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CONSPICUITY OF TARGET LIGHTS: THE INFLUENCE OF FLASH RATE AND BRIGHTNESS

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16. Abstract

For most pilots, collision avoidance continues to depend on visual sightings. The purpose of this study was to examine the stimulus characteristics of lights that might aid a pilot to "see and avoid," by alerting him to a potential threat. This study examined the relative conspicuity of foveally equated, point-source, steady and flashing lights of several brightnesses, seen against a star background. From the subject's viewpoint, these target lights could appear anywhere within a large (40° horizontal by 35° vertical) field of view. The lights appeared at random time intervals while the subject was periodically distracted by a simulated cockpit task.

The results indicate that correct target detection increased and reaction time decreased with increased target intensity. Steady lights were missed more frequently and acquired more slowly than flashing lights, but no significant differences were found among the wide range of flash rates employed. The intensity of the light had a greater effect on both detection and reaction time to steady lights than to flashing lights. These results are compared with results of other researchers who used targets which appeared at fixed locations. The longest reaction times were recorded to lights which appeared either at the extremes or at the very center of the visual field.

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CONSPICUITY OF TARGET LIGHTS: THE INFLUENCE OF FLASH RATE AND BRIGHTNESS

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SUMMARY

For most pilots, collision avoidance continues to depend on visual sightings. The purpose of this study was to examine the stimulus characteristics of lights that might aid a pilot to "see and avoid," by alerting him to a potential threat. This study examined the relative conspicuity of foveally equated, point-source, steady and flashing lights of several brightnesses, seen against a star background. From the subject's viewpoint, these target lights could appear anywhere within a large (40° horizontal by 35° vertical) field of view. The lights appeared at random time intervals while the subject was periodically distracted by a simulated cockpit task.

The results indicate that correct target detection increased and reaction time decreased with increased target intensity. Steady lights were missed more frequently and acquired more slowly than flashing lights, but no significant differences were found among the wide range of flash rates employed. The intensity of the light had a greater effect on both detection and reaction time to steady lights than to flashing lights.

This study revealed that the longest reaction times were recorded to lights which appeared either at the extremes or at the very center of the visual field. Since this finding mimics the retinal sensitivity pattern, it appears that the subjects in this free search situation began their search by focusing the center of the field of view, acquiring first those targets which appeared in the range of 3°-8° from the center.

INTRODUCTION

Midair collisions, although relatively infrequent, do occur. These collisions do not usually attract national attention since most collisions occur between two general aviation aircraft (ref. 1). However, occasionally a commercial aircraft is involved, and less frequently, two commercial aircraft. Near elimination of collisions will require that flights be totally automated or that collision avoidance systems (CAS) be installed. The most feasible CASs under development are cooperative systems, and general aviation cannot be expected to assume the costs of such systems. Thus, use of even the latest technology protects only commercial aircraft from midair collision with each other, leaving most potential collision situations, at least for the near future, unresolved. It is likely to take many years for a workable collision avoidance system to be developed and longer for it to be required for all aircraft. In the meantime, commercial, private, and even military aircraft share much of the same airspace, and the potential for destruction remains unabated. Thus the see-and-avoid principle of collision avoidance is still a necessary procedure for all types of aircraft, and in many cases, the only one available. The problem then becomes one of aiding the pilot so that he can see and avoid aircraft in his area as efficiently and effectively as possible.

There is evidence that a pilot's failure to avoid another aircraft is due, in the overwhelming majority of cases, to a failure to see (ref. 2). To alleviate this problem, at least for nighttime flying, lighting characteristics have received increased attention in recent years. The 1968 Near Midair Collision (NMAC) study (ref. 3) reports that for hazardous night occurrences, lights were the first cause of alert for 49 of the 70 incidents. (A somewhat surprising aspect of this study was that navigation lights were spotted more frequently than rotating beacons whose higher intensity might have been expected to give them a visibility advantage.) A general conclusion of the NMAC study was that "predominant among all recommendations for better aircraft lighting...high intensity strobe lights should be required for all aircraft."

The study described in this paper looked at certain stimulus characteristics of lighting systems that may suggest more effective ways of attracting a pilot or copilot's attention to the outside of the cockpit when he may be engaged in cockpit duties and not actively searching for other aircraft. This is the problem of visual attention-getting, or conspicuity. Although this problem shares many characteristics with the question of perception (since what cannot be seen cannot be attention-getting) it goes well beyond the question of simple threshold perception.

Hambacher and Gallup (ref. 4), using near cockpit vision and stimuli that appeared at a fixed angular distance from fixation, found no differences in reaction time between steady and 2-Hz flashing lights that appeared within the visual field of the subject under the nighttime condition. They found a difference, favoring the flashing light, when the light first appeared outside the subject's field of view. Steady lights were missed more frequently than flashing lights under both conditions, that is, outside and inside the subject's field of view. Similarly, Lincoln et al. (ref. 5) found no effect on the time required for brightness discrimination for flashes varying from 0.6 to 2.8 Hz.

Gerathewohl (ref. 6) used target lights that appeared in a fixed location 15.5° above the central line of sight, the steady or lower frequency signal appearing on the left, the intermittent or higher frequency signal on the right. He found that a flashing white light is more conspicuous than a steady white light at low-contrast thresholds; a steady light is more conspicuous than a flashing light at high-contrast levels. He reported that at high contrast or frequency a change in the opposite factor did not significantly influence the results; at low contrast, conspicuity increased with flash frequency; at low frequency, conspicuity increased with contrast.

Edwards (ref. 7) asked his subjects to report which of two lights was more attention-getting. In one condition, the observer looked from one light to the other; in the second condition, the subject looked between the lights. Edwards found no significant differences among lights over the range of 1.55 to 2.75 Hz. Although Edwards refers to this task as "conspicuity," his task implies a combination of perception and preference and differs conceptually from the meaning of conspicuity as used by Gerathewohl (refs. 6, 8, and 9) and in the present study.

Aitken et al. (ref. 10) measured both skin conductance and subjective preference to flash rates ranging from 1.0 to 2.33 Hz. Over time, skin resistance was higher with higher frequencies. If this increased skin resistance is assumed to have the same relationship to alertness as has been found in other situations (ref. 11), a higher frequency would imply a higher level of alertness. However, the preference data favored the lower frequencies of 1.0 and 1.33 Hz. These authors conclude that the preference data are more reliable indicators of the acceptability of various frequencies than skin conductance. They conclude that drowsiness may be associated with low frequencies and mild irritation with high frequencies, and give qualified support to use of lower frequencies.

These studies indicate that under some, but not all, conditions, flashing lights are superior to steady lights. In addition, Gerathewohl (ref. 6) presents evidence for superior performance with higher frequencies, while the data of the Aitken et al. (ref. 10) on skin conductance provide the physiological rationale for expecting improved performance with higher frequencies, although this improved performance may not translate into pilot acceptance.

One problem inherent in laboratory investigations of conspicuity is that the subject, because of his participation in the study and instructions that must be given him, is already at least partially attending to the task which is "getting" his attention. He is not as distracted as he would be in the more complex, real-world situation. A second limitation of the vast majority of conspicuity studies is associated with the use of a small field of view, few potential target positions, and near vision - conditions that probably reduce differences among stimuli and are not representative of the air-to-air viewing situation.

The present study was an attempt to evaluate the conspicuity-lighting relationship for conditions that are at least partially representative of the actual aircraft-lighting problem. Specifically, the experiment was designed to determine the comparative attention-getting characteristics of steady and of flashing lights over a range of brightnesses (seen at apparent infinity), with lights appearing in unpredictable positions and over a reasonably large search area. Particular emphasis was placed on determining the relative conspicuity of steady lights and lights of various flash rates which appeared while the subject was monitoring an on-going task that periodically required in-the-cockpit fixation.

APPARATUS

The subject's observing station was mounted on a platform in the center of a large, light-tight room. The subject sat on an adjustable aircraft seat and positioned his head on a chin rest in such a way that his line of sight was normal to the black wall which he faced. This wall was 9.14 m from the subject and measured 7.62 m wide by 6.25 m high, providing a visual angle to the subject of approximately 40° horizontal by 34.5° vertical. A star background was simulated by 50-point source lights by varying intensities, mounted in the wall. Among these "stars," 20-point source target lights were positioned randomly with regard to meridian (selected from a possible 1° to 360°) and displacement from the central, eye-level position (0° to 17°). The single restriction imposed on this random selection was that each quadrant should contain five target lights. One light, assigned to the upper left quadrant, drew a 0° displacement and was assigned the central position.

The target lights were Bausch and Lomb 2.5 V, white, center-filament tungsten lamps. Light from each target source was directed at the observer's position through a circular point-source aperture of 0.046 cm diameter. Target lights were matched in apparent intensity for a series of observers; these equal intensity positionings were set and maintained by potentiometers attached to each light. A spectral conversion filter (#80B), placed before each target light, resulted in a more acceptable "white" light (tristimulus coordinates $x = 0.368$, $y = 0.358$) compared with the slight yellowness of the source. Servo-operated filter wheels with 16 available positions were placed before each target light. For the present experiment only white target lights were used. The brightnesses of these white lights were varied by neutral-tint filters mounted on the filter wheels. All filters were either special purchased in sheets large enough so that they could all be cut from a single gelatin filter, or measured and equated for transmittance with a Beckman DK-2A spectrophotometer. The target lights were verified visually for equality of apparent intensity at each filter position used. The experimenter's station (fig. 1) which was in an adjoining room, contained a panel of "master" filter wheel controls on which the appropriate intensity condition was set for each light prior to each experimental run. Filter-wheel settings were duplicated by the "slave" filter wheel mounted in front of the target light. The remainder of the experimental variables, that is, the orderings of target lights, flash rates, and on-off durations, were selected by preprogrammed tapes. Displays for the auxiliary, arithmetic task were mounted on a table 40.6 cm in front of, and diagonally below the subject's line of sight (fig. 2).

PROCEDURE

Auxiliary Task

A software program generated a series of numbers from 0 to 9 in sets of four; these numbers appeared as the visual readout displays of the *auxiliary task*. The distribution of the sums of these numbers peaked around the criterion of 19, becoming less frequent as the program generated numbers of larger and smaller sums. All combinations of numbers that summed to less than 14 or to more than 24 were discarded by the program. Those remaining were used in the auxiliary task as described below.

The purpose of the *auxiliary task* was to divide the subject's attention in a manner analogous to the aircraft viewing situation in which the observer must search for other aircraft while attending to cockpit duties. The *auxiliary task* was presented at 10-sec intervals and the subject was instructed to monitor this task throughout the session. The subject viewed a readout display on which four numbers appeared simultaneously and remained visible for 3 sec. The subject was instructed to depress the dimly illuminated green switch below his left index finger if the sum of these four numbers was less than or equal to the criterion of 19. If the sum of the four numbers exceeded the criterion number, the subject depressed a corresponding switch below his right index finger. The subject's response was recorded if he responded either during the 3 sec when the display readout was visible or up to 1.5 sec after it disappeared. If he responded after this 4.5-sec interval, or if he did not respond, a reading of "no response" was recorded.

The presentation rate of 10 sec from the onset of one problem set to the onset of the next forced the subject to a reasonably high level of concentration, and also allowed him to maintain a high level of accuracy. Although the subject was provided no feedback, he was generally aware of his performance, since he had the balance of the 10-sec trial interval after making his response to recalculate his figures. Performance data were available on counters so that the experimenter could follow the subject's performance as it occurred. By the start of the formal experiment, all subjects were responding correctly to about 80 percent of the trials within the above time constraints. For the *auxiliary task*, correct, incorrect, and "no response" frequencies were recorded.

Target-Detection Task

For the main task of detecting targets against a star background, the total time from the appearance of the target to the completion of the particular presentation (including off-time as well as on-time for flashing lights) was 3 sec. The subjects were instructed to respond to all lights, flashing or steady, that appeared against the star background. If the subject detected a target in the star field in front of him, he depressed a small button located slightly below and between the response buttons for the *auxiliary task*. After the presentation of the target, the subject had an additional 2 sec to record his sighting. While the *auxiliary*, arithmetic task appeared at regular intervals, the primary *target task* was presented at intervals varying randomly between 8 and 26 sec in 1-sec steps. During the training sessions, performance on the *target task* rose to approximately 70 percent correct response, or better, for all subjects.

Each of 10 male, college-student subjects viewed each combination of light position (20), brightness (3), and flash rate (5), twice (one replication), for a total of 600 presentations for each subject. The 20 light positions used are shown in figure 3. The dimmest target intensity was equivalent to about 0.01 ml, just sufficient to be comfortably visible in foveal vision after the 10-min dark-adaptation period that preceded each session. The medium intensity was 0.5 log units higher, and the high intensity 1.0 log units higher, than the lowest setting. The on-off duty cycle was constant at 0.5/0.5 and the exposure duration was 3 sec throughout. Flash rates were 1 Hz (500 msec on/500 msec off, repeated 3 times); 2 Hz (250 msec/250 msec, 6 flashes); 3 Hz (166 msec/167 msec, 9 flashes); 4 Hz (125 msec/125 msec, 12 flashes); and a steady light of 3-sec duration. For all flash rates, the energy level (total on time) was constant. Total on time for the steady light was double that of the flashing lights. (In an earlier pilot study, all lights including the steady light were equated for equal energy output. The steady light in this case was 1500 msec on, 1500 msec off, 1 flash. This condition resulted in reaction to the steady light that was so markedly inferior to reaction to the flashing lights that a further comparison seemed unnecessary.) In the present experiment, exposure duration from the beginning of the first to the end of the last flash was constant for all conditions.

In each of six experimental sessions, each subject viewed 100 target lights - 20 in each of 5 experimental runs. Each run contained one presentation of each of the 20 target lights. A random-selection program ordered the presentation of these lights within a run. As part of the same software program, the other variables, intensity and flash rate, were randomized without replacement within a replication (over 5 experimental sessions). Separate tapes were generated for the replicated sessions so that throughout the experiment the subjects never viewed the same order of target lights presentations twice. Reaction times to sightings, as well as correct and incorrect (missed) responses, were recorded.

EXPERIMENTAL CONDITIONS

The subjects used binocular vision throughout the experiment. The experiment room was darkened so that the subject could see nothing in the visual environment except the response buttons of the arithmetic task and the star background at apparent infinity against which the target lights appeared. The subjects used a free search pattern for detecting target lights. Each subject was given several days of pre-experimental training to allow his performance, both on the primary *target task* and on the secondary *auxiliary task*, to become stabilized. Each subject dark-adapted for from 10 to 15 min prior to each session. The experiment commenced when the stars in the background could be acquired foveally. Subjects were given no indication of the relative priority of the tasks, nor did they know the time periods in which they were expected to respond. As in the training sessions, they were instructed to respond to both tasks as quickly and as accurately as possible.

RESULTS

The purpose of the auxiliary task was to distract the subject. The condition of being distracted was of greater interest in this experiment than the subject's performance on this task. Therefore, data concerning performance on the *auxiliary task* are not presented here.

Responses to the *target task* were analyzed in terms of the number of targets correctly detected and in terms of subject reaction time. These measures are not totally independent, since, for stimuli that were not detected, a reaction time of 5 sec was entered into the reaction time calculations. An analysis of variance performed on the detection data resulted in F ratios that were significantly different from chance for all main and double interaction effects. The reaction time analysis of variance produced significant results for all main effects and for two-way interaction effects, with the exception of the light position-flash rate interaction. Both sets of data were further analyzed by Duncan's Method of Multiple Comparison (ref. 12).

The overall differences in ordering among levels of intensity and among levels of flash rate are shown in table 1. For this and later tables, figures in parentheses below the stimulus condition refer to the mean reaction times. A continuous line below adjoining stimulus levels indicates that those levels are not significantly different from each other. A comma between levels indicates that performance at those levels was the same; a dash indicates a difference in the direction indicated that was not sufficiently large to be statistically significant at the $p = 0.05$ level.

Table 1 shows that correct target detection increased and reaction times decreased with increases in target intensity. For the steady-flashing light comparison, it was found that the steady light, even with its energy advantage, was markedly inferior to all flashing lights. Among the flashing lights, no differences were found for these combined data that could be attributed with 95-percent certainty to other than chance.

Table 2 compares intensities for a fixed flash rate. Although the intensity orderings remain virtually the same over all flash-rate conditions and for both methods of measurement, greater discrimination among responses to various intensity levels is found at the steady and at the 4-Hz conditions than at the lower flash rates. The reaction-time data generally mirror the findings of the detection data, but with greater sensitivity.

Table 3 shows the relationships found among flash rates at fixed intensity levels. Although the steady light results in poorer performance than any flashing light condition at all intensity levels, the differences reach statistical significance only at the medium and at the low intensity levels. In this analysis, the detection data and the reaction-time data yield identical results in delineating statistically significant differences.

The findings concerning the influence of light position do not support any simple hypothesis. The detection data reveal no consistent trends. The reaction-time data show no consistent tendencies for either hemisphere (left or right, upper or lower) or quadrant (upper left, upper right, lower left, lower right) to lead to slower or faster perceptions. However, there does seem to be a more complicated relationship between light position and subject response time. One factor in this relationship appears to be the distance of the light from the center of the field of view. Figure 4 shows mean reaction times as a function of the distance of the light from the center of the visual field for each intensity level. Curves have been fitted visually to aid the reader. Although these data are far from consistent, there is a tendency for longer reaction times to be associated with lights at the extremes and at the center of the visual field compared with those in the 3°-8° peripheral range. The most notable and consistent responses were to the light that occupied the central position; this light had a relatively long reaction time at all intensity levels.

DISCUSSION

The present study indicates that there is a clear conspicuity advantage in using flashing white lights (even with the concomitant reduction in photic energy) over steady white lights, when seen against a star background. In the present study, the flash rates investigated covered a broad range. Although there is some evidence that subjects tend to respond more slowly to a 1-Hz flash than to flashes of higher frequency, the differences among flash rates are small and inconsistent. There is no indication of a monotonic relationship between flash rate and conspicuity as Gerathewohl has reported (ref. 6). The lack of significance of the light position - flash-rate interaction indicates that these flash-rate relationships apply to the entire visual field investigated.

Target intensity differences had greater effect on both detection and reaction time for steady lights than for flashing lights (see table 2). Increasing the intensity by a log unit did significantly shorten reaction time at all flash rates, although for the 1- and 2-Hz rates, it did not result in significant increases in the number of targets detected.

The differences in reaction time as a function of the position of the light in the visual field are difficult to interpret since they do not follow a pattern predicted by any simple hypothesis. Where large mean reaction times occurred, they were generally associated with target lights that were far from the central position, or at the central position itself. The four lights responded to least frequently were the central light and lights at or beyond 13° from the central position.

The detection and reaction-time differences found as a function of the light target position cannot be assumed to have resulted from intensity differences among the lights themselves. First, extensive calibration procedures were employed; lights were carefully equated and frequently checked for brightness equality, using several observers. Second, the central light was usually used as the standard to which all other lights were matched in brightness by looking back and forth between them. If subtle intensity differences were operating, one would expect responses to this light to lie in the middle of distributions of responses to all lights since lights that are directly matched could be assumed to be more similar to each other than lights that are equated indirectly, by comparison to a third light. However, in this study, the opposite is found: the central light is a deviate that results in a low detection rate and high reaction times. Finally, the specific lights that resulted in very long reaction times at one intensity level were not necessarily the same lights that resulted in very long reaction times at another intensity level. Figure 4 shows that for the low intensity condition a long mean reaction time was recorded to a light appearing at 16° from the center of the visual field (this light was located along the 154° meridian); for the medium-intensity condition, the slowest mean reaction time was to a light appearing at 17° from the center of visual field (along the 234° meridian). The only difference between intensity levels was provided by neutral-tint filters that were individually measured and selected for equality of transmission. If the unfiltered lights were equally bright and the filters equal to transmission, differences in response to various lights could not be due to unsuspected variations in the intensity dimension.

The most reasonable explanation of the light position results is that, in using a free-search pattern, the same light, at different times, will very likely impinge on different parts of the retina, causing changing response patterns. However, the data suggest that there is an overall tendency for a subject who is given no specific search instructions to search in a manner conducive to acquiring targets that are close to, but not at, the center of the visual field. This pattern corresponds to the light sensitivity of the retina itself, which gives a perceptual advantage to parafoveally acquired targets (refs. 13-15). Haines has found similar retinal-sensitivity patterns as measured by reaction time for lights appearing against a star field background (ref. 16). Different search patterns, via different instructions to the subject, should result in changing the light position-reaction time relationships of the free-search condition given here.

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TABLE 1.– OVERALL DIFFERENCES AMONG LEVELS OF INTENSITY AND FLASH RATE

	Measures	
	Detection	Reaction time
Intensity	Low Medium High	Low (1255) Medium (1044) High (848)
Flash rate, Hz	Steady 2, 4 - 3 - 1	Steady (1330) 1 (1020) - 4 (989) - 2 (954) - 3 (949)
Low ◄ Performance level ► High		

TABLE 2.– INTENSITY ORDERINGS FOR FIXED FLASH RATES

	Measures	
Flash rate, Hz	Detection	Reaction time
Steady	Low Medium High	Low (1789) Medium (1299) High (908)
1	Medium Low High	Low (1170) Medium (1011) High (878)
2	Low Medium High	Low (1072) Medium (961) High (829)
3	Low Medium High	Low (1067) Medium (982) High (797)
4	Low Medium High	Low (1173) Medium (1099) High (908)
Low ◄ Performance ► High		

TABLE 3.– FLASH RATE ORDERINGS FOR FIXED INTENSITIES

Intensity	Detection	Reaction time				
Low	Steady 4 - 2 - 3 - 1	Steady (1789)	4 (1173)	1 (1170)	2 (1072)	3 (1067)
Medium	Steady 1 - 2 - 3 - 4	Steady (1299)	1 (1011)	3 (982)	4 (967)	2 (961)
High	Steady - 1 - 2 - 4 - 3	Steady (908)	1 (877)	2 (829)	4 (827)	3 (797)

Low ← Performance → High

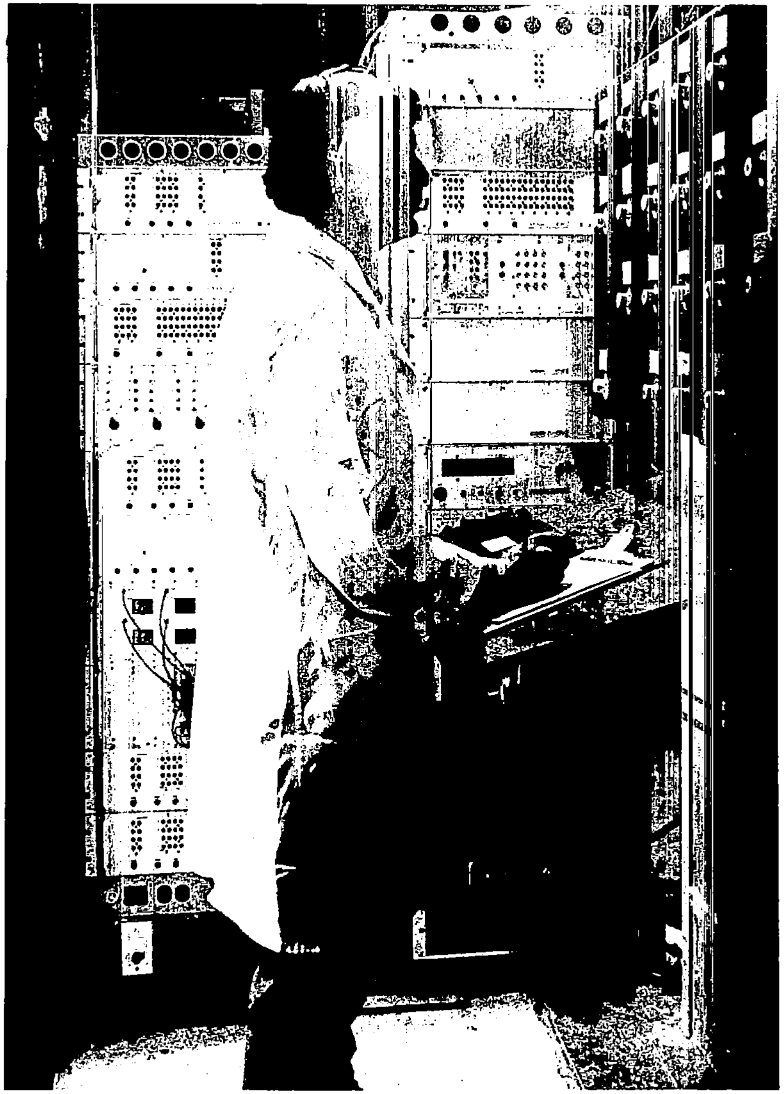

Figure 1.— Experimenter's station.

Figure 2.— Subject's station.

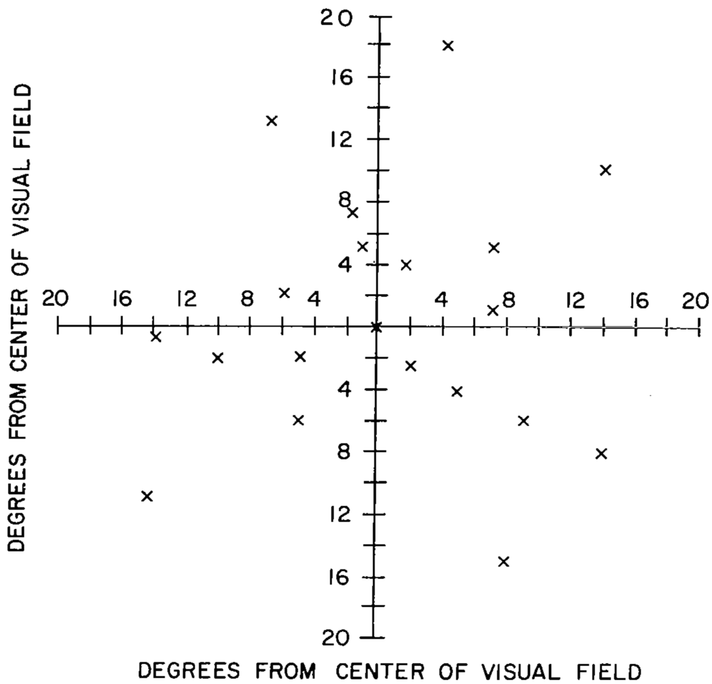

Figure 3.– Position of targets.

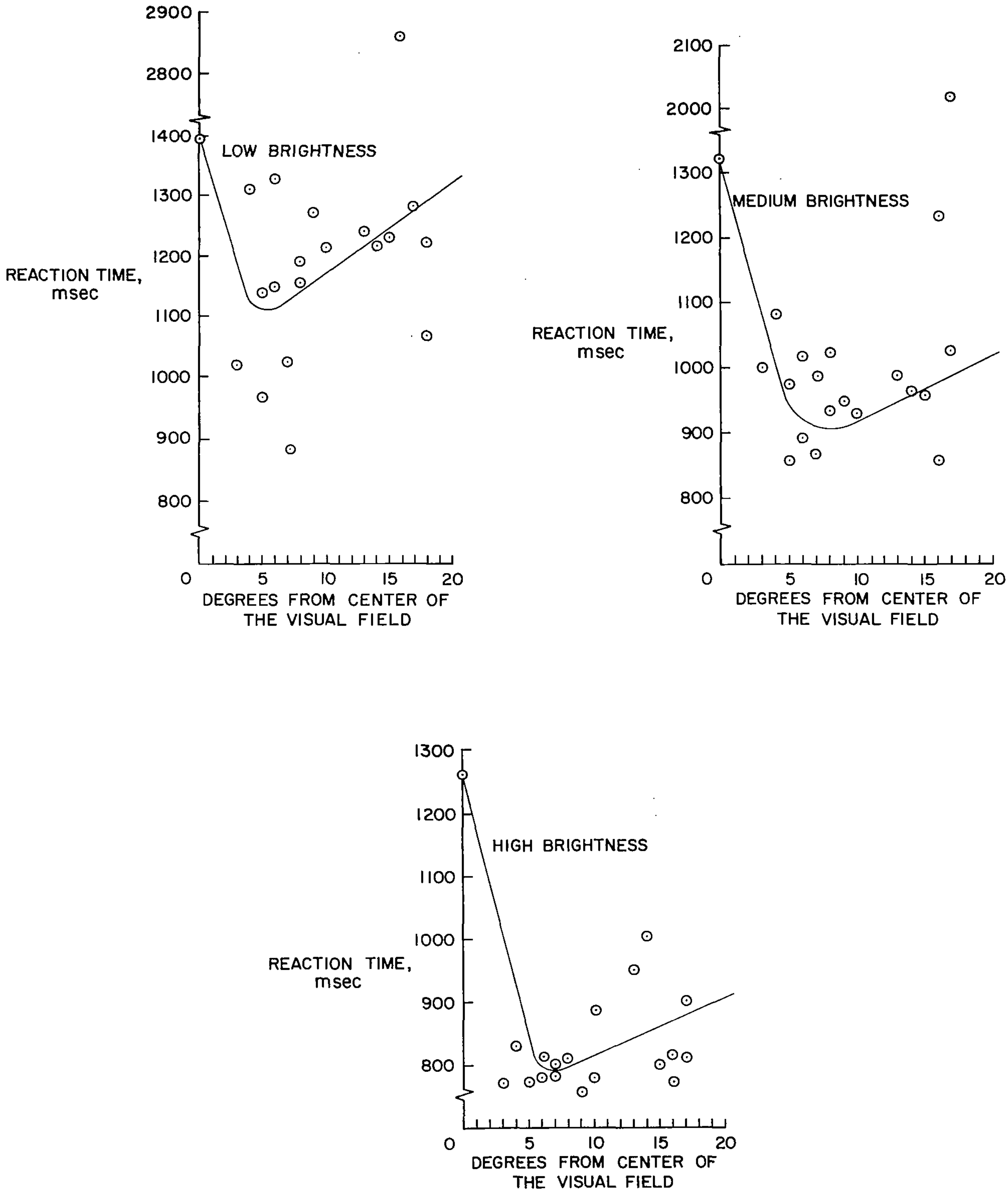

Figure 4.– Mean reaction time as a function of distance from the center of the visual field.