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FINAL REPORT

THE EFFECTS OF FOVEAL LOAD ON PERIPHERAL SENSITIVITY IN THE VISUAL FIELD

EDWARD J. RINALDUCCI, PH.D.

OCTOBER, 1989

U. S. ARMY RESEARCH OFFICE

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UNIVERSITY OF CENTRAL FLORIDA

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The main objective of this research was to investigate the effects of foveal load on sensitivity in the peripheral visual field. In the first of a series of four experiments, foveal load was manipulated by comparing the fixation of a cross vs. a simple first-order compensatory tracking task display. Peripheral sensitivity was determined simultaneously for light flashes presented at different eccentricities along the horizontal meridian. In general, the results showed no losses in peripheral sensitivity or a "tunnel vision" effect under the experimental conditions employed. In the three subsequent experiments, more complex tracking tasks were employed in order to vary foveal load. The difficulty of the perimetry task has also been manipulated in the fourth experiment by including lights on the vertical, as well as the horizontal meridian. Whether or not a loss or a gain in peripheral sensitivity was obtained depended upon the complexity of the foveal task and to some extent the difficulty of the perimetry task. Results are discussed in terms of arousal and resource theory, and recommendations are made for future research in this area.

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The Effects of Foveal Load on Visual Sensitivity in the on Peripheral Field

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FOREWORD

The main objective of this research was to investigate the effects of foveal load on sensitivity in the peripheral visual field. In the first of a series of four experiments, foveal load was manipulated by comparing the fixation of a cross vs. a simple first-order compensatory tracking task display. Peripheral sensitivity was determined simultaneously for light flashes presented at different eccentricities along the horizontal meridian. In general, the results showed no losses in peripheral sensitivity or a "tunnel vision" effect under the experimental conditions employed. In the three subsequent experiments, more complex tracking tasks were employed in order to vary foveal load. The difficulty of the perimetry task has also been manipulated in the fourth experiment by including lights on the vertical, as well as the horizontal meridian. Whether or not a loss or a gain in peripheral sensitivity was obtained depended upon the complexity of the foveal task and to some extent the difficulty of the perimetry task. Results are discussed in terms of arousal and resource theory, and recommendations are made for future research in this area.

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BODY OF THE REPORT

STATEMENT OF PROBLEM

The main objective of this research was to examine the effects of foveal loading on peripheral visual sensitivity. The research described here should have particular relevance o pilot performance and workload as well as to an operator's performance in an automobile driving task. A great deal of visual information must be processed by the pilot, and much of this is presented to the central foveal region of the visual field. In general, and aside from the research of this investigator and his associates (Rinalducci and Rose, 1986, 1987; Rinalducci, Rose, Mitchell, and Lassiter, 1987; Rinalducci, Lassiter, Rose, MacArthur, and Mitchell, 1989; Rinalducci, Lassiter, MacArthur, Piersall, and Mitchell, 1989), previous research in this area indicated that when there is a central visual task employed, vision in the periphery is reduced (Engle, 1971; Holmes, Cohen, and Morrison, 1977; Ikeda and Takeuchi, 1975; Leibowitz and Appelle, 1969; Williams, 1982, 1985, 1986, 1989). In particular, when there is an increase in difficulty of the central task (i.e., an increase in foveal load), there is a narrowing of the functional visual field sometimes referred to as "tunnel vision" or "coning". This results in a lowered detection of peripheral signals and an increased reaction time to peripheral objects, as well as a reduction in the human operator's ability to extract information from the periphery.

Previous investigations on foveal load often had several limitations. First, a number of the studies employed tachistoscopes or CRTs which severely limited an examination f peripheral sensitivity and information processing to about 10 degrees of visual angle. Second, there was no attempt to systematically examine the effects of training of the central task on peripheral sensitivity and the changes in the functional visual field. Third, the previous studies did not employ a tracking task which should have more relevance to pilot and driver performance. A tracking task is also one which is continuous rather than intermittent which has been typical of previous research in this area. Research by this investigator and his associates has examined these variables.

METHOD

Experiment 1

<u>Subjects</u>. Six subjects were employed in this study. They consisted of four males and two females who ranged in age from 21 to 49. All had 20/20 vision either corrected or uncorrected.

<u>Apparatus</u>. The apparatus consisted of two basic components; a display unit and a control unit. The display unit consisted of

a hemisphere (43.2 cm in diameter) in which green LEDs (Chicago CMP52 with a typical peak wavelength of 565 nm) had been inserted through holes in the hemisphere wall. The LEDs were spaced evenly along six meridians. In the present experiment, only the horizontal meridian was employed.

A small black and white television (Panasonic Model PR1030P) whose screen measured 3.81 cm diagonally (subtending 9 degrees of visual angle) was placed at the center of the hemisphere with the screen projecting through the wall in the center of the hemisphere. Twelve LEDs (subtending 1.2 degrees of visual angle) were positioned to each side of the TV screen on the horizontal meridian. Only six LEDs on each side were used, and they were positioned at 10, 17, 25, 34, 41, and 50 degrees from the center of the TV screen. The inside of the hemisphere was painted flat white, and was illuminated fairly evenly by a 40-watt Sylvania Circline fluorescent lamp. An electronic dimming ballast in conjunction with a silicon solar cell and a microammeter were used to maintain a background luminance level of 205.6 cd/m2 (60 fL).

The second major component of the apparatus was the control unit which consisted of an IBM PC-XT microcomputer. The compensatory tracking task and LED luminance and selection were controlled by the computer via Tecmar Graphics Master and Lab Master boards. All data were collected by the IBM PC-XT.

The tracking display consisted of a vertical bar of light as the fixed reference marker and a horizontally moving ball at the top of the marker which served as an error indicator. The display resembled the dual-task tracking device known as ZITA (Walker and Walker, 1982), which includes several types of tracking, and which are either performed alone or with an auxiliary distraction task. In Experiment 1, the track seen on the display consisted of a single 0.4 Hz sinusoid.

<u>Light Intensities</u>. As was indicated above, the Tecmar Lab Master board was used to control the luminance of the LEDs. Software supplied by Tecmar was used to vary the voltage to the LEDs and thereby vary the luminance. The experimenter selected a D/A value, which the software converted to a voltage, which in turn activated the light at a given calibrated luminance level. The luminances employed ranged from 3.84 to 48.4 cd/m^2 (1.12 to 14.13 fL), and the luminances increased in steps of 0.6 log cd/m^2 (0.1 log fL) for a total of twelve steps. The ascending method of limits was the psychophysical method used throughout all phases of this experiment.

<u>Procedure</u>. Each subject received a total of 27 trials, with each trial consisting of an estimate of the threshold for each of the 12 LEDs. On the first 9 trials, subjects fixated the center of a white cross that appeared on the TV screen and pressed a button on a Kraft joystick whenever they detected a LED test flash

(25 msec in duration). On the final 18 trials, subjects performed a compensatory tracking task simultaneously with a light flash detection task. Trials were grouped in blocks, with each block comprising three trials. In addition to these 27 trials, a practice trial was run before the 9 light-only trials and before the 18 light (or perimetry) plus tracking trials.

Subjects were run in three to four test sessions with each session lasting from 30 to 60 minutes. Subjects completed the light-only condition in one session, but the perimetry-plus-tracking trials were distributed across two to three sessions. Once the subject began a session, he or she completed at least two blocks of trials.

The subject's head position was maintained by a chin rest at a distance of 24 cm between the TV and the bridge of the subject's nose. The inter-stimulus interval was 1-second during the light-only trials and 1.25 seconds during the light + tracking trials. About 1.5 minutes elapsed between individual blocks of 3 trials.

Results and Discussion

Threshold obtained for each LED location used with the fixation cross were compared to those obtained during the first and the last tracking trials. The data were analyzed using the non-parametric Sign Test due to the typically large individual differences found in visual threshold data. No significant differences were found between the first and last trials of the track-plus-perimetry conditions or between the perimetry-alone and the overall tracking-plus-perimetry condition. Thus, there was no effect of foveal load on peripheral sensitivity using the first-order compensatory tracking task employing a single sine wave track.

Tracking task performance in terms of RMS error was also analyzed over the 18 tracking trials using a parametric t-test for repeated measures. No significant differences were obtained over trials, indicating tracking performance remained relatively constant.

In general, it was found that when a more complex foveal task was employed, there was no significant loss in peripheral vision or a decrease in the functional visual field. This finding does not support the results of several previous investigations.

There are several possible reasons for this outcome. First, the tracking task may have been so easy that it provided little cognitive load which could effect the detection task. In other words, it is possible that the tracking task did not require any significant amount of attention relative to the detection task.

A second possibility might be that the subjects regarded the detection of the peripheral light flash as being of greater importance than improving performance on the tracking task. Both possibilities could be supported by the finding that tracking performance remained constant from the first to the eighteenth trials.

A third possibility might be the role played by eye movements in this study vs. previous investigations. The nature of that role is not particularly clear. However, if the tracking task is too simple then the subject would be able to sample peripheral signals more easily by eye movements without affecting the tracking task itself or showing a loss in sensitivity.

Experiment 2

The second experiment examined the first two possibilities. First a more difficult first-order compensatory tracking task was used. The tracking display presents for all practical purposes, a random track made up of three sinusoids of varying frequency, amplitude, and phase (frequencies of 0.5, 2.2, and 2 Hz with amplitude ratios of 1.0:1.5:18.5, respectively. In addition, instructions to the subject attempted to impress him/her with the importance of doing as well as possible on both tasks at the same time. The order of the foveal load conditions (i.e., perimetry-alone vs. tracking-plus-perimetry) was counterbalanced to avoid undue emphasis on only one task.

Subjects. Twelve subjects were employed in this study. They consisted of ten males and two females who ranged in age from 20 to 50. All had 20/20 vision either corrected or uncorrected.

Apparatus and Procedures. The apparatus and procedures used in the second experiment were, except for the differences noted above, the same as those used in the first study.

Results and Discussion

Thresholds obtained for each LED location (from 10 to 50 degrees) used with the fixation cross were compared to those obtained during tracking trials (i.e., perimetry-alone and tracking-plus-perimetry). The non-parametric Sign Test was used to analyze the data. Overall, the results indicated a decrease in threshold for increased foveal load ($p = < 0.05$). However, when the results of the first trial with the tracking task were compared with the last (i.e., the eighteenth trial), only the first tracking trial showed a significant decrease in threshold. The t-test for repeated measures found no significant difference in RMS error for the first tracking task trial compared to the last trial.

The obtained results were again not what was expected based on previous findings. It would appear that the perimetry task by itself does not produce much arousal and that the introduction of a tracking task causes a decrease in threshold. However, by the last tracking trial this arousal effect has dissipated and no differences are seen between the perimetry alone and the perimetry plus tracking. It is entirely possible that an inverted U-function exists where little or no arousal is produced by the simple tracking task and the more complex task produces a more optimal level of arousal, at least for the earlier trials. A tracking task which is even more difficult should effectively increase threshold so that there is either no difference between the perimetry alone and the perimetry plus tracking or should actually depress performance below perimetry alone. Thus, increasing the foveal load may have no effect on peripheral sensitivity (as in Experiment 1), it may increase sensitivity (as in Experiment 2), or it may lower sensitivity (as was found below in Experiments 3 and 4).

Experiment 3

The third experiment examined the effects of using a more difficult compensatory tracking task. The task again employed three sinusoids of varying frequency, amplitude, and phase, but with a higher frequency of movement (frequencies of 2.7, 1.8, and 0.5 Hz with amplitude ratios of 1.0:8.5:86.0, respectively). In addition, a tone sounded whenever the error became greater than an arbitrary amount. Thus, the foveal task was more difficult and attention-getting (i.e., produced a higher foveal load). Again, the order of the foveal load conditions (i.e., perimetry-alone vs. tracking-plus-perimetry) was counterbalanced.

Subjects. Twelve subjects were employed in the third experiment: six males and six females. Subjects ranged in age from 20 to 51. All had 20/20 vision either corrected or uncorrected.

Apparatus and Procedures. The apparatus and procedures used in the third experiment were the same as those used in the first two studies with the exception of blocking the trials in groups of three. Instead, each trial was run and recorded individually.

Results and Discussion

The results of Experiment 3 showed that the perimetry-alone thresholds were lower than the tracking-plus-perimetry thresholds, and that the first trial with tracking produced higher thresholds than the last trial with tracking. Again, the data were analyzed using the Sign Test ($p = $ or < 0.05). RMS error data were analyzed using a t-test for repeated measures ($p = $ or < 0.05). The first tracking trial RMS error was found to be significantly greater than the last tracking trial RMS error.

The tracking task employed in Experiment 3 was difficult and attention-getting enough to result in a decrement in peripheral threshold sensitivity. In addition, the task showed the effects of learning for the first time (i.e., no effects had been obtained for Experiments 1 and 2). Therefore, in this experiment, training has an effect.

Experiment 4

The fourth experiment departed from the first three in that the perimetry task was made more difficult by adding lights in the vertical meridian, as well as examining sensitivity in the horizontal meridian. Six lights at the same eccentricities (10, 17, 25, 34, 41, and 50 degrees) were used in the area below the tracking display and four lights above the display (10, 17, 25, and 34 degrees). These eccentricity values were the same as those used in the first three experiments for the horizontal meridian with the exception that two were eliminated above the display due to the subject's face blocking his or her view. The same tracking task used in Experiment 3 was used in Experiment 4.

Subjects. Twelve subjects were employed in Experiment 4 and included 6 males and 6 females. Subjects ranged in age from 18 to 48 years. All subjects had 20/20 vision, either corrected or uncorrected.

Methods and Procedures. Again, the same apparatus and procedures used in the previous experiments were also used in Experiment 4. However, twenty-two light detection thresholds were determined rather than twelve.

Results and Discussion

Using the Sign Test to analyze the data, the perimetry-alone condition for twenty-two lights showed lower thresholds than the tracking-plus-perimetry condition ($p = $ or < 0.05). Unlike Experiment 3, the threshold of the first trial was lower a significant number of times compared to the threshold on the eighteenth trial ($p = $ or < 0.05 using the Sign Test). Although the RMS error was lower for the eighteenth trial as compared to the first, it was not significantly lower as indicated by a t-test for repeated measures. This was mainly the result of the very high level of variability found in the tracking task performance. It was noted that the RMS error was, in general, much greater than it had been in previous experiments, and especially so for the first two or three trials. It would appear that subjects were able to do well on tracking or well on threshold determinations (at least initially) but not on both. It may be that subjects start out by giving more attention to the perimetry task at the expense of the tracking task and then shift some of their attentional resources to the tracking task later in the experimental session.

SUMMARY OF MOST IMPORTANT RESULTS

The results obtained in the four experiments reported here can be explained from two points of view or perhaps a combination of the two. First, the results might be explained by means of arousal theory, or second, in terms of resource theory. In terms of arousal, the perimetry task may be seen as being similar to a classic vigilance task, thereby reducing the overall level of arousal over a period of time. The introduction of the tracking task could result in the manipulation of the level of arousal, and therefore visual performance. This suggests that the results might be usefully described by the Yerkes-Dodson Law (displayed as an inverted U-function). For example, a low level of arousal produces no changes in performance as might be the case in Experiment 1, an optimum level of arousal producing enhancement of visual performance as in Experiment 2, and too much arousal produces a decrement in performance (as in Experiments 3 and 4).

Both the foveal load task and the perimetry task involve visual performance and involve a manual response by the subject. Thus, the results of the experiments would also seem to support attentional resource theories (Boff and Lincoln, 1988), and suggest that attentional resources are manipulated to some extent by task difficulty as well as the arousal that might be produced by a task. Thus, a secondary task such as tracking may not only degrade a primary task such as light detection in the periphery, it may under some conditions have little effect on performance, or it may *enhance performance.* The results of the fourth experiment would seem to suggest that subjects are having a problem with attentional resources. Therefore, it is possible that both attentional resource theory, as well as arousal and the Yerkes-Dodson Law may play a role in explaining the results.

In addition to completing four experiments, two perimetry-tracking systems have been developed for the study of foveal load. The most recent one alleviates some of the drawbacks of the first. The latest apparatus will not only be able to present light stimuli which vary in spectral composition (*e.g.*, *red, green,* and under some conditions, yellow), but also has better control of stimulus presentation and head position. It also provides a larger colored display of the foveally presented task. In addition, all programs used to run and record the data in the third and fourth experiments have been translated to Turbo Pascal which is a faster and more efficient language than Basic used in the first two experiments.

A paper describing this research effort is being prepared for publication in either Human Factors, Human Performance, or Ergonomics. Additional experiments that are either in progress or are planned will examine such variables as the effect of increasing the number of meridians involved in the perimetry task and the use of a pursuit as compared to a compensatory tracking task for foveal loading. Future research might also employ the use of a Sternberg type memory task (Sternberg, 1969, 1975) for foveal loading, varying the characteristics of the peripheral light stimuli (e.g., color and on-set and off-set rate), the long-term effects of training on the tracking task, individual differences (e.g., flying experience and age), and situational awareness as it might apply to the foveal load paradigm.

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APPENDIX

Figures 1 through 10 appear in this Appendix and support the results described in the Body of the Report.

Figure 1. Theoretical and expected results are shown where threshold is plotted as a function of light stimulus position along the horizontal meridian for the first tracking trial, the last tracking trial and the lights only condition.

Effects of Foveal Load on Peripheral Vision

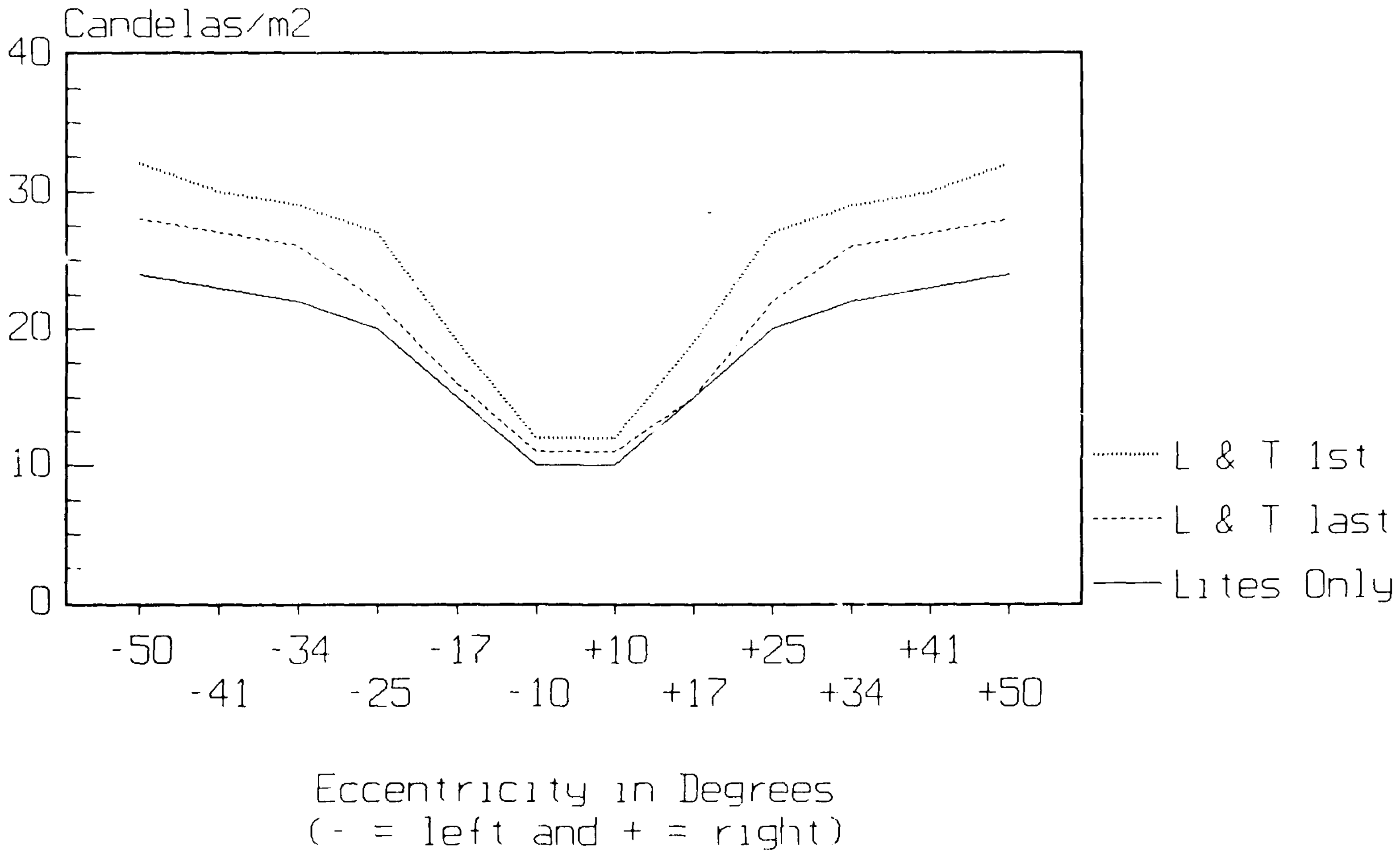


Figure 2. The results of Experiment 1 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the horizontal meridian for the first tracking trial, the eighteenth tracking trial, and the lights only condition.

Effects of Foveal Load on Peripheral
Vision

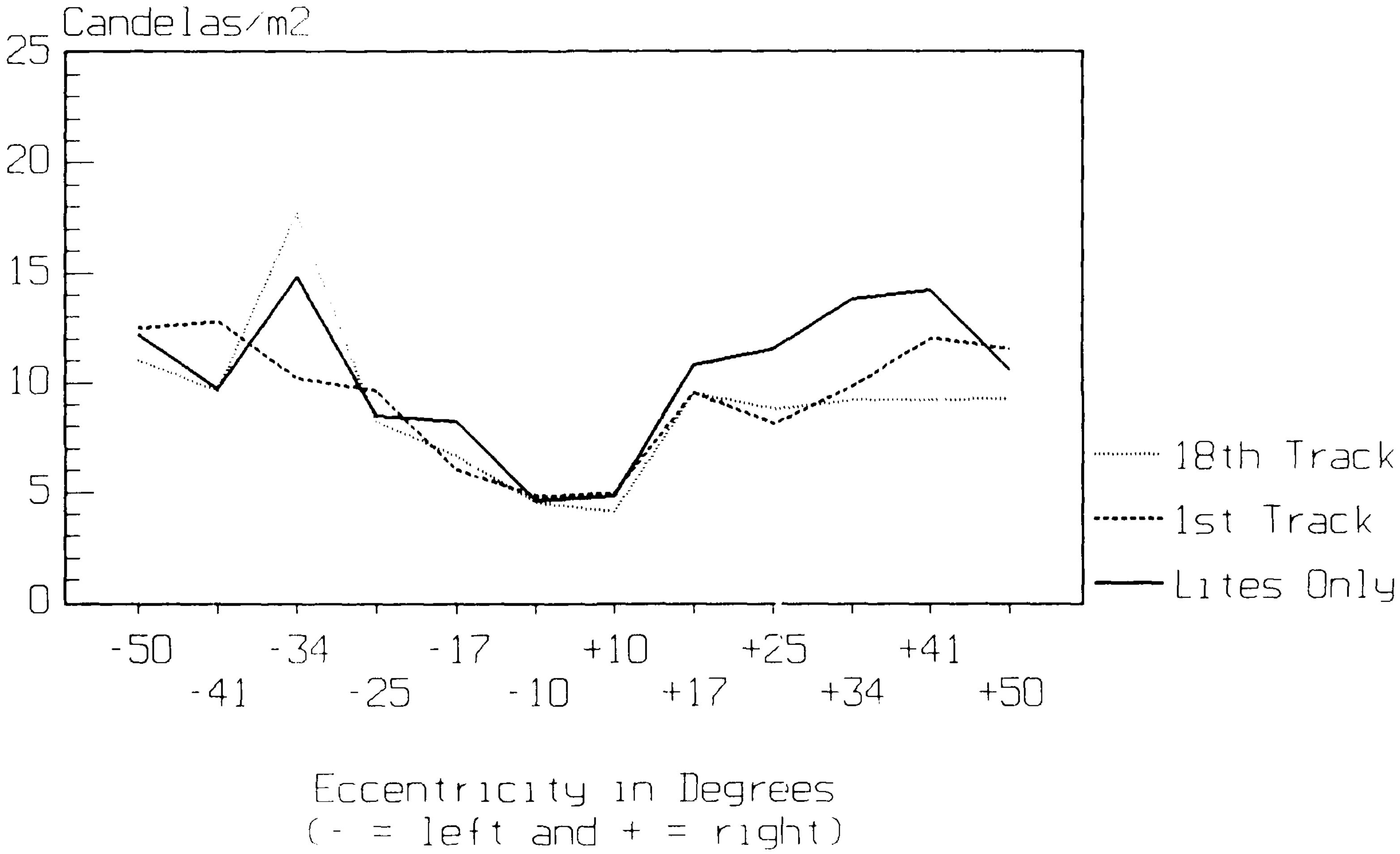


Figure 3. The results of Experiment 2 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the horizontal meridian for the first tracking trial, the eighteenth tracking trial, and the lights only condition.

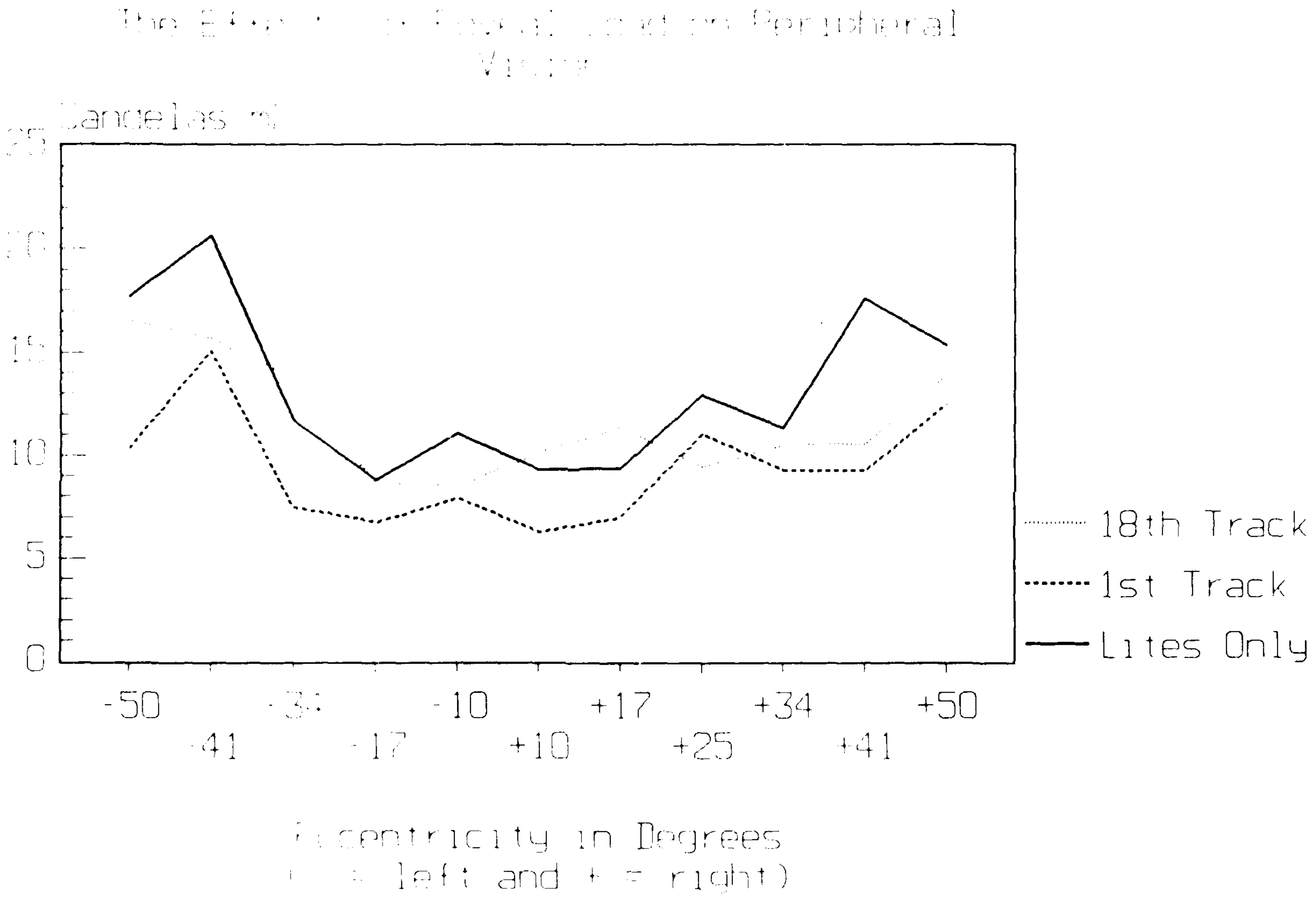

The Effect of a Foveal Load on Peripheral Vision
Candelas m²
25
20
15
10
5
0
-50
-41
-34
-17
-10
+10
+17
+25
+34
+41
+50
Eccentricity in Degrees
(- = left and + = right)
18th Track
1st Track
Lites Only

Figure 4. The results of Experiment 2 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the horizontal meridian for all tracking trials and the lights only condition.

The Effects of Foveal Load on Peripheral Vision

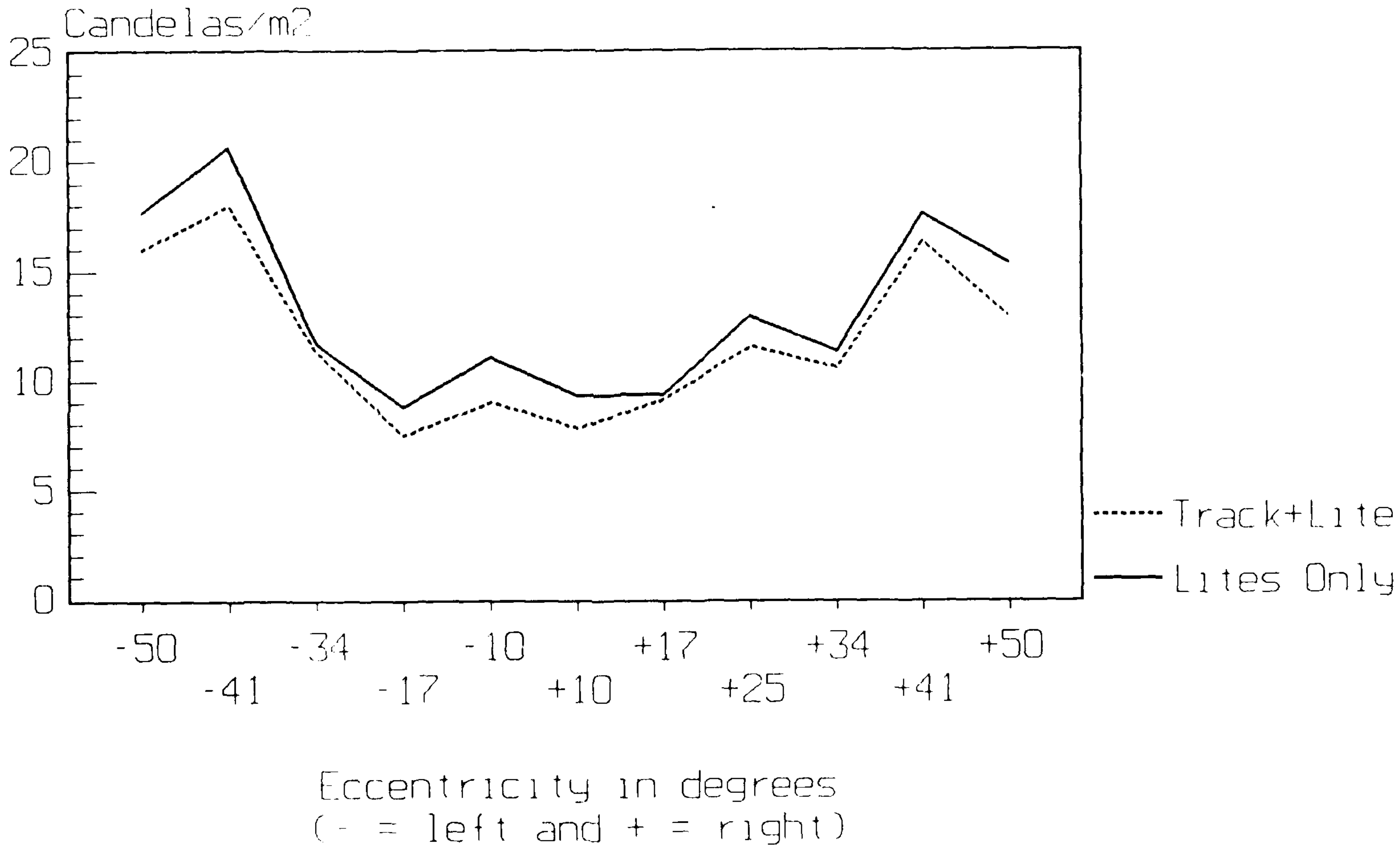


Figure 5. The results of Experiment 3 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the horizontal meridian for the first tracking trial, the eighteenth tracking trial, and the lights only condition.

The Effects of Foveal Load on
Peripheral Vision

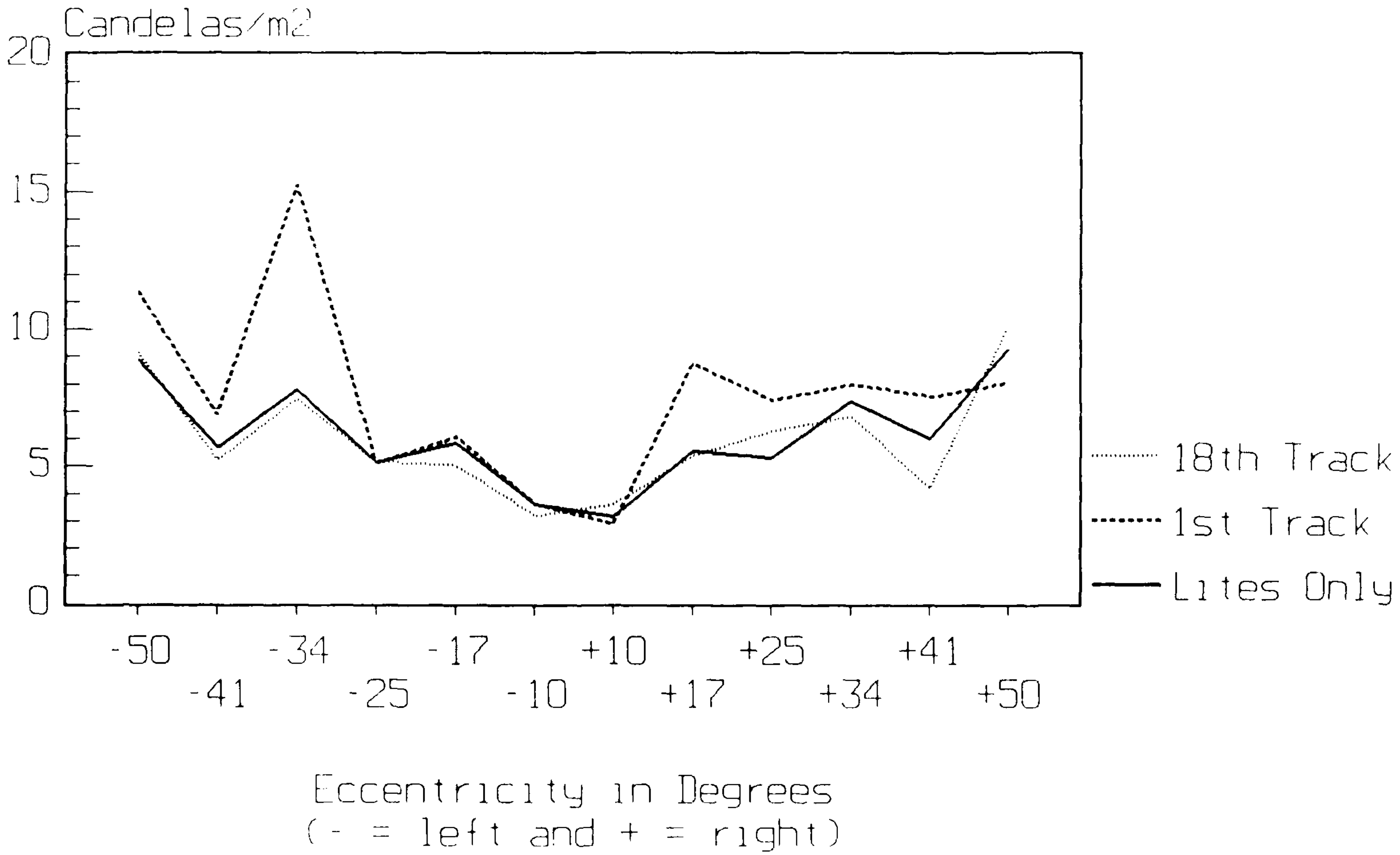


Figure 6. The results of Experiment 3 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the horizontal meridian for all tracking trials and the lights only condition.

The Effects of Foveal Load on
Peripheral Vision

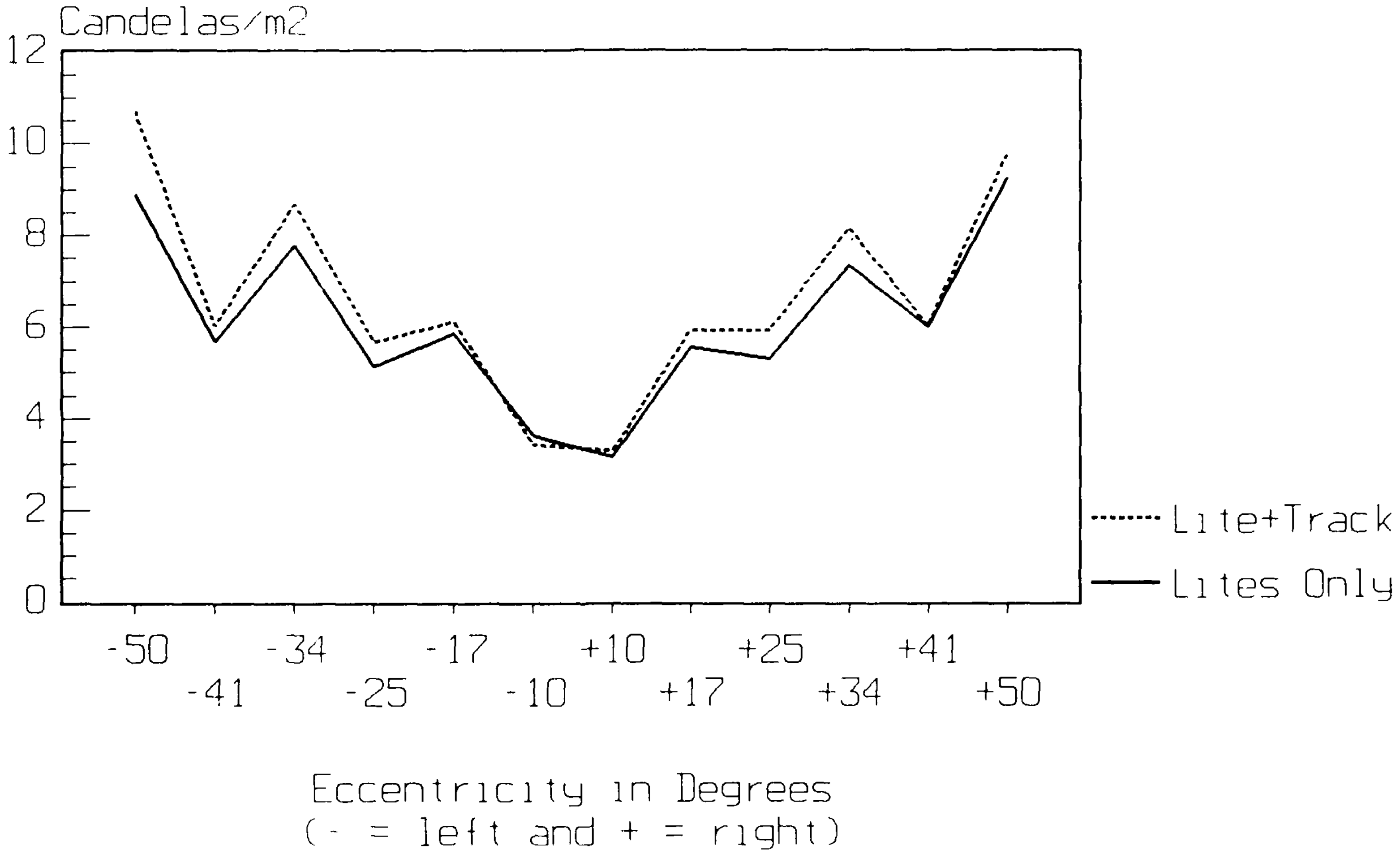


Figure 7. The results of Experiment 4 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the horizontal meridian for all tracking trials and the lights only condition.

Effects of Foveal Load on Peripheral Vision

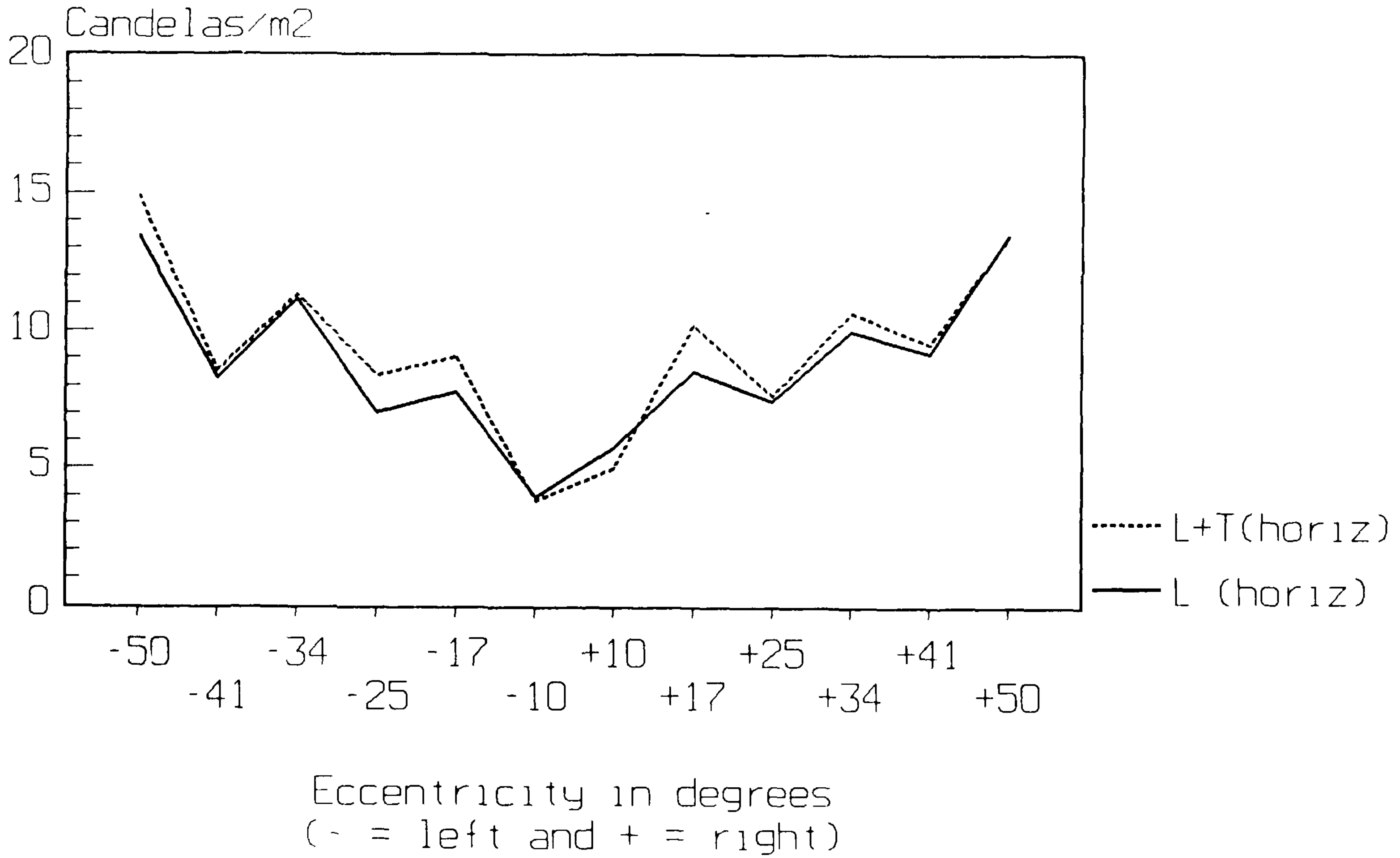


Figure 8. The results of Experiment 4 shown with visual threshold in candelas/m^2 as a function of light stimulus position along the vertical meridian for all tracking trials and the lights only condition.

The Effects of Foveal Load on Peripheral Vision

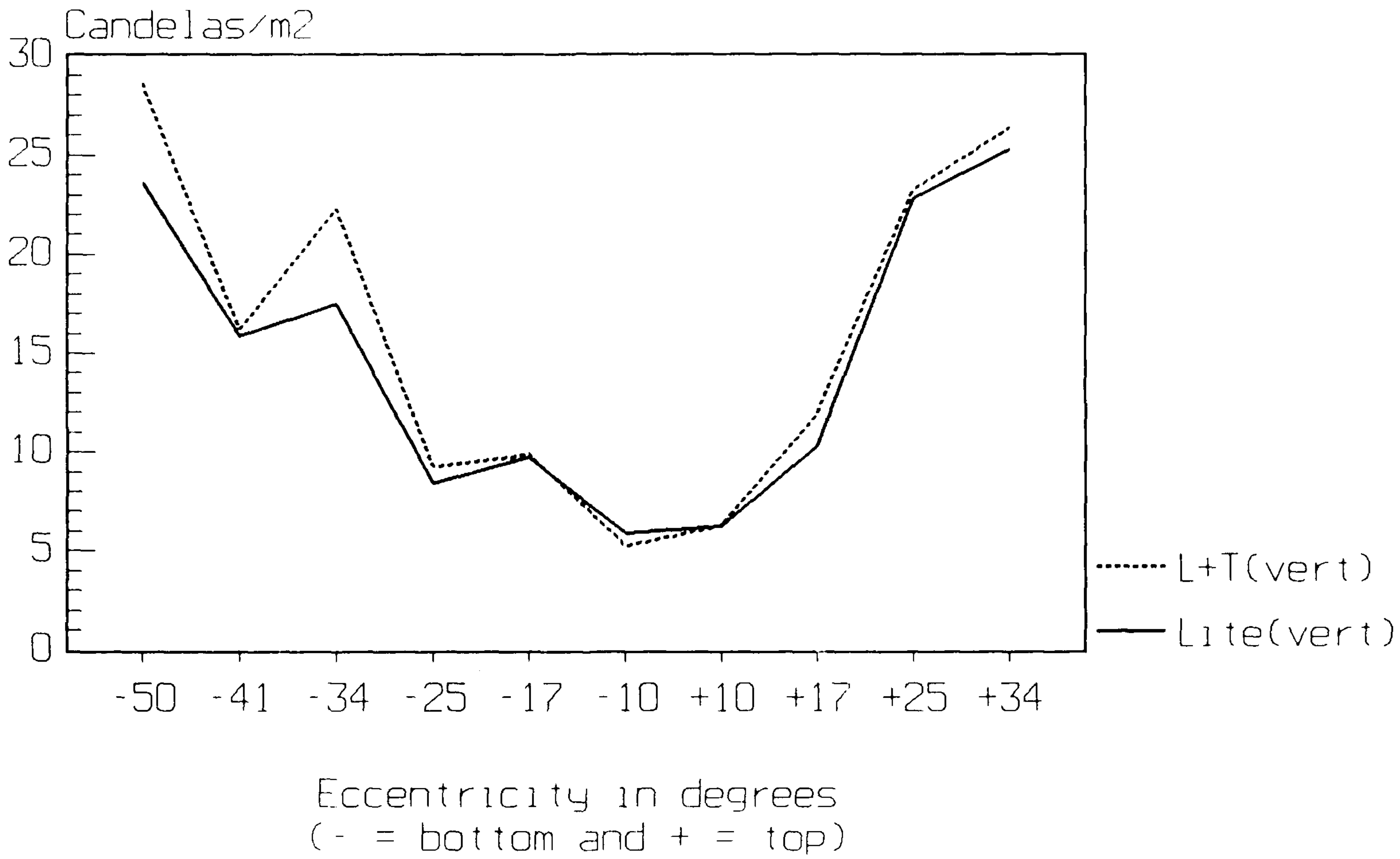


Figure 9. RMS scores for the first and the eighteenth tracking trials for Experiments 1-3.

Tracking Performance for
Experiments 1 to 3

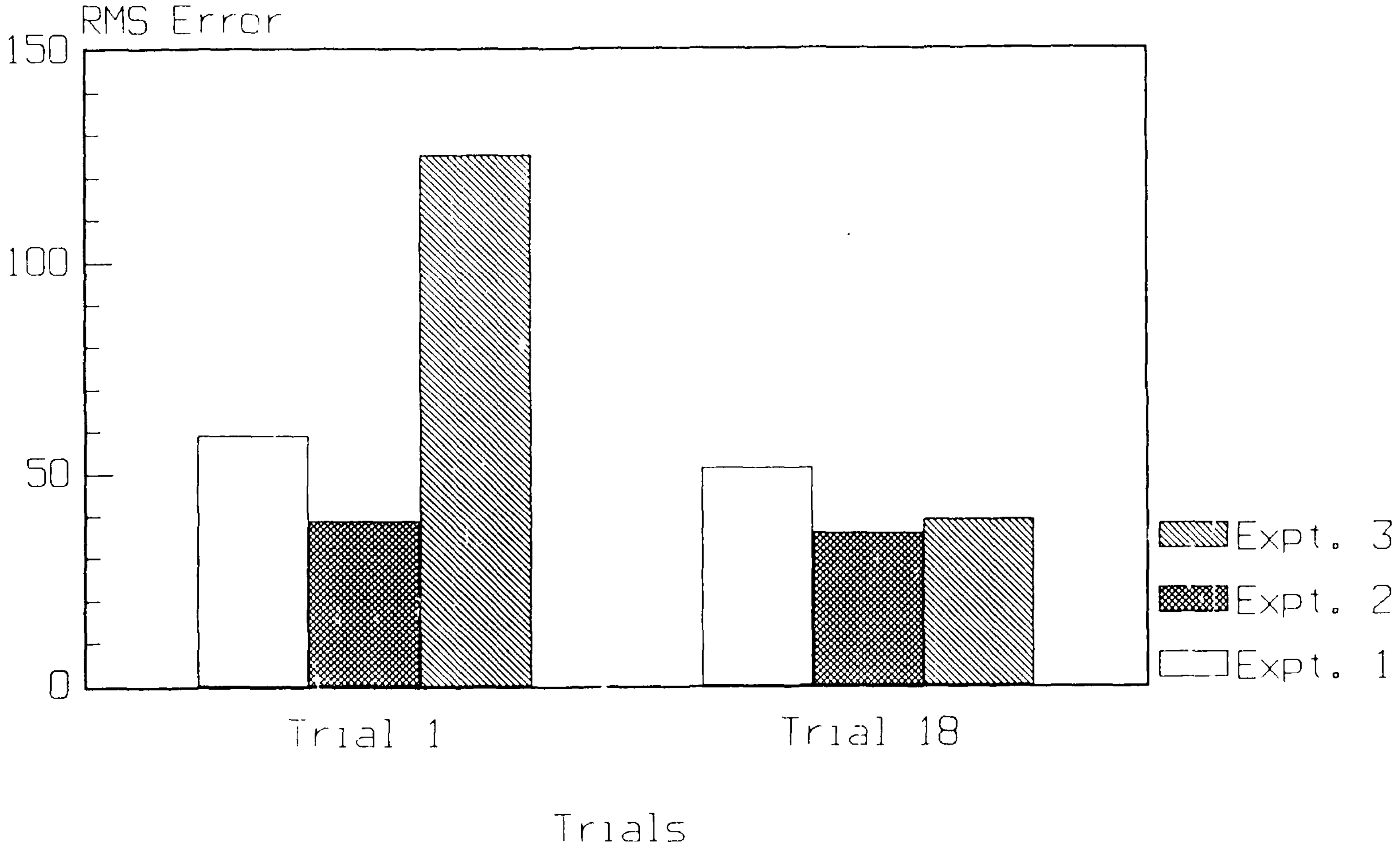
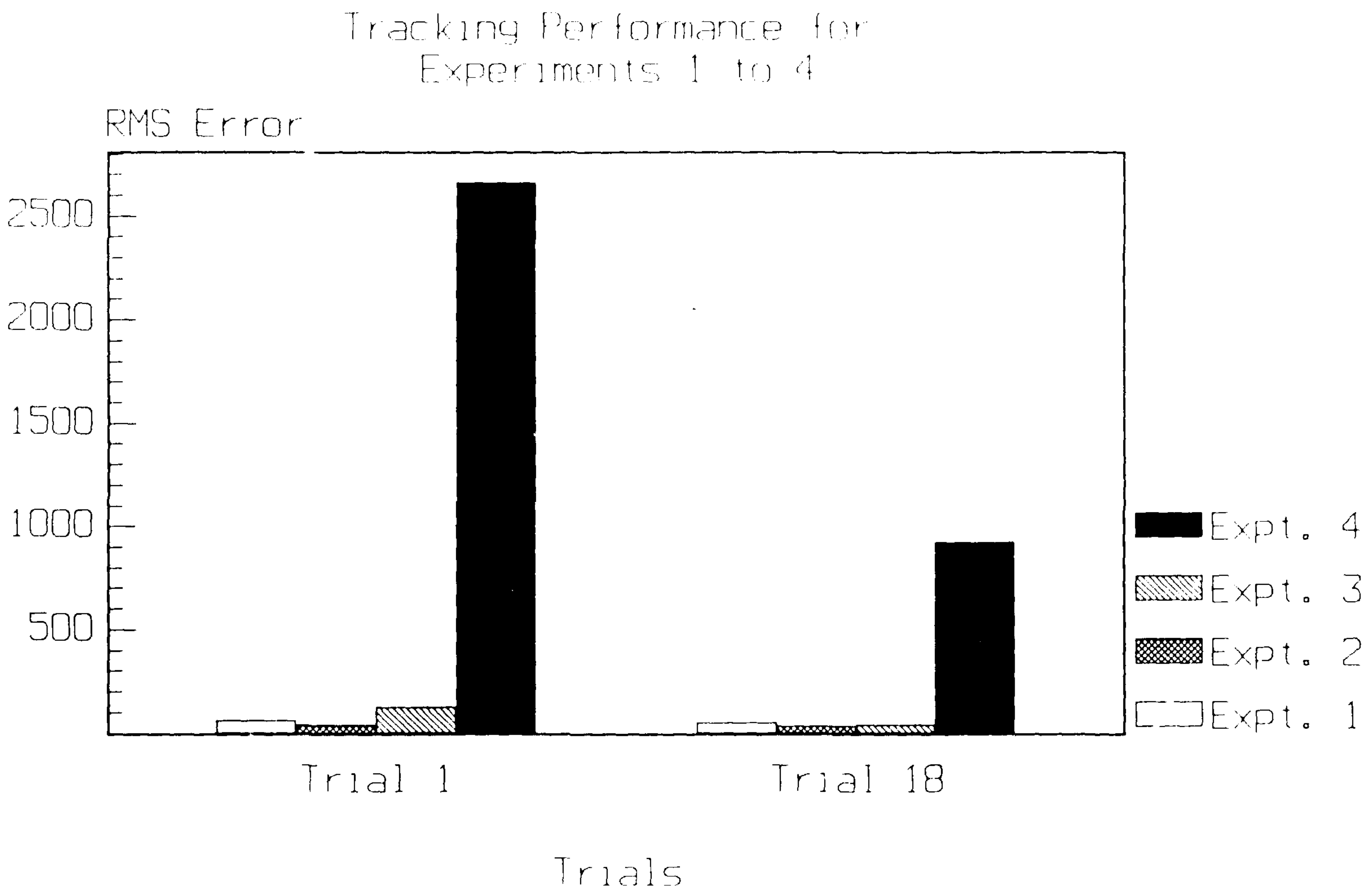


Figure 10. RMS scores for the first and the eighteenth tracking trials for Experiments 1-4.


Tracking Performance for
Experiments 1 to 4
RMS Error
2500
2000
1500
1000
500
Trial 1
Trial 18
Trials
Expt. 4
Expt. 3
Expt. 2
Expt. 1