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INDIVIDUAL DIFFERENCES IN ANGULAR ESTIMATION AS A FUNCTION OF METHOD OF STIMULUS PRESENTATION AND MODE OF RESPONSE

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-64-95

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E. A. Garvin

Prepared for

DIRECTORATE OF COMPUTERS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

Project 704.0

Prepared by

THE MITRE CORPORATION
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ABSTRACT

Four studies of factors influencing accuracy as well as magnitude and direction of constant bias in angular estimation are reported. The parameters investigated were: method of presenting stimuli and mode of subject's response. Ambiguities in the results of previous similar investigations are discussed, and previous results compared with those obtained in the present study.

It was found that subjects could be classified as either high- or low-accuracy in angular estimation. The high-accuracy group showed no difference in level of accuracy in the four experiments, maintaining approximately 80% accuracy of judgment regardless of mode of response or method of presentation. The low-accuracy group was more accurate when there was a reference standard and when the response mode was manual adjustment rather than verbal. The low-accuracy group just reached the 75% accuracy level, using the knob (manual-adjustment) mode of response, and was much below this level using other methods.

No significant constant bias was found in the high-accuracy group for any of the four experimental methods. In the low-accuracy group, significant underestimations and variability of judgment were noted. The low-accuracy group had the least constant error when using a manual-adjustment (knob) mode of response with reference standard.

A control is described that is necessary for accurate determination of direction of constant bias in experiments involving three-dimensional stimuli for angular estimation. Criteria for identification of characteristically high-accuracy subjects are given. Methods for obtaining highly accurate angular estimations for an unselected population are recommended.

REVIEW AND APPROVAL

This technical documentary report has been reviewed and is approved.

SEYMOUR JEFFERY
Major, USAF
Project Officer

CONTENTS

INTRODUCTION

It is difficult to determine from the literature reporting studies into angular estimation what conditions of observation and presentation of angles to the human operator encourages the highest accuracy in judging and reporting angles. Jones, in a review of the literature (1962),[1] found "perennial incongruities in terminologies, data measures, and methodologies." Integration of the results of previous studies is difficult because the experimenters used a variety of methods of presenting the angulations, modes of subject response, subject populations, criteria of accuracy and other variables of possible importance.

The methods of presentation have involved the use of radarscopes,[2] viewing screens or cards,[3] a stereoscope,[4] and photographs.[5] The conditions of presentation of the stimulus have included a standard stimulus[6] and sometimes not,[7] various distances between the standard and the comparison stimulus,[8] variation in size of stimulus,[9] and stimulus presented horizontally[10] or vertically.[11] The stimulus for angular position estimation has usually consisted of straight lines, broken or unbroken[3] geometric forms,[6] or random shapes.[12] The mode of the subject's response has been verbal estimate,[3] written estimate,[13] manual adjustment,[14] or push button.[3]

Individual subject differences within an experiment have been reported on many occasions. Smith[3] found that the two populations in his study were different in level of accuracy of their judgments, and that method of presentation influenced accuracy level. Lichte[11] concluded that the large individual differences found in his experiment "may have been related to uncontrolled differences in attitudes." Other factors that have been mentioned to account for individual differences in accuracy of judgment are: practice effects, shifts in apparent orientation, and differences in sensory efficiency.

The present study attempts to reconcile some of these diverse results, selecting for investigation two important parameters that appear to influence the accuracy of reporting and the response bias of subjects' judgments. These parameters are: the method by which the stimulus is presented, and the mode of the subject's response.

The two most prevalent methods of presenting the stimulus have been used, namely, straight lines presented on cards, and three-dimensional rectangular targets. Straight-line stimuli were presented both with and without a reference standard. The three-dimensional stimulus was presented with response by manual adjustment, and was also contrasted with a straight-line, two-dimensional stimulus with response by manual adjustment. With the manual-adjustment mode, a reference standard was presented.

The two most-used modes of subject response, verbal report and manual adjustment, also have been chosen to be varied. To control ambiguity resulting from subject differences, which have, in past studies, made interpretation of results inconclusive, the same subjects have been used for the four experiments.

The four experiments in which the variables mentioned above were manipulated are reported. The procedure of each experiment is described in detail. Since the studies were planned for comparison of different methods of presenting angled stimuli, integrated results and discussion sections are presented after the procedures of all experiments have been described.

The following conditions were standard for all experiments in this study. Six volunteer subjects from The MITRE staff were used in the four experiments. Their age range was from 23 to 40. There were four male and two female subjects. The subjects were tested with an eye- and hand-dominance test developed by Crovitz and Zener (1962).[15] On the basis of this test, five of the subjects were classified right-eye and right-hand dominant, and one subject was right-eye and left-hand dominant. All subjects professed either normal vision or normal vision with correction. None of the subjects had had prolonged experience, beyond that of their everyday life, in judging angular stimuli. All sessions were held with individual subjects; there were no group sessions. No knowledge of results was given to the subjects during any of the four experiments.

The subject was seated before the viewing apparatus. The stimulus was at eye level. The source of ambient illumination was overhead diffused fluorescent lights.

EXPERIMENT I: Angular judgments verbally reported in terms of normal compass degree headings.

Procedure

The viewing stand and a microphone were on a table approximately 18 inches from the subject's head at eye level. The stand was in the vertical position, not tilted. Illumination at the stimulus card averaged 1.95 log ft-L. The subject's responses were recorded on a tape recorder.

The stimulus material consisted of 21 angles, each presented on a 3- by 5- inch white unlined card. The angles were first drawn with a black pencil, and 11 copies of each angle were then reproduced by the Xerox method. Thus, the angles were black on white background. The length of the line representing the angle was 2 inches. A sample of the type of stimulus used can be seen in Fig. 1. Angular positions presented were 10° intervals from 0 to 90° and 270 to 350°. The lower half of the compass (91 to 269°) was not used. In order to compare the present results with previous studies, in which it had been demonstrated that at the main and mid-meridian positions there was a reduction in errors, the 45 and 315° points were also presented.

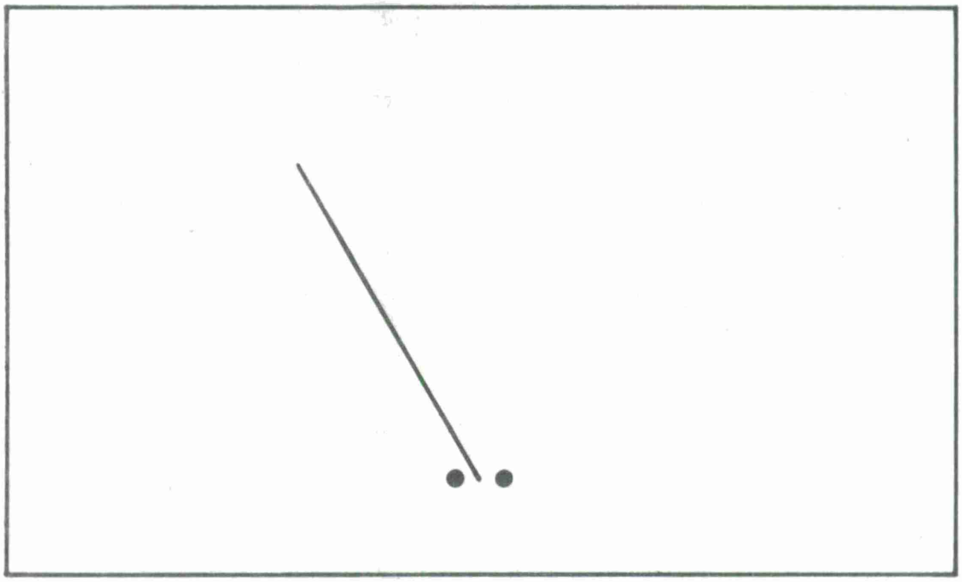


Fig. 1 Sample (actual size) of the type of stimulus used in Experiments, I, II and IV.

The 231 stimulus cards were placed in a random order of presentation by use of a table of random numbers. A different random order of presentation was prepared for each subject. Stimulus exposure was limited to 5 seconds.

The following instructions were read to the subjects:

> A number of cards with various angles from 270° through 0° to 90° will be presented to you on this stand. Your task will be to estimate to the nearest degree the angle that is presented. You will have 5 seconds to make the estimate. For your orientation, here is a half-circle of the compass with the orientations of 270°, 315°, 0 or 360°, 45° and 90°. Any angles from 270° through 0° to 90° may be presented to you.
>
> I will now present five cards representing five angles as a sample of how angles from 270° to 0° to 90° will appear to you. You will notice that there are two dots here. (Experimenter points.) This is the tail of the angle, and you are to make your estimations from the heading at the other end at this point. (Experimenter points.) This method will indicate the heading direction

> of the angle. The angles from 91 to 269° will not be presented. The same angle may be presented more than once during the session. Be as accurate as you can in your estimates, and you must make an estimate for every presentation. Since your answer is being recorded on tape, please speak clearly at your normal voice level for adequate recording.
>
> Remember, your one task is to estimate to the nearest degree the angle you believe has been presented to you within the 5 second period. You must make the best choice you can for each presentation. The experiment will take approximately 15 minutes. Any questions?

The five sample cards and the reference card were removed before the experimental stimuli were presented.

The experimenter then presented the cards, one at a time, on the stand before the subject. Exposure time of the card was controlled by the experimenter, using a stop watch as a guide. The subject's estimations were recorded on a tape recorder and retranscribed onto paper data sheets.

EXPERIMENT II: Angular judgments verbally reported in terms of 0 to 90° quadrant numerals.

Procedure

The hypothesis in this experiment was that accuracy in reporting angular judgments will be improved when the numerals used in reporting are the same for both 90° quadrants. This hypothesis is a recognition of the possibility of conflict of orientation in the requirement that the subject report in different numerals for the two 90° quadrants, as in Experiment I. The subjects were asked, therefore, in this experiment, to report their numerical estimates on the basis of 0 to 90° numerals for both quadrants, rather than 0 to 90° for the quadrant to the right of zero and 270 to 359° for the quadrant to the left of zero, as in Experiment I. All other conditions were identical to those of the first experiment.

EXPERIMENT III: Angular judgments reported by manual adjustment, with a reference standard and the addition of a third dimension to the stimulus.

Procedure

In this experiment, the apparatus consisted of a triangular frame upon which were mounted two rectangular targets and a means for the subject to rotate one of the targets (see Fig. 2). The apparatus was a modification of one used by Lichte.[11] The modifications were in the size of the targets, the distance between the targets, the distance between the subject and the targets and between the targets and the background, and elimination of the side panels and introduction of a head mount.

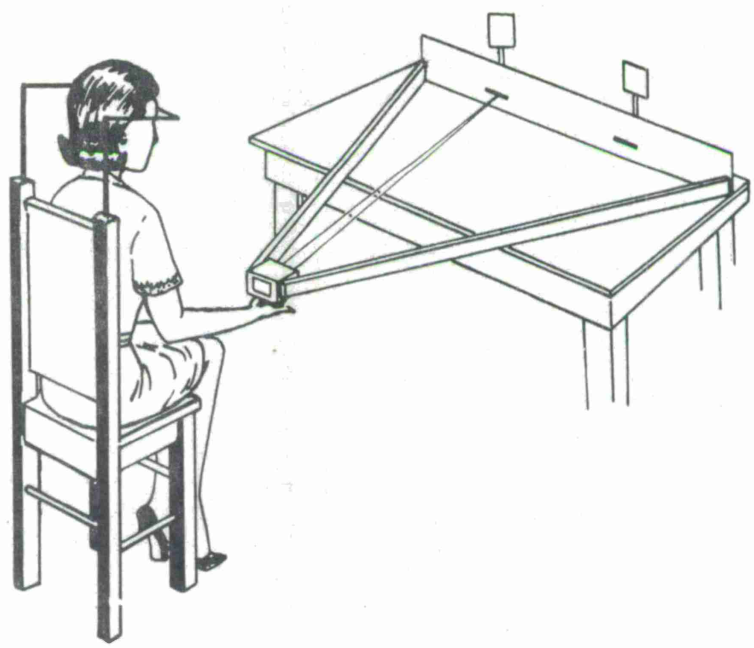


Fig. 2 Apparatus used in Experiment III.

The targets were flat-black cardboard, cut to 5 inches high and 3 inches wide. They were mounted on dowels 0.25 inch in diameter. The distance between the targets was 2-3/4 inches (edge to edge) when the targets were placed at 90° to the subject. At 0° to the subject, the distance between the cards was 5-9/16 inches. The distance from the subject's head to the targets was 46 inches. The targets were placed so that they were equidistant from the subject's line-of-sight.

The following average brightness levels were obtained from the targets used in the experiment: at 27° left rotation, 0.98 log ft-L; at 27° right rotation, 1.1 log ft-L; at 45° left rotation 0.82 log ft-L; at 45° right rotation, 0.88 log ft-L; at 90° rotation, 0.6 log ft-L. During the time the subject was adjusting the variable stimulus, the experimenter remained beyond the line-of-sight of the subject so that a clear, homogeneous background was available for the adjustment.

Each target was connected to a knob at the subject's position by means of a string wound around a shaft attached to the dowel upon which the target was mounted. Attached to the dowel at the bottom of each target and below the front piece so the subject could not see it, was a needle. The needle responded to rotation of the dial by the subject. Underneath the needle was a protractor fastened to the base of the apparatus. A needle and protractor were also positioned in the same way for the other target. The needle, protractor and target were calibrated before each session so that all three parts were in alignment. The experimenter read the subject's dial setting, as recorded on the protractor, to the nearest $1/2^{\circ}$.

The top part of the apparatus was covered (cover is not shown in Fig. 2) so that the subject could not pick up cues of the extent of movement from the excursion of the strings attached to the targets. The position of the chair upon which the subject was seated was fixed to maintain a constant distance from the subject to the targets. A head rest also helped maintain this constant position and was a control for head movement during positioning of the target by the subject.

The subject's task was to rotate the variable stimulus by turning the dial until the variable shape equaled the standard shape in angle of rotation. A 5-second time limit was imposed on the subject for each setting.

The exact instructions to the subject were as follows:

> This is an experiment to determine how accurately you can adjust one of these shapes to equal the standard shape. Your task is, by means of this knob which rotates the variable shape, to make the shape you rotate equal in angle of rotation to the standard. Try to maintain the same basis for adjusting the variable to the standard throughout the experiment. There is a 5-second time limit to make this adjustment. If you have not made an adjustment at the end of the 5-second period, you will be asked to make the best one you can within the next few seconds. Sometime during the experiment, the variable and standard shapes will be interchanged. You will be told of this at the appropriate time. The variable stimulus will be reset by the experimenter to approximately zero after you have made your estimate.

Before each trial, the experimenter adjusted the standard stimulus to the correct angle. This adjustment was made with a shield in front of the target so that the subject could not see the adjustment. The variable stimulus was reset to approximately zero after the subject's setting. An exact zero was not set because a zero angle was among the stimuli to be presented.

A practice session immediately preceded the experiment for all subjects. They were read the instructions with the addition that this was to be a practice session. The practice session continued until a criterion of five successive settings within ±5° of the standard setting had been met by the subject. This allowed the subject to become familiar with the apparatus and ensured that all subjects started the experiment at the same initial level of accuracy. Interchange of standard and variable was accomplished during the practice session. No subject required more than 15 trials to reach the criterion.

The angles presented were as follows (in degrees from zero): 0, 9, 18, 27, 36, 45, 54, 63, 72, 81, 90. There were four presentations of each angle to the right of zero and four presentations of each angle to the left of zero. For each angle presented to the right of zero and to the left of zero, the standard target was changed from either the left or right position. For example, for a 9° setting on the quadrant to the right of zero, a subject would be presented the angle twice with the standard target to the left of the variable and twice with the standard to the right of the variable. This same interchange of standard and variable targets would also be made for 9° presented to the left of zero point. Thus, 9° would be presented eight times: four times to the right of zero and four times to the left of zero. In each quadrant, the standard and variable were interchanged after two observations at each standard position. Thus, there were eight presentations each for 11 angles, or 88 adjustments, for the subject to make in the experiment. Experimental sessions usually took about 75 minutes.

The stimuli for a particular quadrant were presented in random order. When adjustments were completed for that quadrant, the experimenter gave the subject a 10-minute rest period; the standard and variable stimuli were then interchanged for the second half of the presentations. Zero setting was included in the random order, and four presentations were given in each half of the experiment. Three subjects started the experiment with the standard target on the left, and the other three subjects with the standard target on the right. Starting quadrant was also different for half the subjects.

EXPERIMENT IV: Angular judgments reported by manual adjustment, with standard stimulus in two dimensions.

Procedure

The apparatus consisted of a variable resistor with a long shaft carrying a needle at one end and a pointer-type knob at the subject's position. A variable resistor was used merely because it provided some resistance to turning of the shaft. An aluminum housing was fitted in front of the resistor, and a blank, white piece of paper covered the front of the apparatus and acted as the background for the knob. The standard stimuli were cards placed on a small stand hidden behind the paper, and situated such that only the card was showing. The knob was the variable stimulus. In back of the housing and the paper shield a needle was attached to the shaft, which rotated when the subject rotated the knob. Pasted on the housing just behind the needle was a protractor which allowed the experimenter to read the subject's setting to the nearest 1/2°. The apparatus was calibrated before each subject's session so that the knob setting, the needle and the protractor were coincidental. The stimulus cards, the stand and the paper shield were also checked for proper orientation before each session. The apparatus was set on a table and the subject sat in a comfortable chair in front of the apparatus. A sketch of the apparatus is shown in Fig. 3. The exact shape of the knob is also shown in actual size. A white line ran down the center of the black knob from the pointed end.

The stimuli were prepared and presented in the same manner as in Experiments I and II. The angles presented, however, were the same as in Experiment III. There were five presentations of each angle instead of four as in Experiment III. Thus, there were 11 angles presented 5 times each to a subject, or 55 estimations for a subject. The cards containing the angles were put in a different random order for each subject. Room lighting and conditions of time exposure were as before.

The following instructions were read to the subject:

> You will be presented a number of cards on which will be a line like the following examples (experimenter shows sample cards). The inclination or angle of the line will vary randomly from 0 to 90°, right or left of 0°. Notice there are two small dots at one end of the inclined line. This indicates the tail, not the heading, of the line. You are to make your estimate of the angle, using the head of the line with this knob. You have 5 seconds to make a setting and if at the end of that time you have not made one, you will be asked to make a best guess.
>
> The experimenter will make a recording of your estimate by means of a protractor attached to the shaft of the knob. When your setting has been recorded, the experimenter will return the knob to approximately 0°.
>
> Thus, your task is to turn this dial to equal the angle presented on a card on this stand, using the head (opposite the dots) as the reference point.

A typical trial procedure was conducted as follows. The experimenter set the dial to approximately zero; he then placed the card on the stand, and at the end of 5 seconds, when the subject had made his setting, removed the card. The subject's setting was

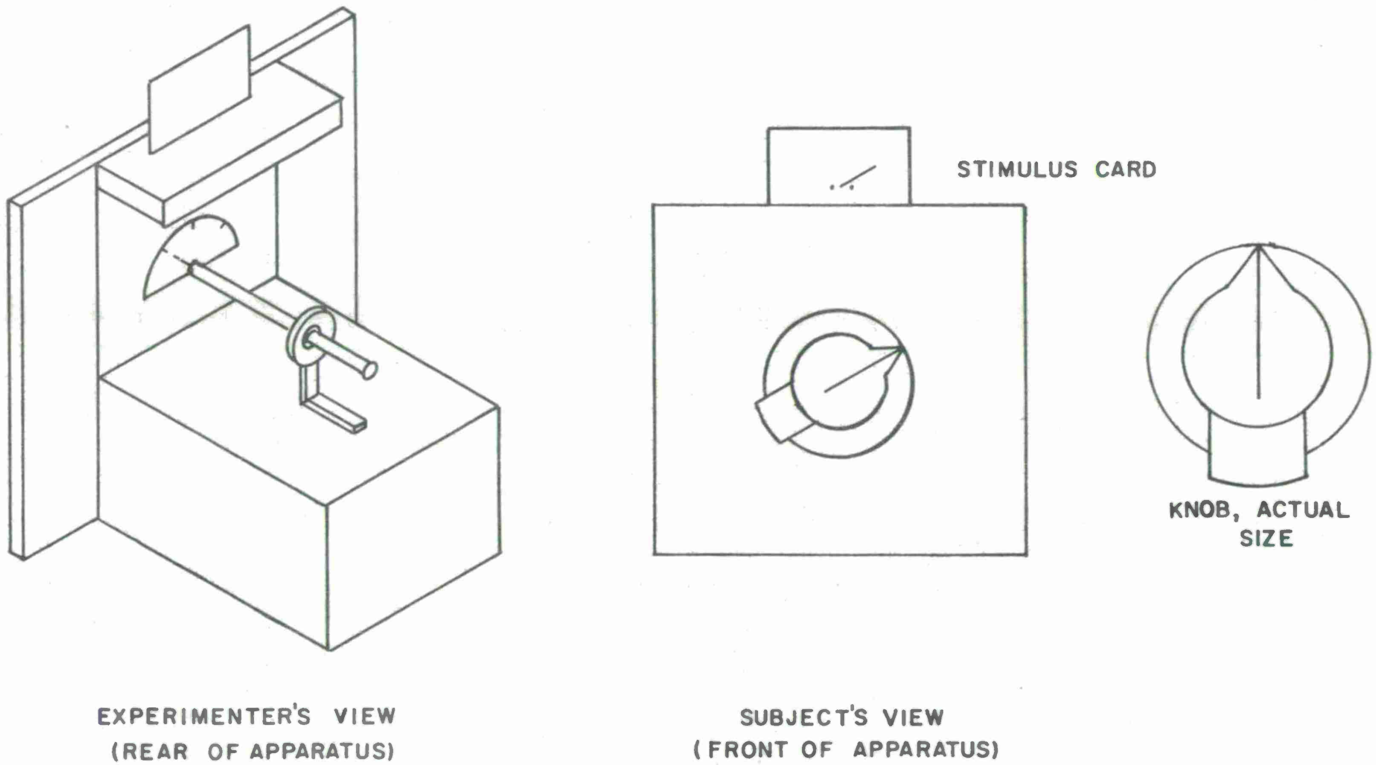


Fig. 3 Sketch of apparatus used in Experiment IV, showing rear view of apparatus (experimenter's view) and front view (subject's view), and type of dial used by subject for angular estimations.

read from the needle over the protractor to the nearest 1/2° by the experimenter, using a magnifying glass. The knob was then returned by the experimenter to an approximately zero position for the next stimulus presentation. The subjects were permitted a 10-minute rest period halfway through the experiment. A session usually lasted 45 minutes.

RESULTS

Accuracy Measures

Although several accuracy class limits were plotted for comparison purposes (Fig. 8), the ±0–5° (most accurate class) interval was chosen for statistical comparisons between the main variables. It is consistent with the tolerable error limit for operational conditions of estimations of bearing.

Accuracy as a Function of Subject Group and of Method

When the 0–5° accuracy classification was used to graph the angular judgments of the six subjects (Fig. 4), two distinct groups emerged. These subject groups will henceforth be labeled high- and low-accuracy groups. To vindicate this dichotomy, the Wilcoxon Test for paired observations was used, and the results showed that the two groups differed significantly ($P < 0.01$), from each other on accuracy of angular estimation with each experimental method. Since there were two distinct populations, the level of accuracy and direction of constant bias were compared within and between each group for all experimental methods.

The four experimental methods were dichotomized on two bases: the first, that Methods I and II required verbal response from the subjects, while Methods III and IV required a manual adjustment; the second, that Methods III and IV each had a comparison stimulus, while in Methods I and II the subject was forced to make a judgment without a comparison stimulus. It should be noted that Method III was quite different from the other methods in that the angular stimuli were three- dimensional (rotated rectangular cards) rather than two- dimensional (a line on a 3- by 5- inch card). The question to be answered was whether these two types of methods had a differential effect on accuracy of estimation by the two accuracy groups. Using the Wilcoxon Test again, it was found that there were no significant differences for the high-accuracy groups among the four experimental methods; for the low-accuracy group, there were two differences: between Methods I and III ($P < 0.01$), and between Methods I and IV ($P < 0.02$). All other comparisons were not significantly different ($P > 0.05$, Wilcoxon Test for related samples).

A group labeled high-accuracy maintained a median of at least 75% accuracy, regardless of the type of stimulus, method of presentation of the stimulus, or mode of subject response. A low-accuracy group did not reach the 75% median level by any method, but tended to be more accurate when they used manual adjustment (Methods III and IV) than when they relied on verbal report without a standard for comparison (Methods I and II).

In the low-accuracy group, judgments reached the highest accuracy level with the knob-adjustment method. (The range of accuracy for the low-accuracy group was from 47.1% with Method I to 72.7% with Method IV.) Thus, as a general conclusion on accuracy as a function of method, it can be stated that (1) a high-accuracy group maintained a median of at least 75% accuracy regardless of method of stimulus presentation; (2) in a low-accuracy group, estimates of angles were most accurate when a knob setting was the response mode, less accurate when a third dimension was added to the stimulus, and least accurate when neither reference standard nor a three-dimensional stimulus was presented, and the subject had to report by verbal means.

When the data for the six subjects were pooled, rather than separated into accuracy groups, there were no significant differences among the results obtained with the four methods. Thus, if the data for the six subjects had not been separated into high- and low-accuracy groups, one would have concluded that neither the method of presenting the stimulus nor the mode of subject's response made any difference (Fig. 5).

Angular Estimations Within and Between Groups as a Function of 45° Quadrant Presentations

When the two accuracy groups were compared on accuracy as related to judgments within the 45° quadrants, significant differences between the two groups were found in all-quadrants ($P < 0.05$) (cf. Fig. 6). However, within groups there were no significant differences in accuracy among the four 45° quadrants. For the low-accuracy group, the difference between Method I and Method II approached, but did not come within, the 0.05-confidence level. The tendency toward greater accuracy in those 45° quadrants adjacent to zero can be seen in Fig. 6 by referring to the center plot, which represents the grand median of the two groups by quadrant. The one group exception was Method III, where there were equally accurate estimates regardless of quadrant (pooled data, both accuracy groups, Fig. 7).

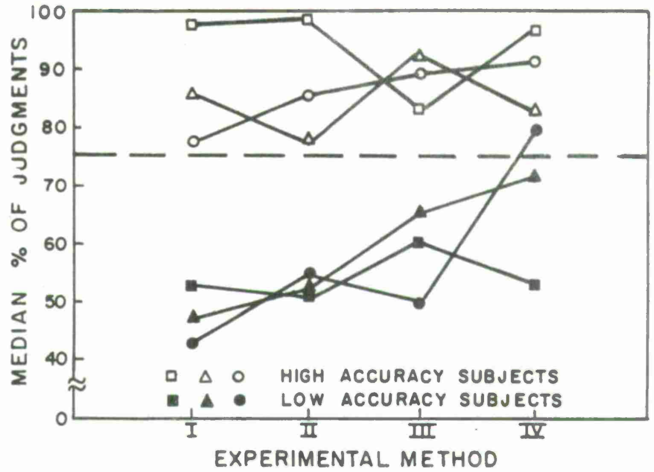


Fig. 4 Median percent of judgments ± 0-5° from presented angle (highest accuracy classification), by experimental method and individual subject.

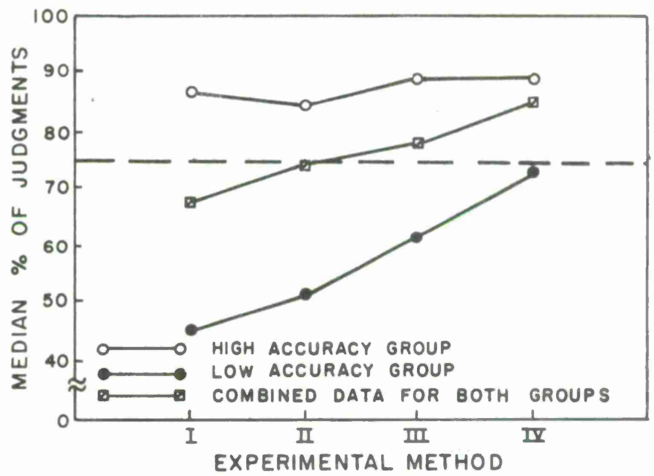


Fig. 5 Median percent of judgments ±0-5° from presented angle, by experimental method and high- and low-accuracy groups, and grand median scores for the combined groups.

Other Observations

While the ±0–5° category was used as the main basis of assessment of accuracy for the two groups, larger categories might have been chosen. Figure 8 has been prepared to illustrate what the accuracy level would have been if increasingly larger accuracy categories had been taken. Perusal of Fig. 8 shows that, when the data for the two groups were pooled, angular estimations were above the 75% median accuracy level in accuracy categories above ±0–5°. The two manual-adjustment methods with reference standard were at still higher accuracy levels.

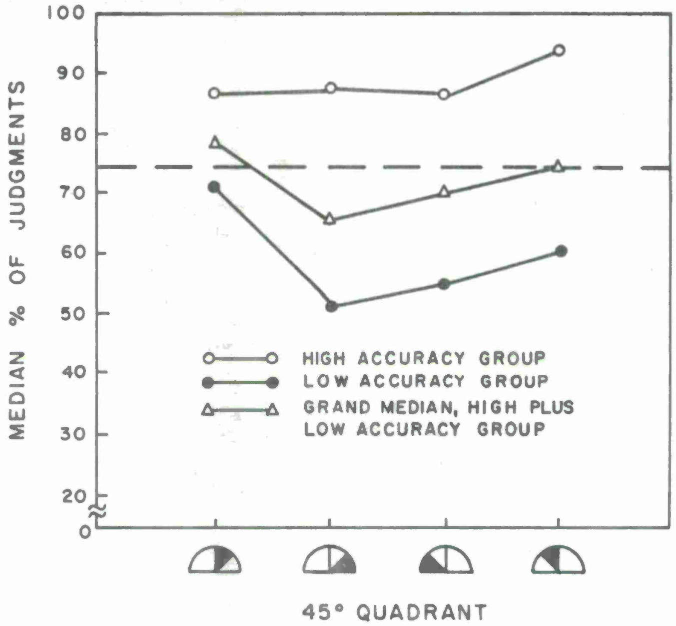


Fig. 6 Median percent of judgments ± 0-5° from presented angle, for each 45° quadrant, pooled data from four experiments, for the high- and low-accuracy groups; and grand median of percent of such judgments for the combined groups.

There were fewer extreme misjudgments (over ±16°) in Methods III and IV (comparison stimulus and manual adjustment) in both accuracy groups. The median percents of judgments in this extreme category for the different methods were as follows: I = 12.8%; II = 6.9%; III = 0%; IV = 1.1% (Table II).

The low-accuracy group had more extreme error scores than the high-accuracy group. The low-accuracy group tended to make less extreme scores on Methods III and IV than on Methods I and II.

Direction of Constant Bias

Constant Bias Compared for 45° Quadrant Estimations

When the high- and low-accuracy groups were considered separately, there were significant differences between the two groups of subjects on 45° quadrant comparisons. When the Wilcoxon Test for paired comparisons was used, it was found that the two groups were significantly different in their angular judgments of the two 45° quadrants

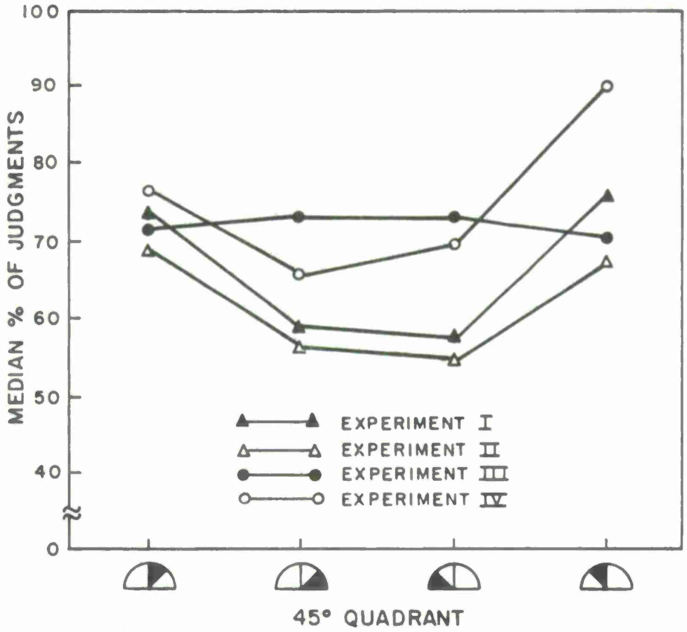


Fig. 7 Median percent of judgments ± 0-5° from presented angle, for each 45° quadrant, for all subjects for each experimental method.

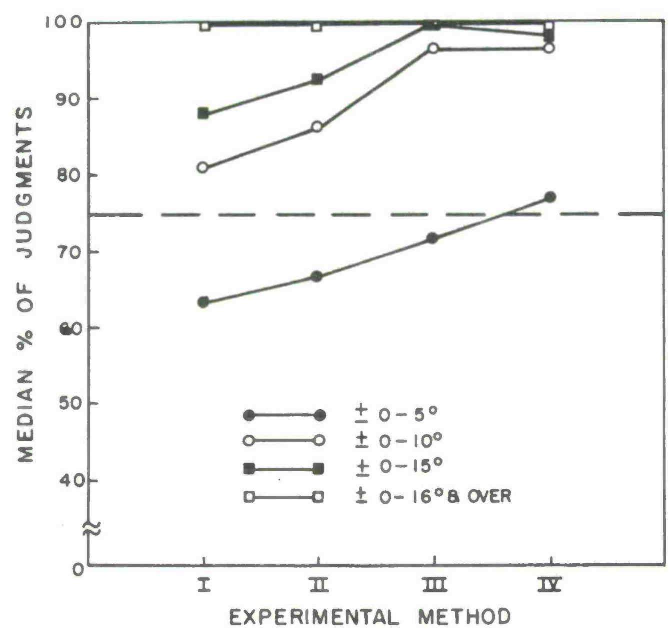


Fig. 8 Median percent of judgments in each accuracy category, for all subjects for each experimental method.

to the right of zero ($P < 0.05$). While both groups underestimated the angles, the low-accuracy group had a much higher magnitude of underestimation than the high-accuracy group. There were no significant differences for the two quadrants to the left of the zero point (Figs. 9, 10).

What differences were there within accuracy groups? For the low-accuracy group there were significant differences in direction of constant bias in the two quadrants to the right of zero, and both comparisons indicated underestimations by the subjects of this group (Fig. 9). Within the high-accuracy group there were no indications of a significant bias toward over- or underestimation (Fig. 10). This result further identifies the characteristics of a group labeled high-accurate; i.e., a higher level of accuracy as measured within a $\pm 0-5°$ accuracy range, and now, no indication of constant bias in angular estimations.

Constant Bias Compared for 90° Quadrant Estimations

It was found that for Method I, there were significantly more underestimations than overestimations within the low-accuracy group for the 90° quadrant to the right of zero

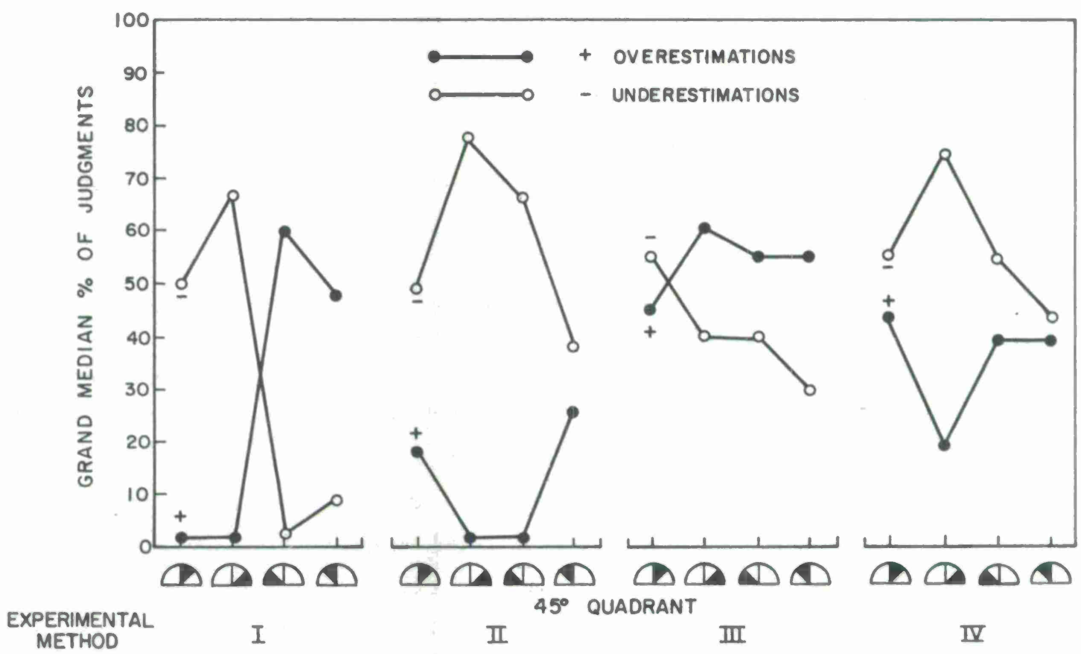


Fig. 9 Low-accuracy group: grand median percent of judgments which were over- or underestimations in each 45° quadrant for each experimental method.

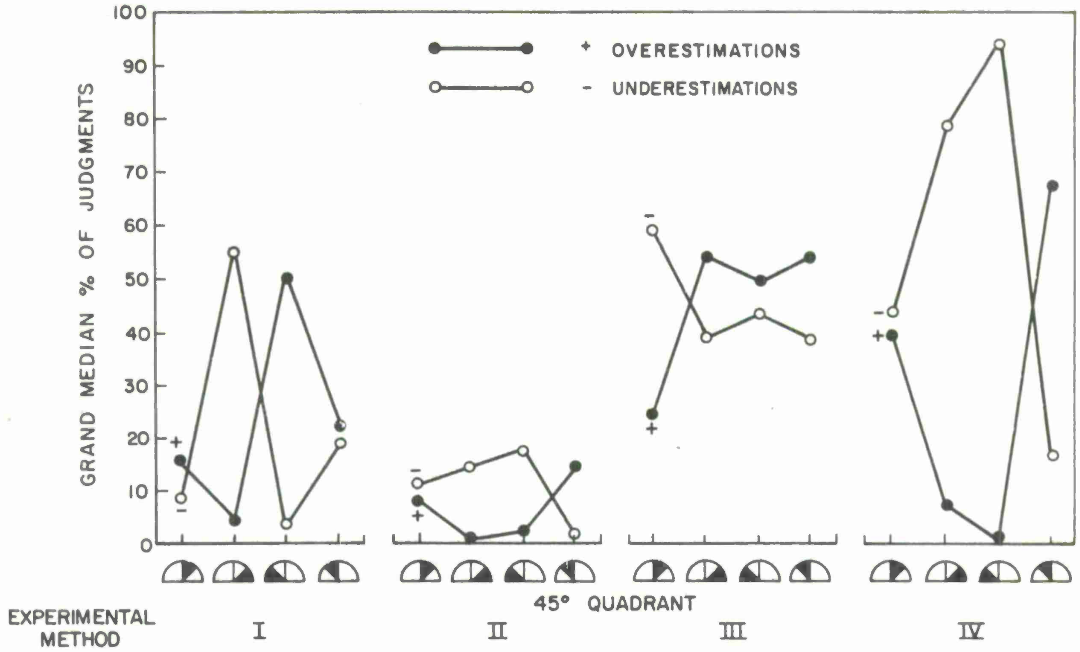


Fig. 10 High-accuracy group: grand median percent of judgments which were over- or underestimations in each 45° quadrant for each experimental method.

($P < 0.05$); for the 90° quadrant to the left of zero, there were significantly more overestimations than underestimations. In Method II, there were significantly more underestimations in both 90° quadrants. There were no other significant differences for either the low- or high-accuracy groups (Fig. 11).

Direction of Constant Bias Compared by Method for Each Accuracy Group

When quadrants were disregarded and the high- and low-accuracy groups were compared for over- and underestimations on each method, there was only one result of note: a significant difference in degree of underestimation exists at the $P < 0.01$ level between the high- and low-accuracy groups for Method II. Thus, it can be concluded that when quadrants are disregarded and the data are pooled within an accuracy group, and the high- and low-accuracy groups are compared on each method, there is little or no difference in over- or underestimations, with but one exception, as noted [Fig. 12 (a) and (b)]. When quadrants are disregarded and the data for the two groups are pooled, and percents of judgments are plotted for over- and underestimations for each experimental method, it is found that underestimations prevailed for all methods (except Method III) [Fig. 12(c)].

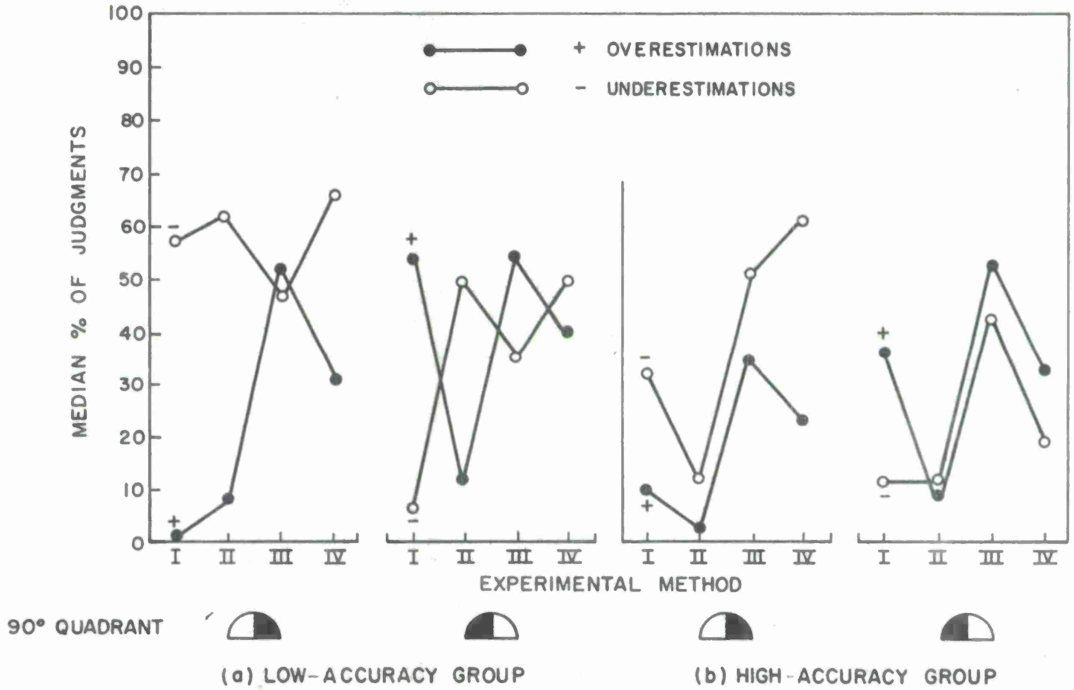


Fig. 11 Median percent of judgments, for the low- and the high-accuracy groups, which were over- or underestimations in each 90° quadrant for each experimental method.

Direction of Constant Bias Compared When the Data of High- and Low-Accuracy Groups Are Pooled

When the data for the two accuracy groups are pooled, conclusions as to the direction and magnitude of judgments in the quadrants can be drawn from what can be called an unselected population. When the 45° quadrants were considered, it was found that for the pooled data there was a significant difference of underestimations rather than overestimations for the 45° quadrant to the right of zero ($P < 0.05$). There was also a significant difference in favor of underestimations for the second 45° quadrant to the right of zero. The two 45° quadrants to the left of zero showed no significant differences in direction of constant bias (Fig. 13).

Thus, for what can be labeled an unselected population, it can be predicted that underestimations can be expected for the 90° quadrant to the right of the zero point, and no bias for the quadrants to the left of the zero point.

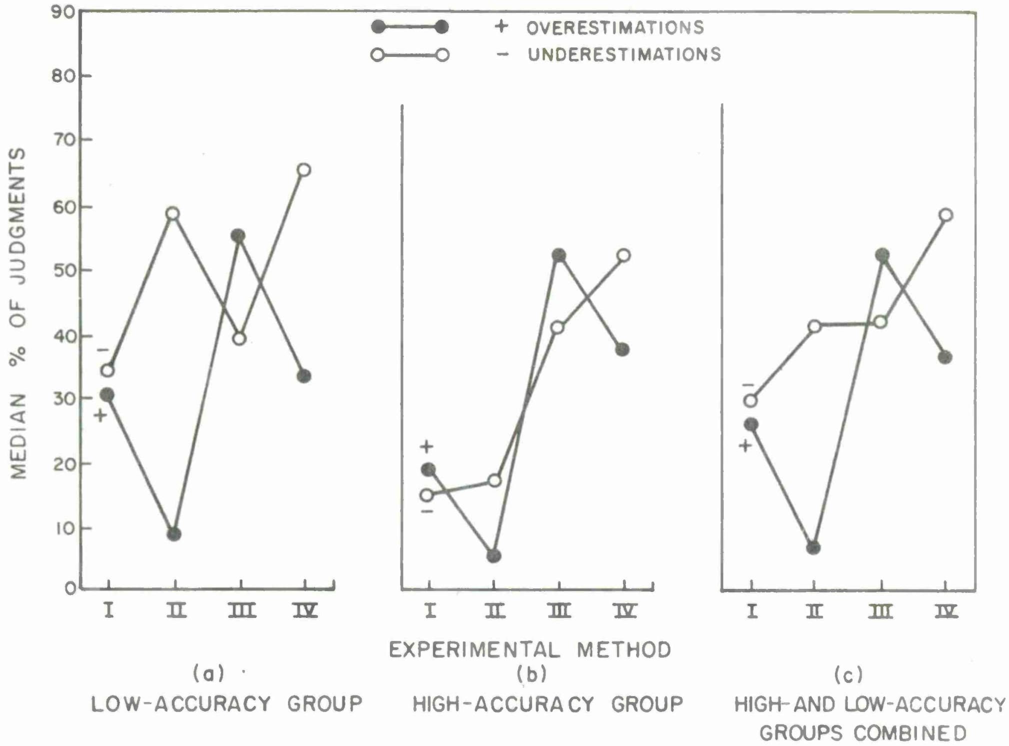


Fig. 12 Median percent of judgments which were over- or underestimations, for each experiment, for (a) the low-accuracy group, (b) the high-accuracy group, and (c) the high- and low-accuracy groups combined.

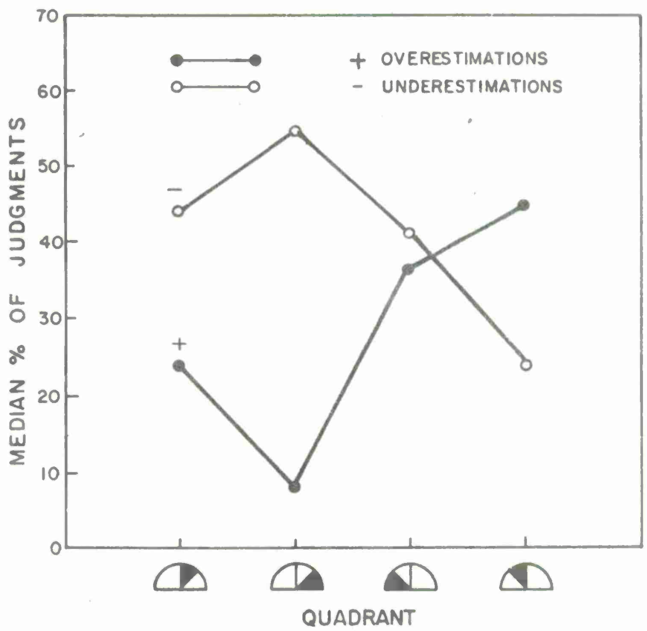


Fig. 13 Median percent of judgments which were over- or underestimations in each 45° quadrant, pooled data from both accuracy groups and all experimental methods.

GENERAL DISCUSSION

It is difficult to deduce from the design of the experiment why it was possible to dichotomize two groups of subjects on the basis of their accuracy and constant bias. Lichte[11] suggested that accuracy differences between individuals are due to attitude of the subject. Lichte's conclusion would imply that one factor in accuracy of reporting is the influence of self-imposed standards. For the low-accuracy group in this experiment, the level of accuracy markedly improved with the dial-estimation method and when a third-dimension was added to the stimulus. In both of these methods the subject had a reference standard, while in the other two methods no reference standard was physically present. Although the method of presenting the stimulus significantly improved the level of judgment of the low-accuracy group, those subjects never reached the accuracy level of the high-accuracy group by any method of stimulus presentation or mode of response. These results lead to a conclusion that the accuracy level of a group labeled low-accurate can be significantly improved by use of reference standards and of manual-adjustment techniques, but that some subjects will be highly accurate in their judgments of angles, regardless of whether there is a reference standard, whether the stimulus is two- or three-dimensional, or whether they must report their estimations verbally or by manual adjustment. Quite probably, also, knowledge of results might, with practice, bring the low-accuracy group up to the level of the high-accuracy group of this experiment, although there are instances when method of presentation is more important than practice (Grether, 1949).[16] The conditions under which each of these factors can effect important increments in level of accuracy are not completely known at this time.

It was found that accuracy among low-accuracy subjects was better for the two 45° quadrants adjacent to zero than for the two 45° quadrants farther away from zero. These results are consistent with the results of many previous studies. In her review of the literature on this aspect of accuracy, Jones[1] found that many studies showed that error size and variability increased as the distance increased from the standard to the variable stimulus. Jones reviews the past use of the standard stimulus as an "anchor," i.e., a reference point to compare to the variable stimulus. It is worthwhile to note that in Method III (manual adjustment based on angular judgment with a reference standard and the addition of a third dimension to the stimulus) this effect did not take place (Fig. 7). Why this method was insensitive to this effect is not known. The stimulus for this method was in three dimensions rather than two as in the other three experiments. There may be something specific about the nature of the stimulus that decreases or eliminates the effect. Further work is needed to verify this hypothesis.

It must be emphasized that the difference in accuracy between near and far quadrants from zero was characteristic only of the low-accuracy group. As Fig. 6 shows, the high-accuracy group did not vary significantly in accuracy as a result of the quadrant in which the stimulus was presented. This would imply that a high-accuracy group might be able to extend its "anchor" to a much greater "psychological distance" than a low-accuracy group. A high-accuracy group appears to be better able to maintain comparison of two stimuli without being seriously affected in judgment of the equality of the two angles by the physical or "psychological" distance between the two stimuli. This was so, at least, for the high-accurate group under the conditions of the present experiment. Needless to say, the experiments in literature and in the present study do not provide direct evidence to support this hypothesis.

Inspection of subjects' estimates on their raw data sheets showed that, with the verbal estimate mode of reply, the majority of estimates were quantized ones of 5 or 10° in Experiments I and II. In Experiments III and IV, where manual adjustment techniques were used by the subjects, quantizing in 5° intervals was practically nonexistent. Smith[3] and Chapanis[14] also found quantizing in 5° intervals more prevalent for verbal estimate than for manual adjustment. Such quantizing took place in both accuracy groups to approximately the same extent.

It was also found that for the low-accuracy group, the manual-adjustment method was significantly more accurate than verbal estimate. For the high-accuracy group, there was no difference in accuracy of estimation as a function of response mode. Again, the basis for this difference must be looked upon as a characteristic of a particular population. However, Smith[3] found that his high-accuracy group was more accurate using manual adjustment than verbal estimate. In this experiment, with multiple replications within each experimental method, high- and low-accuracy groups could be differentiated. While Smith could separate two groups on the basis of accuracy, he did not obtain the consistency of accuracy in all methods for the high-accuracy group that was obtained in this experiment.

The data were assessed for a relationship between hand and eye dominance and direction of bias, and none was found.

Higher accuracy in reporting was found for 0°, 45° and 90° presentations than for angles presented elsewhere than in the mid-meridian or cardinal points. There was also less tendency for extreme estimates by the subjects when the former angles were presented. These results are consistent with many previous investigations.

In the matter of direction of constant bias, the studies in the literature are not consistent when comparing 45 or 90° quadrants. Jones,[1] in her review of the literature on direction of constant bias in the different quadrants, listed studies where overestimations prevailed, and other studies where underestimations predominated, for the same quadrants. Usually there was no attempt by the investigator to determine whether two different accuracy groups could be identified. The problem of constant bias in individual judgment has been known since the 18th century.* The relationship between individual subject direction of constant bias and type of angulation task presented has received little attention in previous investigations. In the present experiment, combined results from both groups tend to show underestimations [Fig. 12 (c)]. However, when the stimulus was a three-dimensional rectangular target, both accuracy groups overestimated in their judgments of the angles. As a control on position of the standard stimulus relative to the variable stimulus, the standard stimulus was presented to the right and then to the left of the variable stimulus the same number of times for the same angular presentations (Method III). Table V (c) (Appendix) shows quite distinctly that in the 90° quadrant to the right of zero, when the standard was to the left of the variable stimulus, 70 judgments were overestimated and 43 underestimated; when the standard was to the right of the variable stimulus in this same quadrant, there were 39 overestimations and 73 underestimations, i.e., a complete reversal. The same reversal situation took place in the 90° quadrant to the left of zero when the standard and variable stimulus positions were interchanged.

Thus, at least when the angular stimulus was a three-dimensional rectangle, the 90° quadrant and the position of the standard stimulus relative to the variable stimulus were determinants of the direction of constant bias. This result demonstrates that, in some experiments, attention to intra-experimental variables may significantly change direction of constant bias. The position of the standard relative to the variable stimulus in previous experiments of angular estimations has not been controlled (cf. Lichte).[11]

The main conclusion to be drawn from the results of the four experiments is that some subjects will be highly accurate in their judgments of angles regardless of conditions of presentation or reporting, while other subjects will be influenced in level of accuracy by method of presentation of the stimulus and means of making the report of their judgments. That is, for a low-accuracy group, manual estimations of angle will

*The astronomer Bessel in the 18th century found a constant bias in the judgments of different astronomers when they reported the passage of a star across a meridian as a function of the magnitude of the star and the rate of movement across the telescope field.

produce significantly fewer errors of accuracy and reduce magnitude of constant bias. By comparison, a group labeled high-accuracy will have a lower magnitude of error and show no constant bias.

These results can be used for selection and training of operators of systems such as SAGE, where operators must estimate direction of bearing of objects. For selection purposes, to identify a subject as belonging to a high- or low-accuracy group, the simplest test to give is a short series of angles presented on paper at various angles of the compass and requiring verbal report of angular estimation (Method I). A high accuracy subject should have judgments within ±5°, 80% of the time. If low-accuracy subjects have to be accepted, then the dial estimation mode of reporting should be used rather than verbal estimate.

APPENDIX
TABULAR DATA

The data from the four experiments in this study are presented in the following tables.

Table I is a record of the percent of judgments by each subject by accuracy class for each experimental method. For example, for Method I for subject H, 58.1 % of his judgments of the presented angles were accurate within ±0–5°.

Table II shows the percent of all subjects' judgments for each experimental method for each accuracy category by 45° quadrant. The cumulative percent of each accuracy class as the error rate goes higher is also shown for each experimental method.

In Table III, (a), (b), (c), and (d), are the data for each individual subject in each of the four experiments. Each score represents frequency of reporting, or the number of times a subject made a judgment, within each 45° quadrant for a particular accuracy classification. For example, in Table III (a), the score 32 for subject H is the number of times out of the total (N=55) that the subject made a judgment of the presented stimulus within ±0–5° accuracy.

Table IV, (a) and (b), displays the percent of judgments by the low- and high-accuracy groups which were overestimated (+ in Table), underestimated (– in Table), or reported correctly (0 in Table), in each experiment for each 45° quadrant. The median of each accuracy class and the grand median of each accuracy class are also given.

Table V, (a), (b), (c) and (d), shows the number of judgments in each 45° quadrant which were overestimated, underestimated or reported correctly for each subject for each method. These data represent frequency of reporting rather than percent of judgments.

TABLE I

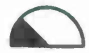
PERCENT OF JUDGMENTS IN EACH ACCURACY CLASS FOR EACH EXPERIMENT, BY INDIVIDUAL SUBJECT

		Right Quadrants 							
		ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	METHOD	±0-5°	±6-10°	±11-15°	±16°→	±0-5°	±6-10°	±11-15°	±16°→
H	I	58.1	18.1	9.0	14.5	50.9	5.4	20.0	23.6
	II	72.7	23.6	3.6	0	29.0	9.0	23.6	38.1
	III*	55.0	35.0	10.0	0	70.0	30.0	0	0
	IV	84.0	12.0	0	0	20.0	36.0	32.0	12.0
N	I	30.9	29.0	21.8	18.1	38.1	18.1	9.0	34.5
	II	34.5	25.4	25.4	14.5	56.3	10.0	7.2	25.4
	III*	52.5	35.0	35.0	0	65.0	35.0	0	0
	IV	84.0	16.0	0	0	60.0	40.0	0	0
M	I	76.3	21.8	0	1.8	38.1	12.7	20.0	29.0
	II	61.8	29.0	7.2	1.8	45.4	14.5	20.0	20.0
	III*	80.0	20.0	0	0	60.0	30.0	10.0	0
	IV	52.0	40.0	8.0	0	52.0	44.0	4.0	0
D	I	100.0	0	0	0	98.1	1.8	0	0
	II	98.1	1.8	0	0	100.0	0	0	0
	III*	90.0	10.0	0	0	55.0	35.0	10.0	0
	IV	80.0	20.0	0	0	100.0	0	0	0
T	I	87.2	9.0	3.6	0	60.0	23.6	5.4	10.9
	II	94.5	5.4	0	0	56.3	40.0	1.8	1.8
	III*	75.0	25.0	0	0	100.0	0	0	0
	IV	84.0	16.0	0	0	72.0	28.0	0	0
TE	I	94.5	5.4	0	0	70.9	29.0	0	0
	II	83.0	16.9	0	0	84.4	15.5	0	0
	III*	95.0	5.0	0	0	95.0	5.0	0	0
	IV	76.0	24.0	8.0	4.0	92.0	8.0	0	0

(Table Continued)

*Median percent of all judgments, using both right and left reference standards.

TABLE I (Continued)

		Left Quadrants 							
		ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	METHOD	±0-5°	±6-10°	±11-15°	±16°→	±0-5°	±6-10°	±11-15°	±16°→
H	I	50.0	10.6	7.5	31.8	56.3	25.4	7.2	10.0
	II	34.3	16.4	17.9	31.3	69.0	16.3	10.9	3.6
	III*	60.0	40.0	0	0	60.0	30.0	10.0	0
	IV	20.0	32.0	36.0	12.0	71.4	25.7	2.8	0
N	I	51.5	12.1	7.5	28.7	49.0	16.3	14.5	20.0
	II	63.6	18.1	6.0	12.1	63.6	23.6	10.9	1.8
	III*	60.0	40.0	0	0	55.0	40.0	5.0	0
	IV	76.0	20.0	4.0	0	94.2	8.5	0	2.8
M	I	28.7	16.6	9.0	45.4	49.0	30.9	0	20.0
	II	42.4	4.5	24.2	28.7	61.8	30.0	5.4	1.8
	III*	65.0	20.0	15.0	0	50.0	50.0	0	0
	IV	84.0	16.0	0	0	94.2	5.7	0	0
D	I	96.9	1.5	0	1.5	94.4	5.5	0	0
	II	100.0	0	0	0	98.1	0	0	1.8
	III*	95.0	5.0	0	0	85.0	15.0	0	0
	IV	96.0	4.0	0	0	97.1	2.8	0	0
T	I	64.6	30.7	1.5	3.0	80.3	16.0	0	3.5
	II	77.2	18.1	0	0	87.2	12.7	0	0
	III*	95.0	5.0	0	0	90.0	10.0	0	0
	IV	56.0	40.0	0	0	97.1	2.8	0	0
TE	I	60.6	30.3	7.5	1.5	87.2	7.2	3.6	1.8
	II	84.6	15.3	0	0	85.4	14.5	0	0
	III*	75.0	25.0	0	0	90.0	10.0	0	0
	IV	88.0	8.0	4.0	0	91.4	5.7	5.7	2.8

*Median percent of all judgments, using both right and left reference standards.

TABLE II

PERCENT OF JUDGMENTS IN EACH ACCURACY CLASS
FOR ALL SUBJECTS, BY EXPERIMENTAL METHOD

	Right Quadrants							
								
EXPERIMENTAL METHOD	ACCURACY CLASS				ACCURACY CLASS			
	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
I	74.2	14.1	5.8	5.8	59.2	15.1	9.1	16.4
Cum. %		88.3	94.1	100.0		74.3	83.4	100.0
II	71.8	19.5	5.9	2.6	62.2	14.9	8.6	14.0
Cum. %		91.3	97.2	100.0		77.1	85.7	100.0
III*	70.8	21.6	7.4	0	74.1	22.4	3.3	0
Cum. %		92.4	100.0	100.0		96.5	100.0	100.0
IV	76.6	21.3	1.3	0.06	66.0	26.0	6.0	2.0
Cum. %		97.9	99.2	100.0		92.0	98.0	100.0
Grand Mdn.	73.0			3.87	64.1			8.0

(Table Continued)

*Median percent of all judgments, using both right and left reference standards.

TABLE II (Continued)

	Left Quadrants 							
EXPERIMENTAL METHOD	ACCURACY CLASS				ACCURACY CLASS			
	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
I	58.7	16.9	5.5	18.7	69.3	16.9	4.2	9.3
Cum. %		75.6	81.1	100.0		86.2	90.4	100.0
II	62.2	19.0	7.5	11.2	77.5	16.3	4.5	1.5
Cum. %		81.2	88.7	100.0		93.8	98.3	100.0
III*	74.9	22.4	2.5	0	72.1	25.6	2.4	0
Cum. %		97.3	100.0	100.0		97.7	100.0	100.0
IV	70.0	20.0	7.3	2.6	90.7	8.5	0.009	0.004
Cum. %		90.0	97.3	100.0		99.2	99.009	100.0
Grand Mdn.	65.1			6.9	74.8			2.25

*Median percent of all judgments, using both right and left reference standards.

TABLE III

NUMBER OF JUDGMENTS IN EACH ACCURACY CLASS FOR EACH SUBJECT, BY EXPERIMENTAL METHOD

(Each score represents the total number of judgments in the accuracy class interval for the entire quadrant)

a. Experiment I (verbally reported, using normal compass headings)

	Right Quadrants 0-45°				Right Quadrants 46-90°			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
H	32.0	10.0	5.0	8.0	28.0	3.0	11.0	13.0
N	17.0	16.0	12.0	10.0	21.0	10.0	5.0	19.0
M	42.0	12.0	0.0	1.0	21.0	7.0	11.0	16.0
D	51.0	0	0	0	53.0	1.0	0	0
T	48.0	5.0	2.0	0	33.0	13.0	3.0	6.0
TE	52.0	3.0	0	0	39.0	16.0	0	0
ΣX	242.0	46.0	19.0	19.0	195.0	50.0	30.0	54.0
Mdn.	45.0	10.0	5.0	8.0	0	8.5	0	14.5
%	74.2	14.1	5.8	5.8	59.2	15.1	9.1	16.4
Cumulative %	0	88.3	94.1	0	0	74.3	83.4	0

	Left Quadrants 270-315°				Left Quadrants 316-360°			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
H	33.0	7.0	5.0	21.0	31.0	14.0	4.0	6.0
N	34.0	8.0	5.0	19.0	27.0	9.0	8.0	11.0
M	19.0	11.0	6.0	30.0	27.0	17.0	0.0	11.0
D	64.0	1.0	0	1.0	51.0	3.0	0	0
T	42.0	20.0	1.0	2.0	45.0	9.0	0	2.0
TE	40.0	20.0	5.0	1.0	48.0	4.0	2.0	1.0
ΣX	232.0	67.0	22.0	74.0	229.0	56.0	14.0	31.0
Mdn.	0	0	0	8.5	0	0	0	0
%	58.7	16.9	5.5	18.7	69.3	16.9	4.2	9.3
Cumulative %	0	75.6	81.1	0	0	86.2	90.4	0

(Table Continued)

TABLE III (Continued)

b. Experiment II (verbally reported, using 0 to 90° quadrant numerals.)

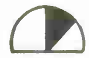
	Right Quadrants							
	 0-45°				 46-90°			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
H	40.0	13.0	2.0	0	16.0	5.0	13.0	21.0
N	19.0	14.0	14.0	8.0	31.0	6.0	4.0	14.0
M	34.0	16.0	4.0	1.0	25.0	8.0	11.0	11.0
D	54.0	4.0	0	0	56.0	0	0	0
T	52.0	3.0	0	0	31.0	22.0	1.0	1.0
TE	44.0	9.0	0	0	49.0	9.0	0	0
ΣX	243.0	66.0	20.0	9	208.0	50.0	29.0	47.0
Mdn.	42.0	0	0	4.5	0	0	0	0
%	71.8	19.5	5.9	2.6	62.2	14.9	8.6	14.0
Cumulative %	0	91.3	97.2	0	0	77.1	85.7	0

	Left Quadrants							
	 90-45°				 46-0°			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	+11-15°	±16° →
H	23.0	11.0	12.0	21.0	38.0	9.0	6.0	2.0
N	42.0	12.0	4.0	8.0	35.0	13.0	6.0	1.0
M	28.0	3.0	16.0	19.0	34.0	17.0	3.0	1.0
D	66.0	0	0	0	54.0	0	0	1.0
T	51.0	15.0	0	0	48.0	7.0	0	0
TE	55.0	10.0	0	0	47.0	8.0	0	0
ΣX	265.0	81.0	32.0	48.0	256.0	54.0	15.0	5.0
Mdn.	0	0	0	0	0	0	0	0
%	62.2	19.0	7.5	11.2	77.5	16.3	4.5	1.5
Cumulative %	0	81.2	88.7	0	0	93.8	98.3	0

(Table Continued)

TABLE III (Continued)

c. Experiment III (manual adjustment response, with reference standard and three-dimensional stimulus.)

	Right Quadrant 							
	RIGHT STANDARD				LEFT STANDARD			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16°→	±0-5°	±6-10°	±11-15°	±16°→
H	7.0	1.0	2.0	0	4.0	6.0	0	0
N	4.0	4.0	2.0	0	2.0	3.0	5.0	0
M	6.0	4.0	0	0	10.0	0	0	0
D	8.0	2.0	0	0	10.0	0	0	0
T	7.0	3.0	0	0	8.0	2.0	0	0
TE	10.0	0	0	0	9.0	1.0	0	0
ΣX	42.0	14.0	4.0	0	43.0	12.0	5.0	0
%	70.0	23.3	6.6	0	71.6	20.0	8.3	0
Cumulative %	0	93.3	99.9	100.0	0	96.1	99.9	100.0

	Right Quadrant 							
	RIGHT STANDARD				LEFT STANDARD			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16°→	±0-5°	±6-10°	±11-15°	±16°→
H	7.0	3.0	0	0	7.0	3.0	0	0
N	5.0	5.0	0	0	8.0	2.0	0	0
M	7.0	2.0	1.0	0	5.0	4.0	1.0	0
D	4.0	6.0	0	0	7.0	1.0	2.0	0
T	10.0	0	0	0	10.0	0	0	0
TE	10.0	0	0	0	9.0	1.0	0	0
ΣX	43.0	16.0	1.0	0	46.0	11.0	3.0	0
%	71.6	26.6	1.6	0	76.6	18.3	5.0	0
Cumulative %	0	98.2	99.8	100.0	0	94.9	99.9	100.0

(Table Continued)

TABLE III (Continued)

c. Experiment III (manual adjustment response, with reference standard and three-dimensional stimulus.) (Continued)

	Left Quadrant 							
	RIGHT STANDARD				LEFT STANDARD			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16°→	±0-5°	±6-10°	±11-15°	±16°→
H	3.0	5.0	2.0	0	9.0	1.0	0	0
N	8.0	2.0	0	0	3.0	6.0	1.0	0
M	7.0	3.0	0	0	3.0	7.0	0	0
D	7.0	3.0	0	0	10.0	0	0	0
T	8.0	2.0	0	0	10.0	0	0	0
TE	8.0	2.0	0	0	10.0	0	0	0
ΣX	41.0	17.0	2.0	0	45.0	14.0	1.0	0
%	68.3	28.3	3.3	0	75.0	23.0	1.6	0
Cumulative %	0	96.6	99.9	100.0	0	98.0	99.6	100.0

	Left Quadrant 							
	RIGHT STANDARD				LEFT STANDARD			
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16°→	±0-5°	±6-10°	±11-15°	±16°→
H	7.0	3.0	0	0	5.0	5.0	0	0
N	4.0	6.0	0	0	8.0	2.0	0	0
M	5.0	2.0	3.0	0	8.0	2.0	0	0
D	9.0	1.0	0	0	10.0	0	0	0
T	10.0	0	0	0	9.0	1.0	0	0
TE	5.0	5.0	0	0	10.0	0	0	0
ΣX	40.0	17.0	3.0	0	50.0	10.0	0	0
%	66.6	28.3	5.0	0	83.3	16.6	0	0
Cumulative %	0	94.9	99.9	100.0	0	99.9	100.0	0

(Table Continued)

TABLE III (Continued)

d. Experiment IV (manual adjustment response, with reference standard in two dimensions.)

	Right Quadrants							
								
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
H	21.0	3.0	0	1.0	5.0	9.0	8.0	3.0
N	21.0	4.0	0	0	15.0	10.0	0	0
M	13.0	10.0	2.0	0	13.0	11.0	1.0	0
D	20.0	5.0	0	0	25.0	0	0	0
T	21.0	4.0	0	0	18.0	7.0	0	0
TE	19.0	6.0	0	0	23.0	2.0	0	0
ΣX	115.0	32.0	2.0	1.0	99.0	39.0	9.0	3.0
%	76.6	21.3	1.3	0.06	66.0	26.0	6.0	2.0
Cumulative %	0	97.9	99.2	100.0	0	92.0	98.0	100.0

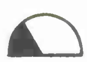
	Left Quadrants							
								
	ACCURACY CLASS				ACCURACY CLASS			
SUBJECT	±0-5°	±6-10°	±11-15°	±16° →	±0-5°	±6-10°	±11-15°	±16° →
H	5.0	8.0	9.0	3.0	25.0	9.0	1.0	0
N	19.0	5.0	1.0	0	31.0	3.0	0	1.0
M	21.0	4.0	0	0	33.0	2.0	0	0
D	24.0	1.0	0	0	34.0	1.0	0	0
T	14.0	10.0	0	1	34.0	1.0	0	0
TE	22.0	2.0	1.0	0	32.0	2.0	1.0	0
ΣX	105.0	30.0	11.0	4.0	189.0	18.0	2.0	1.0
%	70.0	20.0	7.3	2.6	90.7	8.5	0.009	0.004
Cumulative %	0	90.0	97.3	100.0	0	99.2	99.009	100.0

TABLE IV

PERCENT OF OVERESTIMATIONS (+), UNDERESTIMATIONS (−) AND CORRECT JUDGMENTS (0) FOR EACH SUBJECT FOR EACH EXPERIMENT, BY 45° QUADRANT

(a) Low-Accuracy Group

		Right Quadrants						Left Quadrants					
													
SUBJECT	METHOD	+	−	0	+	−	0	+	−	0	+	−	0
H	I	15.0	50.9	33.9	3.8	67.3	28.3	61.4	3.5	35.0	48.2	16.0	35.7
	II	18.1	49.0	32.7	1.8	80.0	18.1	1.8	67.2	30.9	25.3	33.3	41.2
	III	55.0	40.0	5.0	30.0	70.0	0	55.0	40.0	5.0	75.0	20.0	5.0
	IV	48.0	44.0	8.0	20.0	64.0	16.0	80.0	12.0	8.0	40.0	45.7	14.2
Mdn.		33.0	46.5	20.3	11.9	68.6	17.0	58.2	26.0	19.4	44.1	26.6	24.9
N	I	0	90.0	9.0	0	69.0	30.9	60.9	7.8	31.2	73.2	0	26.7
	II	0	87.5	12.5	11.5	59.6	28.8	17.8	48.2	33.9	3.0	66.1	30.7
	III	45.0	55.0	0	60.0	40.0	0	65.0	35.0	0	55.0	30.0	15.0
	IV	44.0	56.0	0	24.0	76.0	0	0	96.0	4.0	68.5	25.7	5.7
Mdn.		22.0	71.7	4.5	17.7	73.7	14.4	39.3	41.6	17.6	75.2	27.8	20.8
M	I	0	48.2	51.7	1.8	68.5	29.6	78.7	1.5	19.6	46.2	9.2	44.4
	II	39.6	22.6	37.7	0	78.9	21.0	0	75.9	24.0	35.1	38.8	25.9
	III	35.0	65.0	0	65.0	30.0	5.0	40.0	55.0	5.0	35.0	60.0	5.0
	IV	20.0	80.0	0	12.0	88.0	0	40.0	56.0	4.0	37.1	48.5	14.2
Mdn.		27.5	56.6	18.8	6.9	73.7	13.0	40.0	55.5	12.3	36.1	43.6	20.0
Grand Mdn.		27.5	56.6	18.8	11.9	73.7	14.4	40.0	41.6	17.6	44.1	27.8	20.8

(Table Continued)

TABLE IV (Continued)

(b) High-Accuracy Group

SUBJECT	METHOD	Right Quadrants 						Left Quadrants 					
		+	–	0	+	–	0	+	–	0	+	–	0
D	I	12.9	33.3	53.7	14.2	10.2	75.5	19.6	10.6	69.6	25.9	20.3	53.7
	II	9.0	21.8	67.2	11.3	0	88.6	10.9	14.5	74.5	5.0	33.8	61.0
	III	25.0	75.0	0	45.0	45.0	10.0	30.0	45.0	25.0	15.0	70.0	15.0
	IV	40.0	44.0	16.0	20.0	64.0	16.0	80.0	12.0	8.0	91.4	2.8	5.7
Mdn.		18.9	38.6	34.0	17.1	27.6	45.7	24.8	13.2	47.3	20.4	40.5	34.3
T	I	16.3	7.2	76.3	3.6	58.1	38.1	50.0	3.0	46.9	20.0	12.7	67.2
	II	9.0	5.4	85.4	0	54.7	45.2	3.6	41.8	54.5	21.5	3.0	75.3
	III	50.0	50.0	0	65.0	15.0	20.0	50.0	45.0	5.0	55.0	40.0	5.0
	IV	76.0	12.0	12.0	8.0	88.0	4.0	0	100.0	0	68.5	17.1	14.2
Mdn.		33.1	9.6	44.1	5.8	56.4	29.0	26.8	43.4	25.9	38.2	14.9	40.7
TE	I	63.6	9.0	27.2	5.4	67.2	27.2	81.8	1.5	16.6	23.6	49.0	27.2
	II	10.5	10.5	78.9	0	15.0	84.9	1.8	18.1	80.0	15.1	1.5	83.3
	III	20.0	65.0	15.0	55.0	40.0	5.0	65.0	25.0	10.0	55.0	40.0	5.0
	IV	24.0	72.0	4.0	8.0	80.0	12.0	0	96.0	4.0	22.8	60.0	17.1
Mdn.		22.0	37.7	21.1	6.7	53.6	19.5	25.3	22.0	13.3	23.2	44.5	22.1
Grand Mdn.		22.0	37.7	34.0	6.7	53.6	29.0	25.3	22.0	25.9	23.2	40.5	34.3

TABLE V

NUMBER OF JUDGMENTS IN EACH OF THE 45° QUADRANTS THAT WERE UNDERESTIMATED, (–) OVERESTIMATED (+), OR CORRECT (0) FOR EACH SUBJECT FOR:

(a) METHOD I

SUBJECT	Right Quadrants						Left Quadrants					
												
	+	–	0	+	–	0	+	–	0	+	–	0
H	8.0	27.0	18.0	2.0	35.0	15.0	35.0	2.0	20.0	27.0	9.0	20.0
N	0	50.0	5.0	0	38.0	17.0	39.0	5.0	20.0	41.0	0	15.0
M	0	27.0	29.0	1.0	37.0	16.0	52.0	1.0	13.0	25.0	5.0	24.0
D	7.0	18.0	29.0	7.0	5.0	37.0	13.0	7.0	46.0	14.0	11.0	29.0
T	9.0	4.0	42.0	2.0	32.0	21.0	33.0	2.0	31.0	11.0	7.0	37.0
TE	35.0	5.0	15.0	3.0	37.0	15.0	54.0	1.0	11.0	13.0	27.0	15.0
Σ	59.0	131.0	138.0	15.0	184.0	121.0	226.0	18.0	141.0	131.0	59.0	140.0
Mdn.	7.5	22.5	23.5	2.0	36.0	16.5	37.0	3.5	20.0	19.5	8.0	22.0

(b) METHOD II

SUBJECT	Right Quadrants						Left Quadrants					
												
	+	–	0	+	–	0	+	–	0	+	–	0
H	10.0	27.0	18.0	1.0	44.0	10.0	1.0	37.0	17.0	16.0	21.0	26.0
N	0	49.0	7.0	6.0	31.0	15.0	10.0	27.0	19.0	2.0	43.0	20.0
M	21.0	12.0	20.0	0	45.0	12.0	0	41.0	13.0	19.0	21.0	14.0
D	5.0	12.0	37.0	6.0	0	47.0	6.0	8.0	41.0	3.0	20.0	36.0
T	5.0	3.0	47.0	0	29.0	24.0	2.0	23.0	30.0	14.0	2.0	49.0
TE	6.0	6.0	45.0	0	8.0	45.0	1.0	10.0	44.0	10.0	1.0	55.0
Σ	49.0	109.0	174.0	13.0	157.0	153.0	20.0	146.0	164.0	64.0	108.0	200.0
Mdn.	5.5	12.0	28.5	0.5	30.0	19.5	1.5	25.0	24.5	12.0	20.0	31.0

(Table Continued)

TABLE V (Continued)

(c) METHOD III

Right Quadrant 						
DEGREES	L* (+)	R* (+)	L (−)	R (−)	L (0)	R (0)
9	9	2	2	10	1	0
18	6	4	6	8	0	0
27	7	3	5	9	0	0
36	4	3	8	8	0	1
45	4	3	6	7	2	1
Σ	30	15	27	42	3	2

Right Quadrant 						
DEGREES	L (+)	R (+)	L (−)	R (−)	L (0)	R (0)
54	6	4	5	8	1	0
63	9	5	3	7	0	0
72	9	7	2	3	1	2
81	8	5	4	6	0	1
90	8	3	2	7	2	2
Σ	40	24	16	31	4	5

ΣΣ	70	39	43	73	7	7

*L & R are left and right standard stimulus; i.e. standard stimulus was presented either to left or right of variable stimulus.

(Table Continued)

TABLE V (Continued)

(c) METHOD III (Continued)

Left Quadrant 						
DEGREES	+ L	R	− L	R	0 L	R
9	7	6	5	5	0	1
18	5	6	7	5	0	1
27	5	5	5	6	2	1
36	6	4	5	7	1	1
45	7	7	3	4	2	1
Σ	30	28	25	27	5	5

Left Quadrant 						
DEGREES	+ L	R	− L	R	0 L	R
54	5	7	7	4	0	1
63	4	6	6	2	2	1
72	4	10	7	2	1	0
81	3	10	8	1	1	1
90	1	12	8	0	3	0
Σ	17	48	36	9	7	3

ΣΣ	47	76	61	36	12	8

*L & R are left and right standard stimulus; i.e. standard stimulus was presented either to left or right of variable stimulus.

(Table Continued)

TABLE V (Continued)

(d) METHOD IV

	Right Quadrants						Left Quadrants					
												
SUBJECT	+	–	0	+	–	0	+	–	0	+	–	0
H	12.0	11.0	2.0	2.0	22.0	1.0	1.0	24.0	0	14.0	16.0	5.0
N	11.0	14.0	0	6.0	19.0	0	0	24.0	1.0	24.0	9.0	2.0
M	5.0	20.0	0	3.0	22.0	0	10.0	14.0	1.0	13.0	17.0	5.0
D	10.0	11.0	4.0	5.0	16.0	4.0	20.0	3.0	2.0	32.0	1.0	2.0
T	19.0	3.0	3.0	2.0	22.0	1.0	0	25.0	0	24.0	6.0	5.0
TE	6.0	18.0	1.0	2.0	20.0	3.0	0	24.0	1.0	8.0	21.0	6.0
Σ	63.0	77.0	10.0	20.0	121.0	9.0	31.0	114.0	5.0	115.0	70.0	25.0
Mdn.	10.5	12.5	1.5	2.5	21.0	1.0	0.5	24.0	1.0	19.0	12.5	5.0
%	42.0	51.3	6.6	13.3	80.6	6.0	20.6	76.0	3.3	54.7	33.3	11.9

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