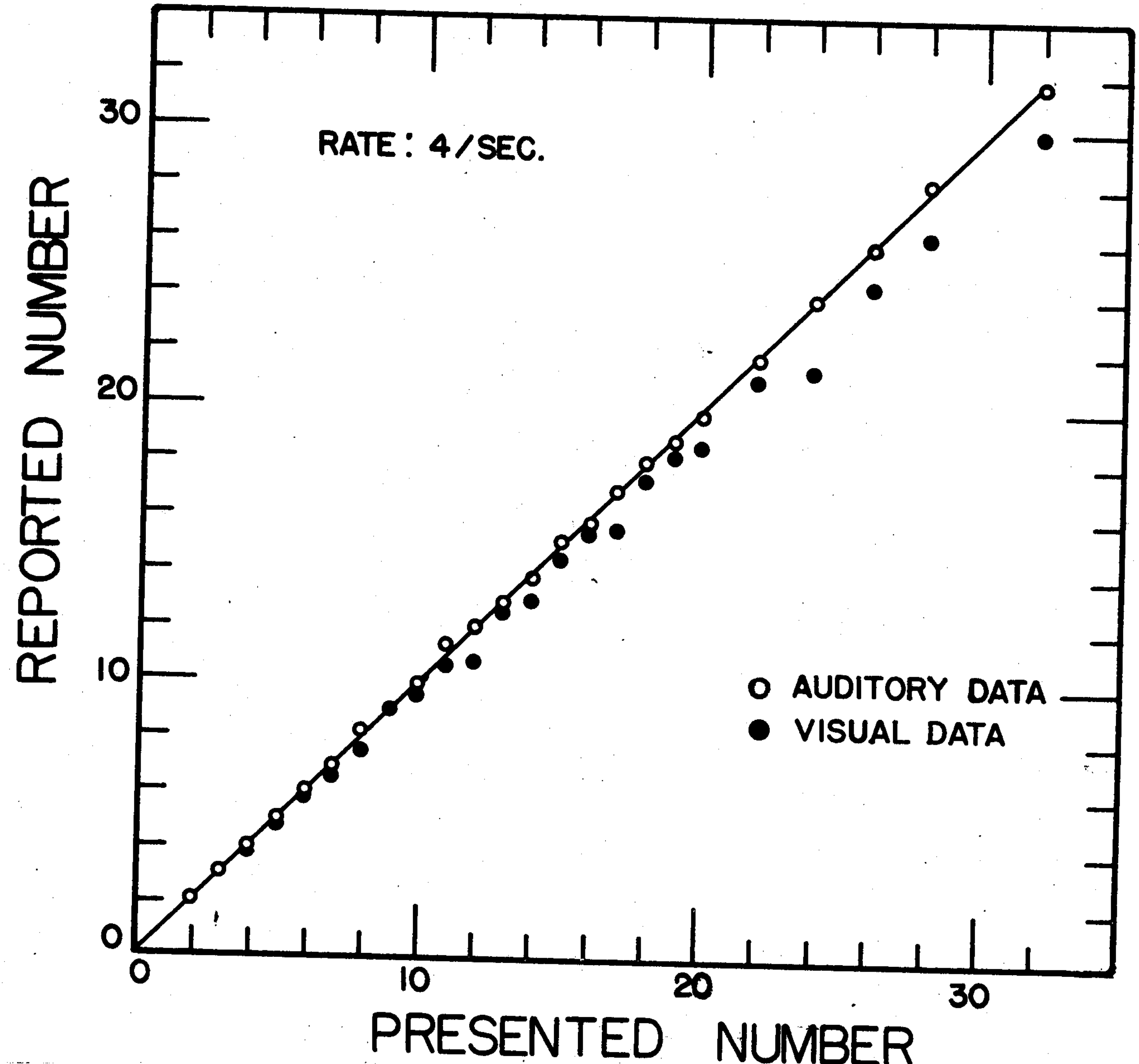


Figure 7. MEAN NUMBER REPORTED AS A FUNCTION OF NUMBER OF DOTS PRESENTED Auditory and visual series presented at a rate of 4 pps; results for five subjects

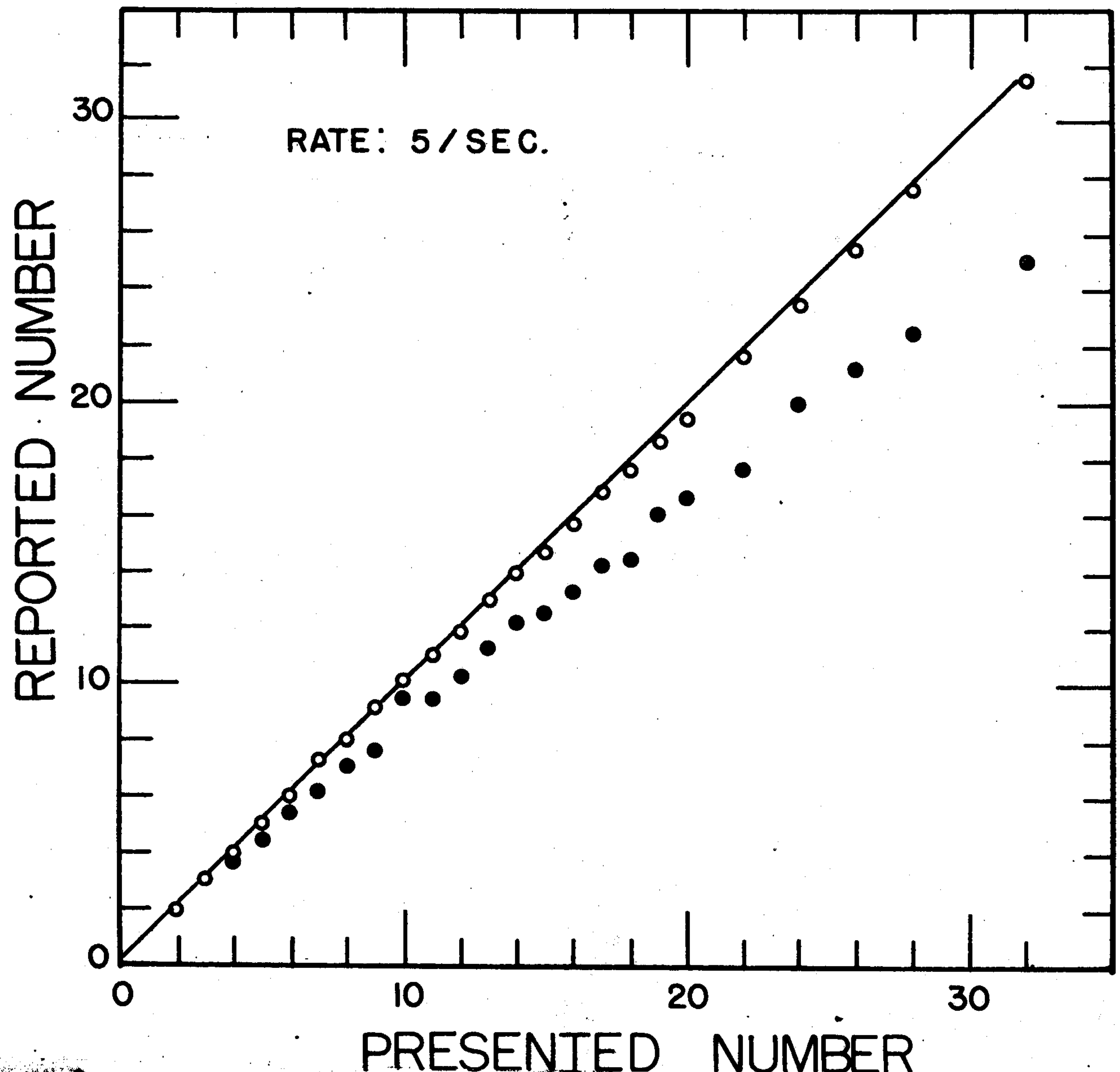


Figure 8. MEAN NUMBER REPORTED AS A FUNCTION OF [illegible] OF DOTS PRESENTED [illegible] auditory and visual series presented at a rate of 5 pps; [illegible] for five subjects. Use same symbol key as for [illegible]

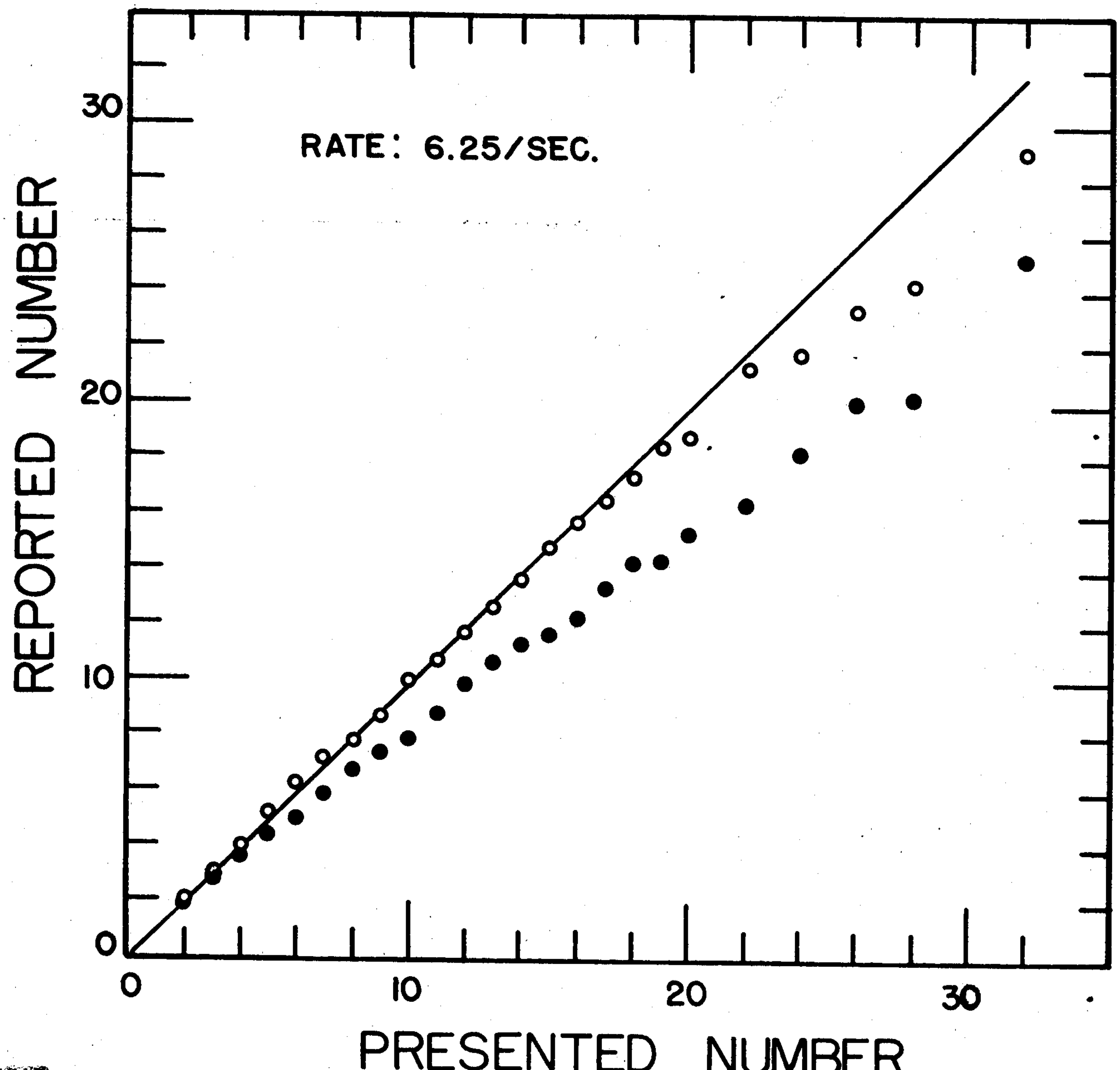


Figure 9. MEAN NUMBER REPORTED AS A FUNCTION OF NUMBER OF DOTS PRESENTED Auditory and visual series presented at a rate of 6.25 pps; results for five subjects. Use same symbol key as for Figure 7.

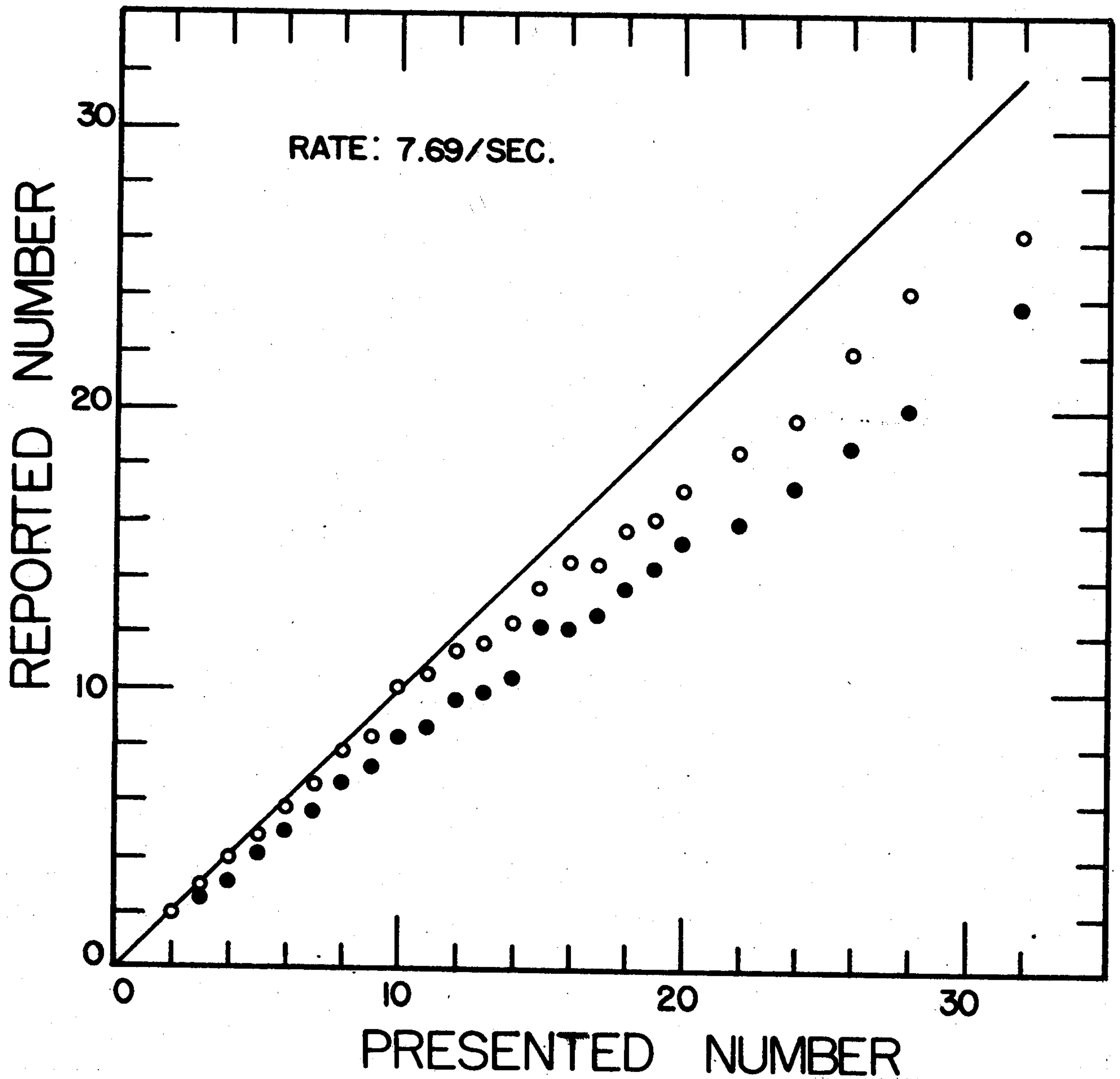


Figure 10. MEAN NUMBER REPORTED AS A FUNCTION OF NUMBER OF DOTS PRESENTED Auditory and visual series presented at a rate of 7.69 pps; results for five subjects. Use same symbol key as for Figure 7.

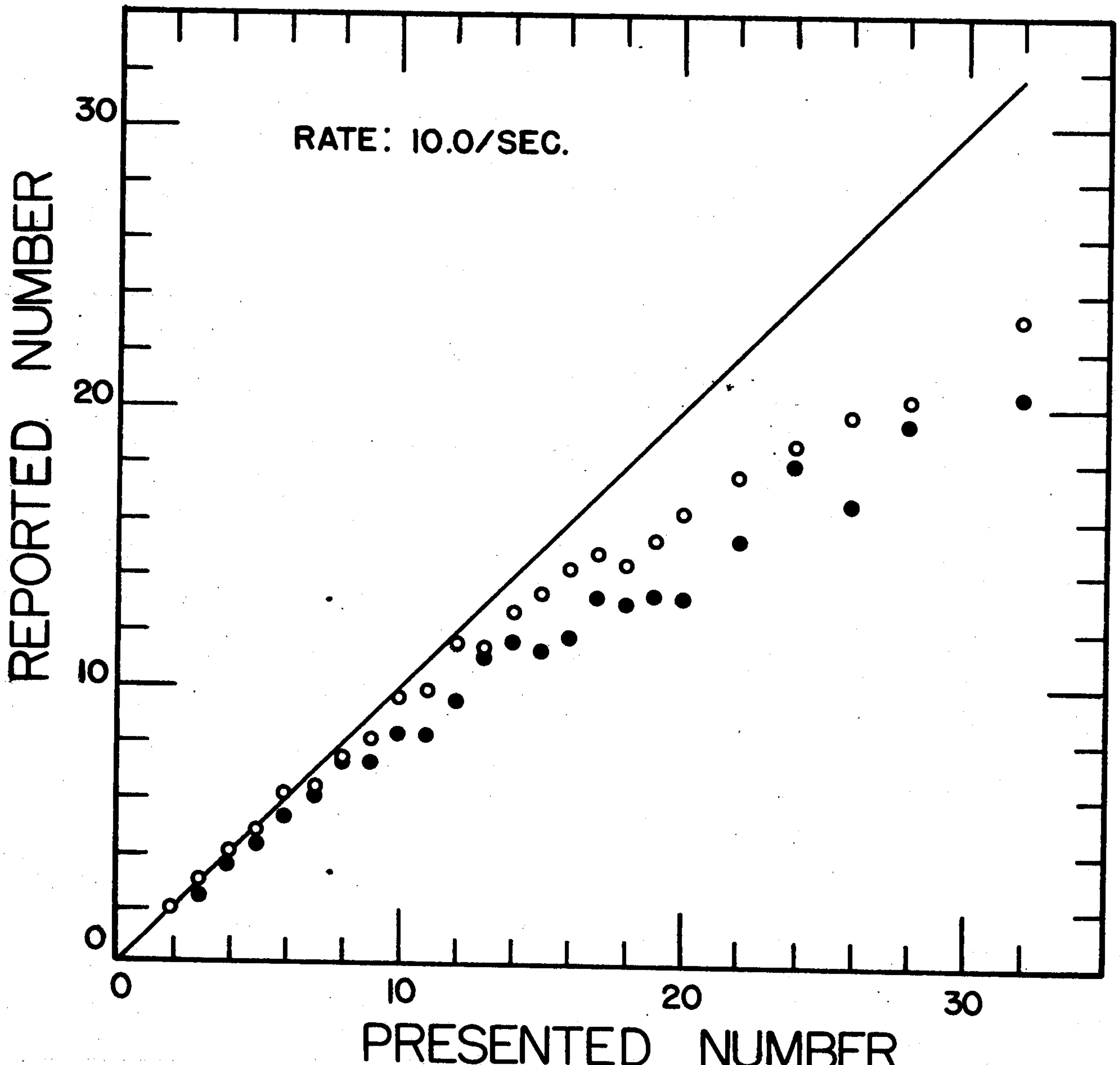


Figure 11. MEAN NUMBER REPORTED AS A FUNCTION OF NUMBER OF DOTS PRESENTED Auditory and visual series presented at a rate of 10 pps; results for five subjects. Use same symbol key as for Figure 7.

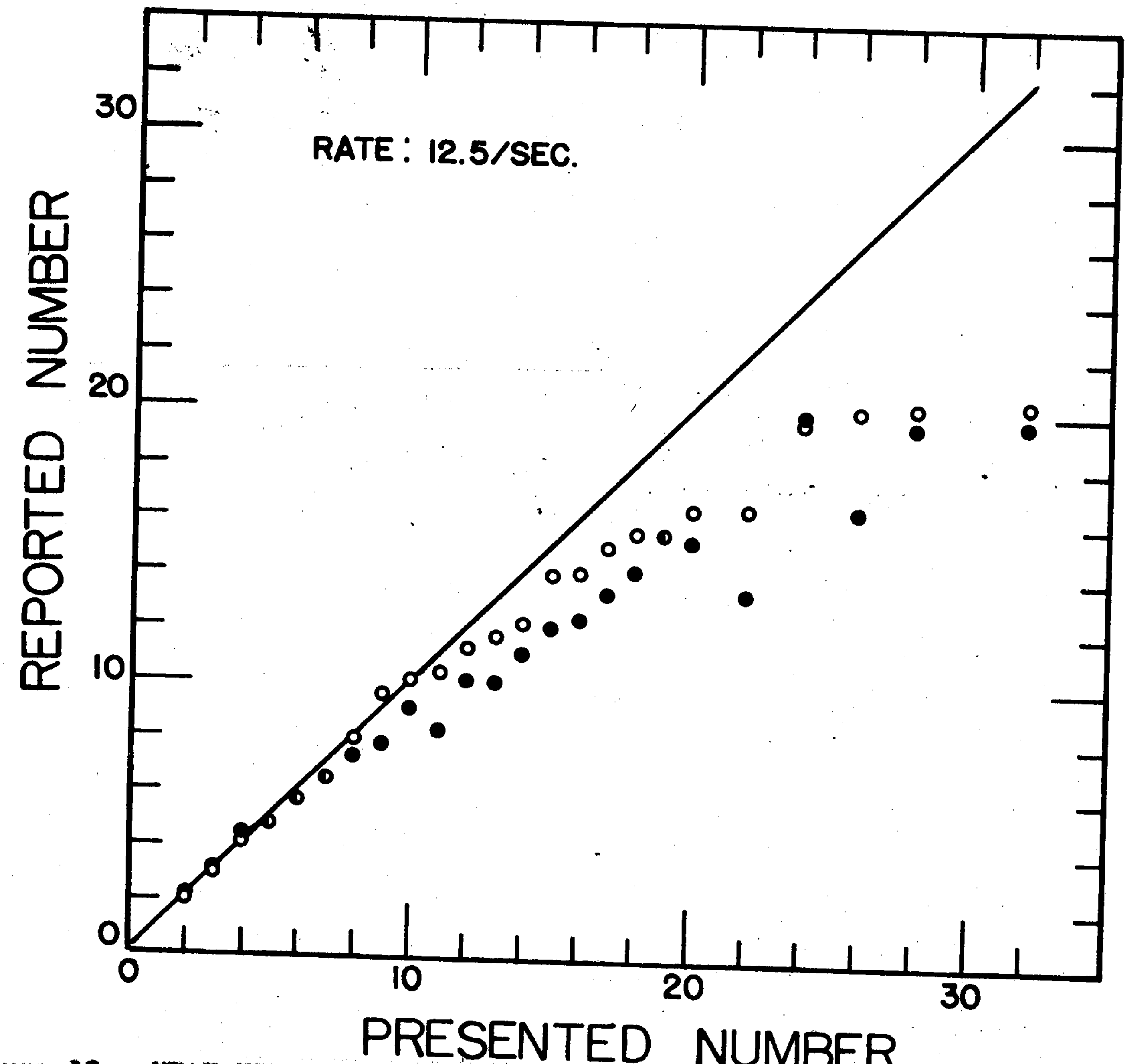


Figure 12. MEAN NUMBER REPORTED AS A FUNCTION OF NUMBER OF DOTS PRESENTED Auditory and visual series presented at a rate of 12.5 pps; results for five subjects. Use same symbol key as for Figure 7.

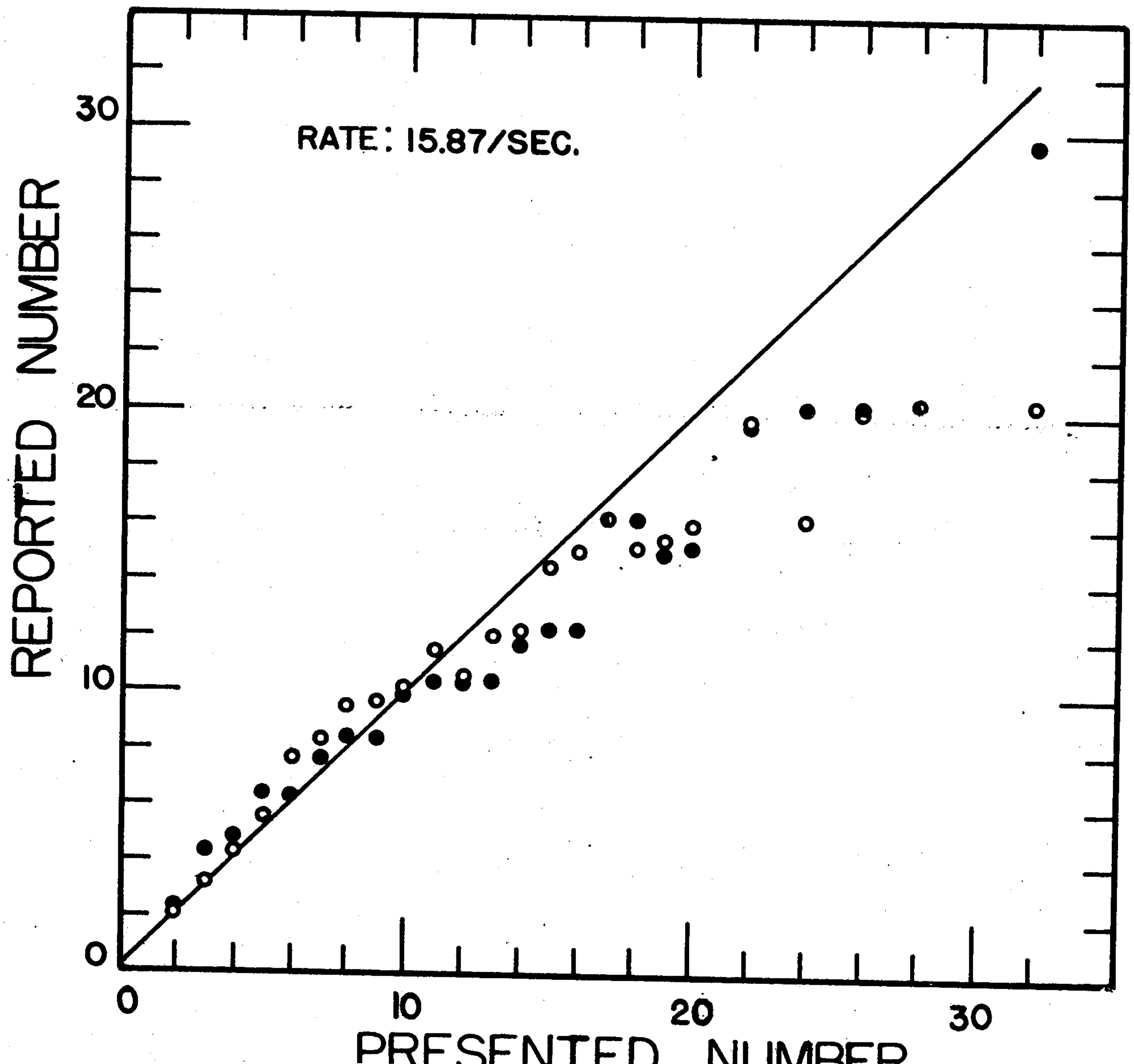


Figure 13. MEAN NUMBER REPORTED AS A FUNCTION OF NUMBER OF DOTS PRESENTED Auditory and visual series presented at a rate of 15.87 pps; results for five subjects. Use same symbol key as for Figure 7.

accuracy is still good for series containing less than ten stimuli, but again there is increased error as the length of the stimulus series is increased and as the rate of presentation is increased. Visual reports at all three of these rates are in greater error than are the auditory reports although they are, like the auditory reports, more accurate for series below ten. The effect on visual reports of increasing the stimulus rate is not as striking as it is for the auditory reports. Error increases slightly, but very similar reports are given at all three rates when the series are presented visually.

For rates below 10.0 pps the auditory and visual report functions are essentially linear below a presented number of ten and linear but with a different slope, for presented numbers above ten. At 10.0 pps both functions lose their linear characteristics above ten and become step-shaped. The change is clearest in the visual function. Step-shaped functions for both kinds of reports are found at the two highest rates, 12.5 and 15.87 pps. At these high rates changing the rate does not change in any consistent manner the relation between reported number and presented number for series containing more than ten stimuli.

Accuracy for series below ten continues to be good as it was at lower rates. Visual accuracy has even improved slightly. At 15.87 pps the shorter series, both auditory and visual, are reported as containing more stimuli than they actually do.

Although no measures of variability have been calculated for the present data--they are inadequate for such measures as calculated by Garner[18]--it is evident that the five subjects differ as much from each other both visually and auditorily as Garner's calcuations would predict. For series and rates where accuracy is high variability is low. Individual reports of number are within ± 1.0 of the mean. Where accuracy has decreased there is a rise in both the inter- and intra-subject variability. At rates of 12.5 and 15.87 pps two subjects overestimate and the other three still underestimate with the exception of the short series at 15.87 pps where all subjects overestimate.

The range of reports increases as the length of the series and/or the rate is increased. At 10.0 pps for an auditory stimulus series of 15 the range extends from a reported number of 8 to one of 17 with a mean of 13.2. For a corresponding visual series the range of reports is 6 to 16 and the mean is 11.3. At 15.87 pps an auditory series of 15 has a mean of 14.7 and a range from 8 to 26; a visual series has a mean of 12.3 and a range from 7 to 25. For longer series at these rates the range is larger. At 10.0 pps an auditory series of 26 stimuli has a mean of 19.9 and the range is 15 to 26. At 15.87 pps a series of 26 has a mean of 20.0 and the range is 12 to 45.

There is a correlation between accuracy and the way a

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[18] Garner, op. cit., pp. 313-315.

subject said he evaluated the number of stimuli in a series. Those subjects who grouped the stimuli by threes, fours, or fives at rates where they could not count were less accurate than those who tried to give only one evaluation of the number of stimuli presented. The attempt to group superimposed upon the series caused a greater loss of information than the process of not grouping.

In summary, the accuracy of reporting either auditory or visual successive number is a function of both the presentation rate and the number in the stimulus series. Increasing either the rate or the length of the series decreases the accuracy of both auditory and visual reports. In general the auditory sense is a better discriminator of successive number than the visual sense. All auditory reports are more accurate than corresponding visual reports at low rates of stimulus presentation. At all presentation rates for series containing ten or fewer stimuli auditory accuracy is slightly better than visual accuracy. However, at faster rates for longer stimulus series there is little difference in the two kinds of reports.

When errors are made in the discrimination of successive number they are made in the same direction; series not reported accurately are reported as having fewer stimuli than they actually do--with one exception. At the fastest rate both auditory and visual series which contain less than ten stimuli are reported as containing more stimuli than there actually are in the presented series.

SECTION FIVE

DISCUSSION

Like other published data[19,20,21,22] these data show that the accuracy of discrimination of both visual and auditory successive number is a function of the length of the stimulus series and the rate of presentation. Mean responses obtained by others and the responses obtained in this study differ very little for comparable series and rates.

It is interesting to look at the present data in terms of the discussion of numerosity and numerousness given in Section One.

The numerosity of a stimulus group is determined by the process of counting. An accurate determination of numerosity requires that every stimulus, in this case every light flash or auditory pulse, be paired with a numeral. Figures 7 through 13 show that accurate determinations of numerosity can be made at faster rates and for longer series when the stimuli are auditory than when they are visual. It is only for series of two or three at rates of 4 or 5 fps that the means for reported visual number correspond to the presented

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[19] Psychophysical Research Summary Report, op. cit., p.101.

[20] Garner, op. cit., pp.311-312.

[21] Taubman, R. E., Studies in judged number:I. The judgment of auditory number, J. Gen. Psychol., 43, 1950, pp.181-183.

[22] Taubman, R. E., Studies in judged number:II. The judgment of visual number, J. Gen. Psychol., 43, 1950, pp.200-206.

number. Many individual visual reports for faster rates and longer series are still accurate, but errors are made and are reflected in the mean score.

Subjects count after they cease to give accurate reports of numerosity. However, if subjects are counting at a constant rate, the relation between reported number and elapsed time of a series should be linear no matter whether the subject is accurate or in error in his final report (see Figures 14 and 15).

In Figures 14 and 15 reported number is plotted as a function of time in milliseconds. The first point on each function is the mean reported number for a series containing two stimuli, such a series occurring in a shorter elapsed time as the stimulus presentation rate is increased. The next point is for a series of three stimuli, and so on. Linear functions are obtained for rates up to and including 7.69 pps when the stimuli are auditory (Figure 14) although reports for the longer series do not fit the function at 7.69 pps. For longer series the counting rate is probably not held constant. Visual functions become non-linear at 7.69 fps (Figure 15). Apparently subjects will count auditory series at slightly higher rates than they will visual series.

It has been pointed out in Section One that subjects estimate when they are unable to count. This kind of report determines the numerousness of a group of stimuli. Subjects are probably estimating both auditory and visual series at

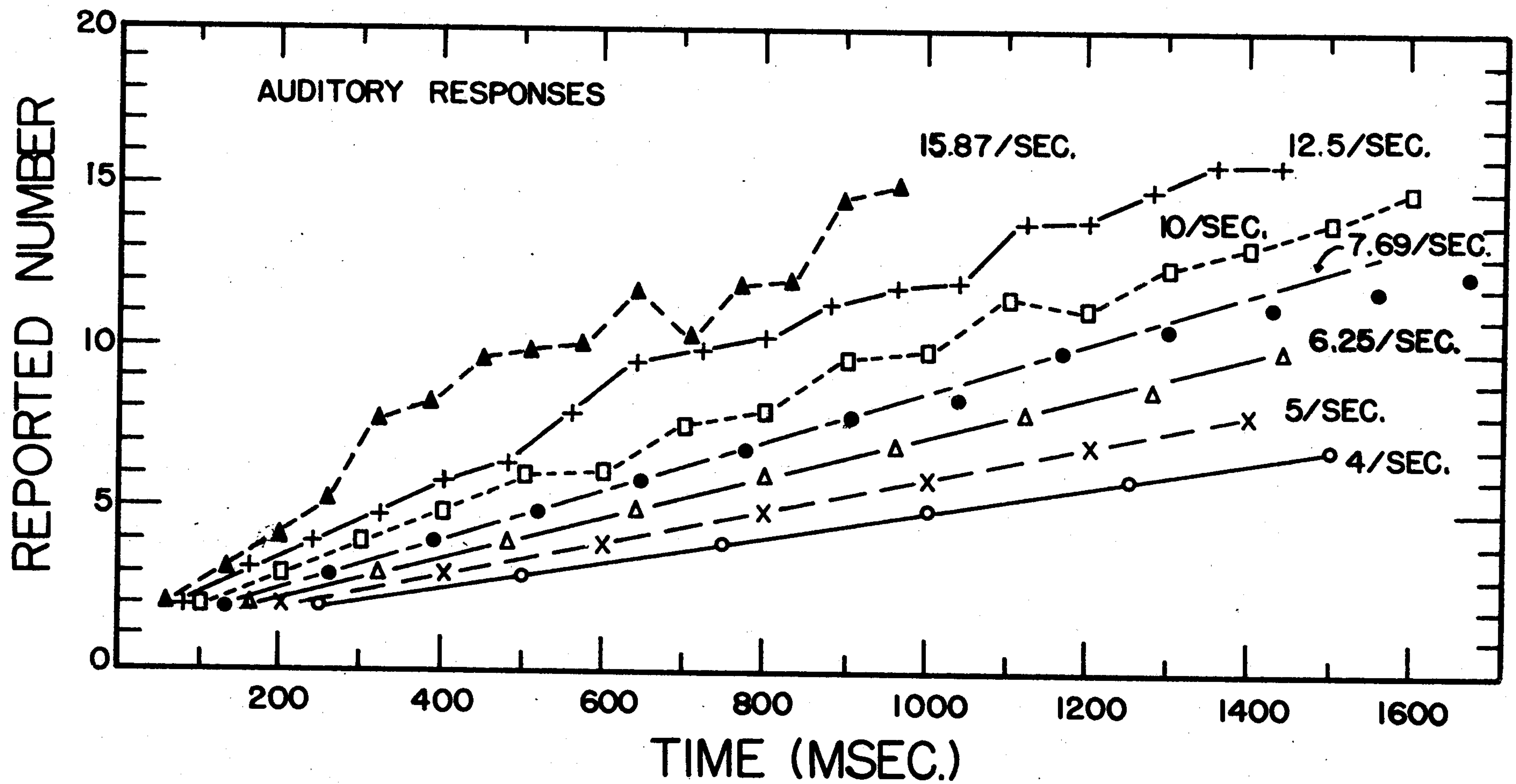

Figure 14. MEAN NUMBER REPORTED AS A FUNCTION OF ELAPSED SERIES TIME IN MILLISECONDS. Auditory series presented at several rates; results for five subjects.

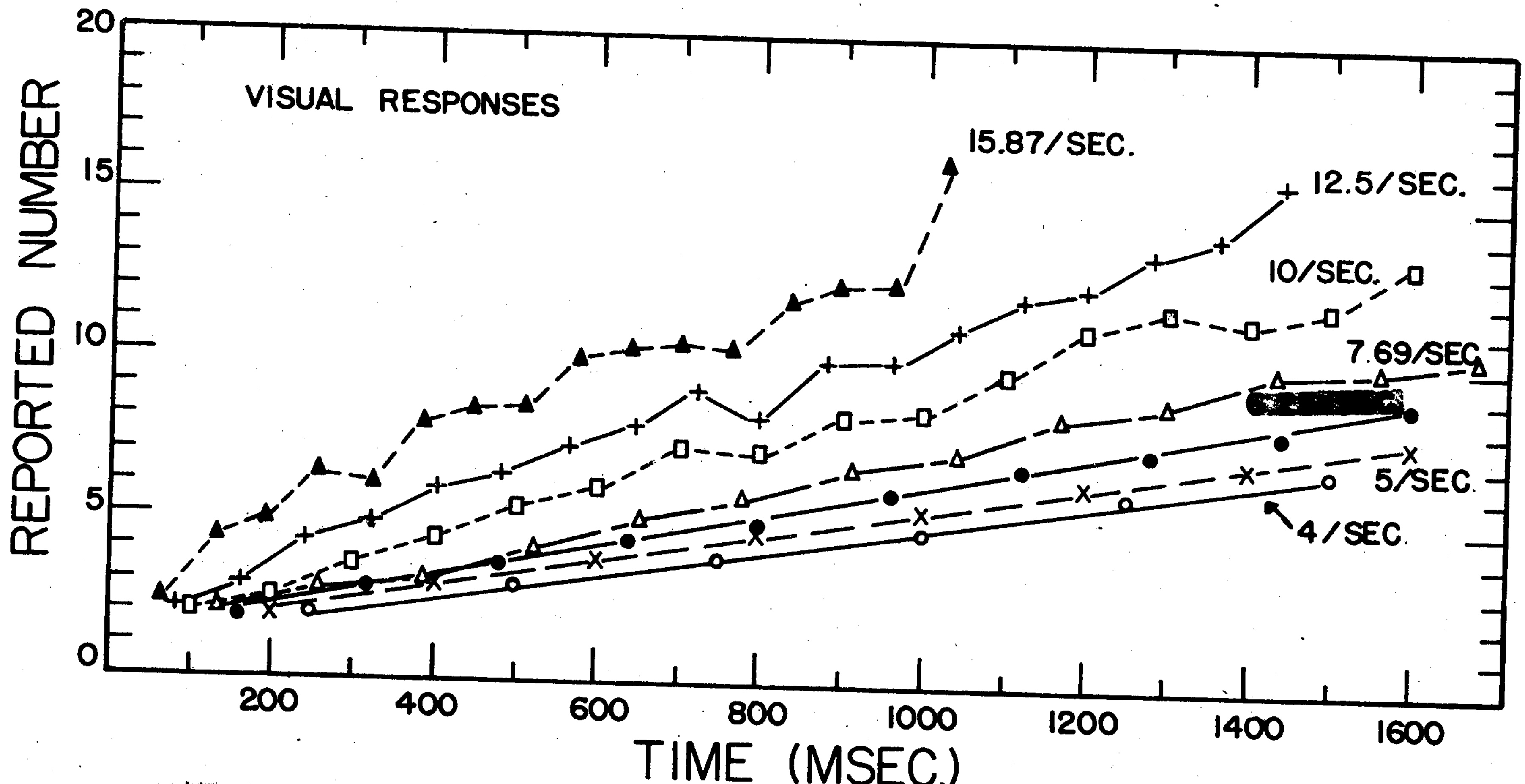

Figure 15. MEAN NUMBER REPORTED AS A FUNCTION OF ELAPSED SERIES TIME IN MILLISECONDS. Visual series presented at several rates; results for five subjects

rates of 12.5 and 15.87 pps. The step functions obtained at these rates indicate at least that something different from counting is taking place. The step characteristics of these functions become clearer in Figures 14 and 15 where reported number is plotted as a function of time in milliseconds. Differences of one stimulus between series which can be reported when subjects can count are not discriminated at these higher presentation rates. Series differing in time by as much as 150 milliseconds and by as many as four stimuli are in the same report category.

A series of successive stimuli presented at a fast rate has two main characteristics by which an estimate of number can be made. First there is a specific elapsed time from the beginning of the first stimulus to the end of the last one. Second, this time is "filled" with stimuli which cannot be separated from each other but which have flutter or flicker characteristics as the stimuli go off and on. Two series of varying length can then be differentiated by differences in elapsed time and/or differences in the amount of flicker or flutter. Time and flutter cues are undoubtedly used at 12.5 and 15.87 pps in estimating the number of stimuli in the group.

The visual data of Cheatham and White[23] and auditory

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[23] Cheatham and White, _op_. _cit_., p.449.

data of theirs to be published[24] indicate that the presentation rate of successive stimuli can be so fast that estimates are made on the basis of elapsed time alone. They have data obtained at several rates above 15.0 pps (their highest was 30.0 pps) that have the same slope and almost the same intercept, regardless of rate, when reported number is plotted as a function of time.

The better accuracy obtained for the discrimination of series of ten or less stimuli is easy to explain at rates where subjects are counting. Probably an optimum counting rate is maintained for ten or so stimuli. Then the counting rate changes to a slower but still constant rate which maintains the linearity of the response curve but flattens its slope. The slower counting rate would necessarily mean more cumulated errors. The elapsed time of series below ten is very short at rates where subjects estimate. The effect may be almost one of simultaneity of presentation. At least it is interesting to note that high accuracy for up to five dots, overestimation from five to ten dots, and underestimation of larger groups was found by Kaufman _et al._[25] in their experiments with simultaneous visual number.

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[24] Cheatham, P. G. and C. T. White, Temporal numerosity: III. Auditory perception of number (to be published)

[25] Kaufman _et al._, _op. cit._, pp.507-508.

SECTION SIX

CONCLUSIONS

A comparison of the discrimination of successive auditory and visual number at several presentation rates and for stimulus series of varying length has been made. An attempt has been made to show the kinds of response differences obtained when subjects count (at slow rates) and when they estimate (at fast rates).

The accuracy of the discrimination of successive number decreases as the presentation rate is increased and the number in a series is increased. In general the auditory discrimination of successive number is more accurate than the corresponding visual discrimination. However, at rates where subjects estimate both auditory and visual series the two kinds of reports are very similar.

Subjects attempt to count auditory stimuli at faster rates and for longer series than they do visual stimuli. When subjects start to estimate they use discrimination of elapsed series time and/or the amount of flicker or flutter to determine the number of stimuli in a series of successive stimuli.

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