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Summary An important function of perimeter security lighting is to enable guards to detect and recognise possible intruders. The experiments presented here were designed to systematically assess the performance of guards at these two tasks. The behaviour of intruders was also studied. Two experiments were undertaken on a large open field on four clear, moonless nights. In the first experiment, eighteen guards tried to detect and to recognise one of four intruders walking along a known path. In the second experiment the guards tried to detect an intruder moving in an unspecified manner across the open field. In the first experiment, the intruders provided data on the locations where they believed they had been detected and recognised. Their ability to see an acuity target located at the guard's position was also assessed. In the second experiment the intruders simply reported when they believed they had been detected. Both experiments were performed in the dark and under four different perimeter security lighting installations. Two light sources, low-pressure sodium and high-pressure sodium, and two lighting distributions, floodlighting and street lighting, were employed. The distances at which the guards detected and recognised the intruders were measured. The distances at which the intruders believed they had been detected and recognised were also measured. Measurements of vertical illuminance were obtained for the four security lighting installations, throughout the large open field. The main conclusions derived from the results are as follows. The presence of security lighting increases the distance at which intruders can be detected and recognised. A vertical illuminance in the range 4–10 lux will usually ensure a high level of detection and recognition. The low-pressure sodium discharge lamp is as effective as the high-pressure sodium discharge lamp for the detection of intruders and the recognition of their faces. Guards' and intruders' preferences for the different lighting conditions are consistent with the effect of those conditions on their ability to perform their respective tasks.

Security lighting: Effects of illuminance and light source on the capabilities of guards and intruders†

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1 Introduction

The use of exterior lighting to enhance security for commercial and industrial premises has increased dramatically in recent years. Such lighting allows guards to search a large area for potential intruders, much more effectively than is possible with a hand-held torch. Despite this increased usage and the existence of several guidance documents[1–3] there is only limited experimental evidence for the lighting conditions necessary for detection and recognition of intruders by guards[4–6]. Yet the lighting conditions provided have a major impact on the cost of supplying and operating a security lighting installation. The higher the illuminance provided, the greater the capital and operating costs for a given light source. The choice of light source is also important—for three reasons. First, different light sources convert electricity to light with different luminous efficacies, and as most security lighting installations are used for many hours, a difference in luminous efficacy has a major impact on operating costs. Second, different light sources have different lives. The longer the life of the light source, the lower will be the maintenance cost of the installation. Third, the most efficient light source in terms of luminous efficacy, the low-pressure sodium discharge lamp, is essentially monochromatic so no colour information is available. Doubt has been cast on the use of the low-pressure sodium discharge lamp for security lighting for this reason[1].

The main objectives of this study were to propose design criteria for perimeter security lighting based on the performance of guards at detecting and recognising intruders and to determine whether light source colour plays an important role in a guard's ability to detect and recognise intruders.

2 Method

2.1 Location

The experiment was conducted on a grass sports field at the Electricity Council Research Centre. A coffin-shaped area 100 m long and 63 m wide at the widest point, was defined as the field boundary (Figure 1). Four scaffolding towers were erected on 12 m centres at one end of the field. All lighting equipment used in the experiments was mounted on these towers. Twenty guards, ten on either side of the field centre line, sat in small open-air cubicles positioned in a row under the two central towers. A Landolt ring was located on a small platform at the same end of the field in the centre of the group of guards. The centre of the Landolt ring was 1 m above the ground and it was positioned on the centre line so as to have a background luminance of 0.2 cd m^{-2} under every lighting installation. The contrast of the Landolt ring was 0.9 and the size of the gap was 40 mm. The ring was mounted on one face of a cube. By rotating this cube, the gap in the ring could be made to appear in four different orientations. Figure 2 shows two of the lighting towers, the observers' cubicles and the Landolt ring.

Distributed around the area in front of the guards were fifteen brown garden fence panels, 1.26 m high × 1.83 m wide, of reflectance 0.2. These panels were introduced to

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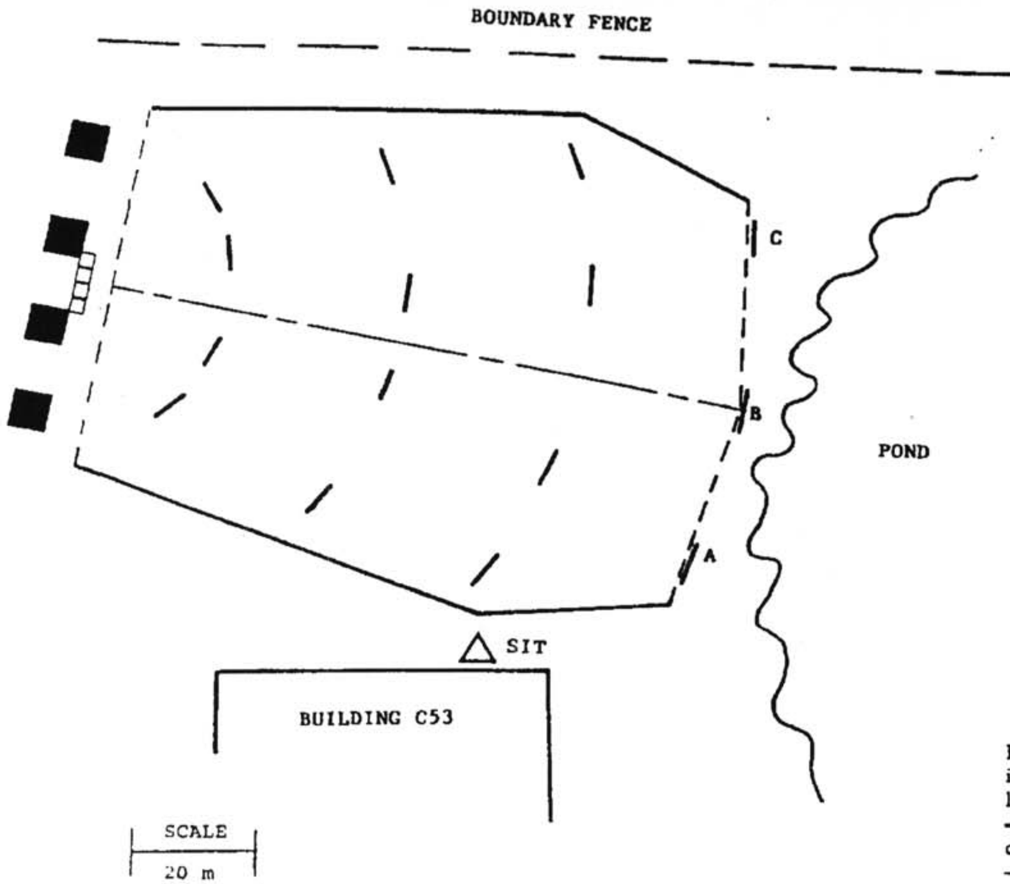


Figure 1 Plan of the field showing the layout of equipment (■ = lighting towers; □ = guards; —— = barriers; Δ = SIT video camera; - - = infra red beam; —— = centre line).

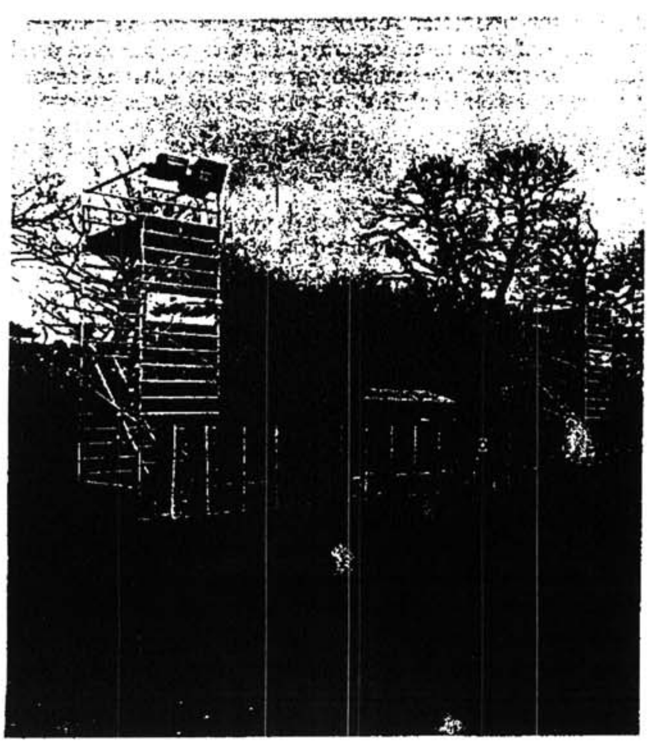


Figure 2 View of two lighting towers, the guards' cubicles and the Landolt ring.

act as barriers behind which the intruder could take cover and rest. These panels were located on one of four arcs, all of which were centred on the middle of the row of guards. The radii of the arcs were 22.5 m, 45 m, 67.5 m and 100 m. Looking along the field centre line from the guards' position there were a large ECRC building beyond the right boundary of the field, a pond and sparsely inhabited countryside beyond the far field boundary, and a sunken road beyond the boundary fence on the left side. Figure 3 shows a view of the defined field area from near the end of the line of lighting towers.

2.2 Lighting installations

The four different perimeter security lighting installations and the 'dark' condition used in the experiments are described below. The capital letters in brackets after each description are used to identify each installation.

Installation 1 had 4 floodlights, each containing a 150 W high pressure sodium discharge lamp (SON-T). One floodlight was mounted on each tower 5.2 m above the ground and aimed so that the maximum luminous intensity was 65° downward from the vertical (HPS FLOOD).

Installation 2 had 4 floodlights, each containing a 66 W low-pressure sodium discharge lamp (SOX-E). One floodlight was mounted on each tower 5.2 m above the ground and aimed so that the maximum luminous intensity was 65° downward from vertical (LPS FLOOD).

Installation 3 had 4 street lighting lanterns, each containing a 70 W high-pressure sodium discharge lamp (SON) mounted

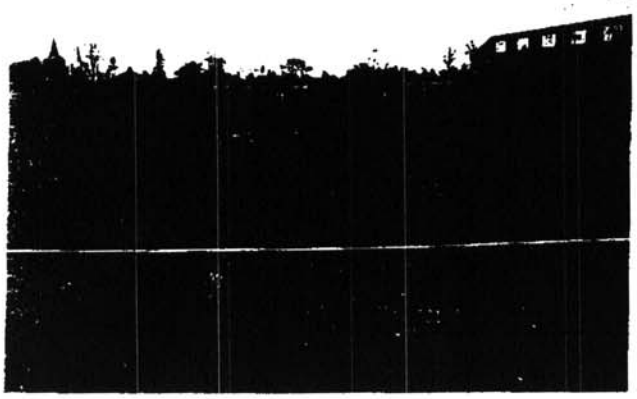


Figure 3 A view of the field from near one end of the line of lighting towers. The white marking tape apparent in the foreground and background was removed during the experiment.

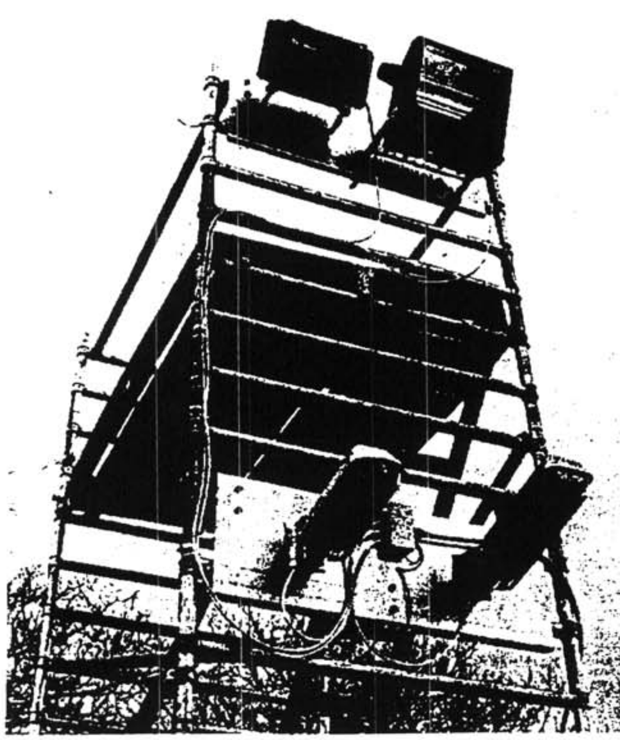


Figure 4 The two floodlights and the two lanterns mounted on one of the towers. Top left = floodlight for installation 1 (HPS FLOOD); Top right = floodlight for installation 2 (LPS FLOOD); Bottom left = lantern for installation 3 (HPS DOWN); Bottom right = lantern for installation 4 (LPS DOWN).

3.3 m above the ground. The inclination of the lantern was defined by the mounting bracket as 13° above horizontal (HPS DOWN).

Installation 4 had 4 street lighting lanterns, each containing a 36 W low-pressure sodium discharge lamp (SOX-E) mounted 3.3 m above the ground. The inclination of these lanterns was defined by the mounting bracket as 13° above the horizontal (LPS DOWN).

In the 'dark' condition all installations were switched off: the only light on the field came from outside the ECRC site. Except for occasional vehicles passing parallel to the boundary fence (Figure 1), only starlight and stray light from the surrounding rural area illuminated the field (DARK).

Figure 4 shows the two floodlights and two lanterns mounted on one of the scaffolding towers.

Vertical illuminance measurements were taken on a grid pattern, 1 m above the ground on a plane parallel with and facing the line of lighting towers. Figure 5 shows the distribution of vertical illuminances along the field for the HPS FLOOD, LPS FLOOD, HPS DOWN and LPS DOWN lighting installations. The vertical illuminances are shown on a log scale. No measurements could be obtained under the DARK condition because the illuminances were lower than could be measured reliably (<0.1 lx). Full details of all these measurements are given in Reference 7.

2.3 Basic procedure

Two experiments were performed together on four successive clear, dry nights, without a moon, in early March. Every night twenty guards sitting at one end of the field (Figure 1) were asked to detect and to recognise one of four intruders moving towards them from the other end of the field. The procedure for both experiments may be summarised as follows.

In Experiment 1 an intruder traverses the open field by walking along the centre line (Figure 1) towards the guards at a steady pace.

The guards' tasks are—

(*a*) to detect the intruder and,

(*b*) to recognise the intruder from one of four photographs provided (Figure 6).

The intruders' tasks are—

(*a*) to tell the experimenter when he believes he has been detected

(*b*) to tell the experimenter when he believes he has been recognised

(*c*) to detect the orientation of the gap in the Landolt ring placed on the centre line, level with the guards.

In Experiment 2 an intruder traverses the open field in any manner he deems most likely to avoid detection by the guards. The guards' task is to detect the intruder. The intruders' tasks are—

(*a*) to get as close to the guards as possible before being detected and

(*b*) to tell the experimenter when he believes he has been detected.

Intruders always wore dark blue overalls, black shoes, navy blue ski masks and gloves, and carried a black two-way radio

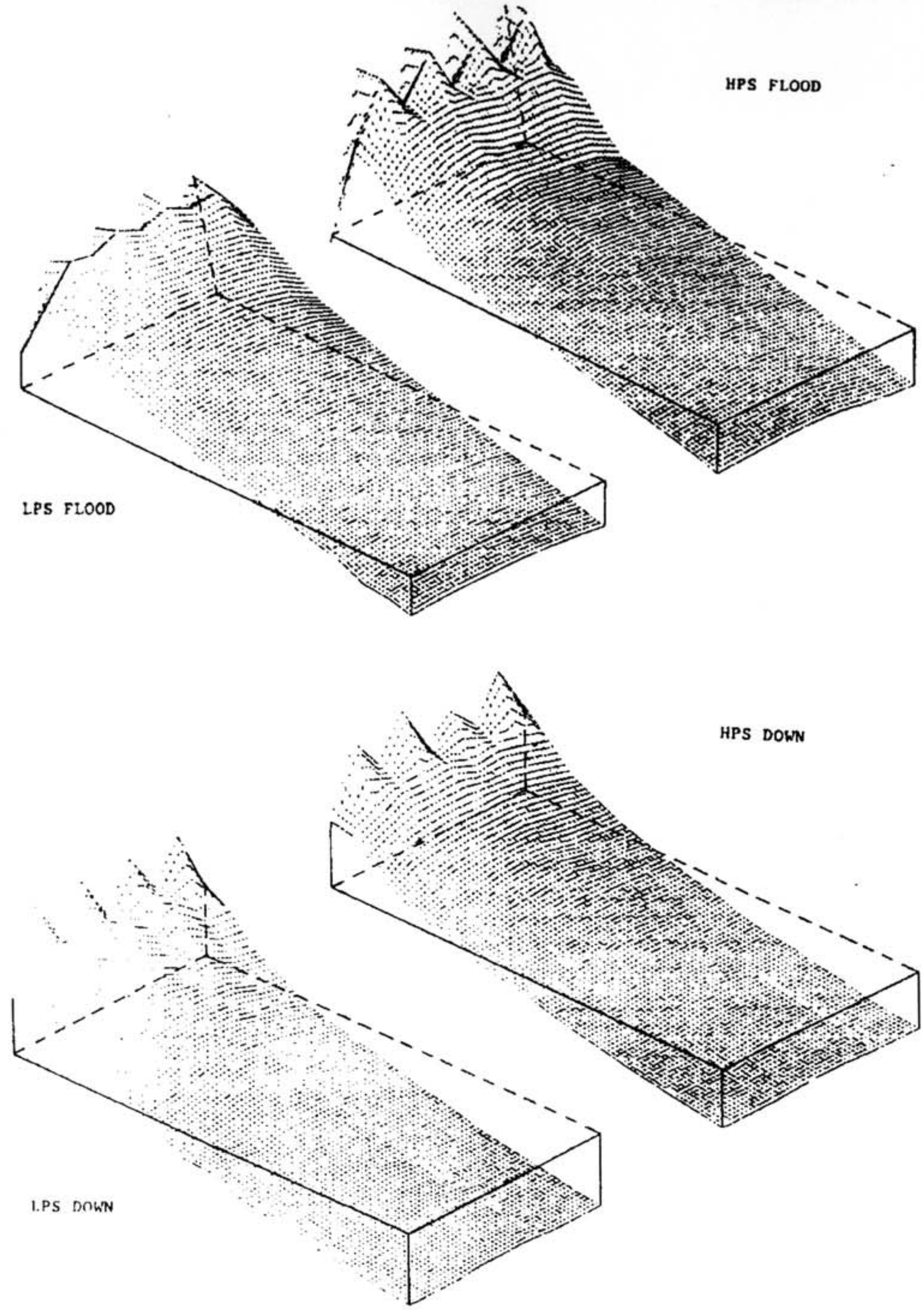


Figure 5 Three-dimensional surfaces of the log vertical illuminance for the four lighting installations. The horizontal plane corresponds to a vertical illuminance of 1 lux (log vertical illuminance = 0) (see Reference 7 for details of illuminance measurements).

(Figure 7). In Experiment 1 when the intruder was walking down the centre line of the field his ski mask was raised to expose his face, any long hair being tucked under the ski mask. The two-way radio, used to communicate believed detection and recognition, was always held close to the right cheek in Experiment 1 to minimise idiosyncratic movement by the different intruders. In Experiment 2 when the intruder was moving across the field to avoid detection, his ski mask covered his face.

In Experiment 1 the intruder always started his walk towards the guards from behind barrier B in Figure 1. Whether he started from the right or left side of this barrier was determined randomly by an experimenter. In Experiment 2 the intruder started from behind the left or right side of one of the three barriers (A, B or C in Figure 1); again, selections from the six possible starting positions were randomised by an experimenter.

Every guard sat in one cubicle (Figure 2) and was equipped with a push-button, several copies of a map of the field, a felt-tip pen and photographs of the four intruders (Figure 6). Ear protectors were worn to minimise audible cues. In Experiment 1, guards were required sequentially to press

Figure 6 The photographs of the four intruders given to the guards.

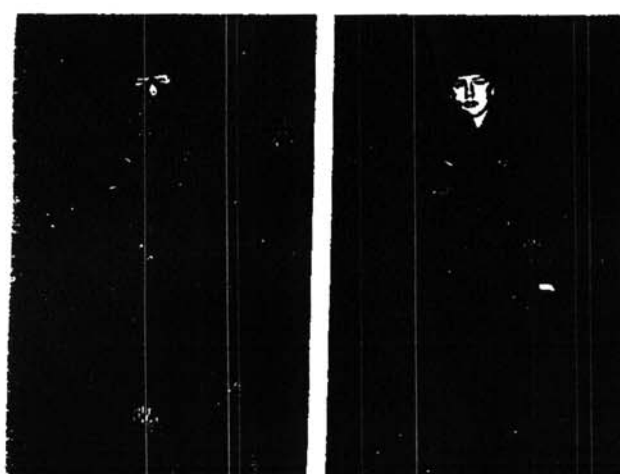


Figure 7 An intruder with the ski mask up and down. The marks on the overalls are earth and grass stains acquired while crawling over the field.

the push-button when the intruder was detected, mark the location of detection on the map, press the push-button when the intruder was recognised, mark the location of the recognition on the map and record the intruder recognised. In Experiment 2, guards were required to press the push-button when the intruder was detected and then mark the location on the map.

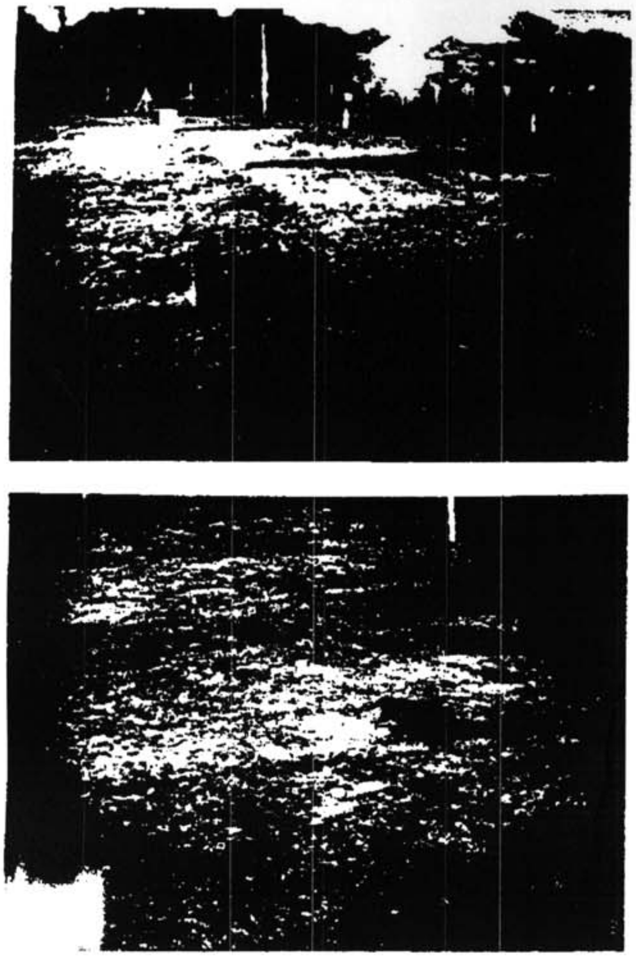
To begin a trial for Experiment 1 the guards were warned that an intruder would soon be moving from behind barrier B at the far end of the field. After a delay of variable length the intruder moved from the designated starting position. This movement interrupted an infrared beam (shown dashed in Figure 1), which simultaneously started two clocks; the two clocks stopped when the intruder crossed another infrared beam 4 m in front of the guards (shown dashed in Figure 1), and the trial ended. The first clock started an event recorder which also signalled the time each guard pressed his or her push-button signalling detection or recognition of the intruder. The event time obtained from the second clock was superimposed on a video recording obtained from a highly sensitive silicon intensified target (SIT) video camera mounted in an upper window of the building adjacent to the field (marked SIT in Figure 1). An experimenter followed the movement of the intruder with this highly sensitive camera. When the intruder considered he had been detected or recognised or when he could just discriminate the orientation of the gap in the Landolt ring he communicated this information to the experimenter over the two-way radio. The video tape also recorded the voice transmissions from the intruders. The perceived distance for detection, recognition and orientation for each intruder could be obtained from the voice recordings and the visual information on the video tape. The guards pressed their push-buttons when they detected or recognised the intruder. The distances for detection or recognition by the guards could be determined by comparing the times on the synchronised event recorder and video tape.

To begin a trial for Experiment 2, the guards were warned that an intruder would soon be moving from behind one of the three barriers at the far end of the field. After a variable time delay the intruder moved from the designated starting position. This movement broke the infrared beam and started two clocks; crossing the beam 4 m in front of the guards stopped the clocks and ended the trial. An experimenter obtained video recordings from the window-mounted SIT camera (Figure 8). When the intruder considered he had been detected he communicated this information to the experimenter over the two-way radio. Distance data for the intruders were obtained from the voice recordings and visual information on the video tapes. Distance data for detection by the guards were obtained by comparing the synchronised video tape and event recordings.

Video recordings of the intruders in Experiment 1 were also obtained from four types of CCTV cameras positioned behind the Landolt ring on the centre line. The effectiveness of these video cameras will be considered in a separate report.

2.4 *Experimental design*

In order to balance the possible effects of training and to obtain sufficient data, the above procedure was repeated many times. The basic experimental cycle was one movement chosen by the intruder (Experiment 2), followed by two walks along the centre line, (Experiment 1). Four cycles were completed under a lighting condition and then one was done in the DARK. In all, the guards were asked to detect intruders on sixty different occasions every night. The order of examining the lit installations was counterbalanced over nights so that each of the lit installations occurred in each possible position once only.



3 Still photographs from the video record of an intruder moving under a lit installation and the DARK condition.

The aim was to use the same twenty guards throughout the four nights. In practice, only eighteen guards served for all four nights. The same four intruders were used for all four nights. Only one intruder moved over the area at a time. In Experiment 2 the order in which the four intruders traversed the field was counterbalanced across lit installations on each night and was also counterbalanced across the four nights. The order in which the four intruders traversed the field in the DARK condition was counterbalanced across nights. In Experiment 1 the order in which the four intruders walked along the centre line took two forms. In the first form (called random selection without replacement) the order in which the intruders walked the centre line was counterbalanced across lit installations within one night and was also counterbalanced between nights. Just like Experiment 2 then, every intruder traversed the field under every lighting installation once on each night. The order that the four intruders walked along the centre line in the DARK condition was counterbalanced across nights.

Counterbalancing ensures equal presentation of all experimental conditions to every intruder and minimises systematic confounding of extraneous variables such as learning and fatigue with these experimental conditions. However, it is conceivable that with the counterbalanced experimental design the guards could logically deduce which intruder would be the last one to walk the centre line under a given lighting condition, based upon correct recognition of the previous three intruders. If this were true, then a guard's performance on the recognition task would not be due exclusively to vision, but partly to his or her capabilities for deductive reasoning. Obviously, this could occur to varying degrees amongst guards or for a given guard over time. To limit this possibility a second method of determining the order in which intruders walk the centre line was used—namely random selection. For this form, (called random selection with replacement) it is impossible for the guards to deduce which intruder should appear on the basis of correct recognition of the intruders on previous trials. It was further supposed that implementing this second form of ordering would limit deductive reasoning for the first since there was no obvious difference between the two forms to either the guards or the intruders.

The time taken for the four cycles used for one lit installation and one cycle for the DARK condition was approximately forty minutes. At the end of this period, a twenty minute break was allowed for the guards to warm themselves in a nearby building while the lamps for the next installation were run up to full light output. A complete session, one night, took about four hours. All the guards and intruders were volunteers but they were paid for their participation in the experiment. Payment was not related to their performance. However, an additional incentive was given to the intruders by the offer of a prize for the intruder who got closest to the observers before being detected.

2.5 *Subjects*

Four young men were chosen as intruders. They were in their teens except for one who was 35 years of age. They were all in good physical condition and of similar height and build. Vision screening using the Keystone Optical Tester showed that they all had excellent vision with a distance acuity better than 20/20.

Eighteen guards, four women and fourteen men, between the ages of 17 and 48 (median = 29) years completed the experiment. Vision screening with the Keystone Optical Tester showed that all the guards had a distance acuity of at least 20/20. Three wore glasses for distance viewing.

2.6 *Debriefing*

The guards were debriefed after the completion of the experiment using a questionnaire[7]. The questionnaire was designed to:

(*a*) quantify preferences for lighting installations

(*b*) identify the cues used to detect and to recognise intruders

(*c*) examine the influence of weather on performance

(*d*) establish search strategies in Experiment 2

(*e*) establish whether a pattern had been recognised in the order of intruders' appearance.

The four intruders were debriefed using another questionnaire[7]. The questionnaire was designed to:

(*a*) quantify opinions about the different lighting conditions in both experiments

(*b*) establish any preferred routes and manners of movement in Experiment 2

Table 1 Analysis of variance summary table for distances at which the intruder was detected when walking along the centre line (Experiment 1).

Source	Sum of squares	Degrees of freedom	Mean square	*F* ratio	Significance level	% variance explained
Guards	171 152.6	17	10 067.8	27.4	<0.001	10.4
A = Installation	317 324.8	4	79 331.2	215.9	<0.001	81.7
B = Night	6 335.0	3	2 111.7	5.8	<0.001	2.2
C = Replication	5 383.3	7	769.0	2.1	<0.05	0.8
$A \times B$	25 600.3	12	2 133.4	5.8	<0.001	2.2
$A \times C$	25 457.1	28	909.2	2.5	<0.01	0.9
$B \times C$	17 315.7	21	824.6	2.2	<0.01	0.8
$A \times B \times C$	52 975.9	84	630.7	1.7	<0.01	0.6
Residual	993 074.2	2703	367.4			
Total	1 614 618.9	2879				

(*c*) establish what cues had been used to conclude they had been detected or recognised

(*d*) quantify the observers' opinions about the lighting installations for seeing the Landolt ring in Experiment 1 and

(*e*) establish whether any patterns in their allocation to the various experimental conditions had been identified.

3 Results of Experiment 1

3.1 Distances for detection of intruders when walking along the centre line

From the measured elapsed times and the associated video record, the distance from the centre of the group of guards at which each guard claimed to detect each intruder was established. This information was obtained for every lighting condition and every intruder on every night. The complete set of data was checked against the event recorder times and any notes made on the maps by every guard to eliminate any premature responses. The complete set of checked data was then analysed statistically by a three-factor analysis of variance[8]. The analysis of variance summary table (Table 1) shows that all main effects and interactions are statistically significant. While statistical significance is important, the practical significance of the variables examined is even more important. This importance can be quantified in terms of the percentage of variance explained by the variable. In order to take both statistical and practical significance into account when assessing the result of an analysis of variance, two criteria have been adopted in this study. Both criteria have to be met for a variable to be considered further. The criteria are (*a*) a probability of occurrence by chance of less than 0.05 and (*b*) the variance explained by the variable to be greater than 15%. Table 1 shows that the lighting installation used is the only important factor. How important it is can be seen in Table 2 which shows the mean distances for detection for each of the lighting installations. Tukey Honestly Significant Difference (HSD) tests of the differences between the mean detection distance for every lighting condition[8] showed that every mean is statistically significantly different from all the others ($p < 0.05$).

One way to display the effects of lighting conditions is as the cumulative frequency of detection against distance. The data are shown in Figure 9. As would be expected, the percentage of the guards detecting the intruder increases with decreasing distance, all the guards detecting the intruder before the finish line is reached. Further, the different lit installations are well separated in terms of the distances at which detection occurs, and all allow greater detection distances than occur for the DARK condition.

Table 2 Mean distances for detection and recognition of intruders and the distance at which 50% of the guards detected and recognised an intruder walking along the centre line (Experiment 1).

Installation	Mean distance for detection (m)	Distance at which 50% of guards detected intruduer (m)	Mean distance for recognition (m)	Distance at which 50% of guards claimed to recognise intruder (m)	Distance at which 50% of guards correctly recognised the intruder (m)
HPS FLOOD	80.1	86.8	23.0	22.7	22.3
LPS FLOOD	82.9	90.6	24.9	24.5	24.1
HPS DOWN	70.2	69.7	18.6	18.3	18.0
LPS DOWN	63.4	62.8	17.5	17.2	16.9
DARK	54.5	54.3	—	—	—

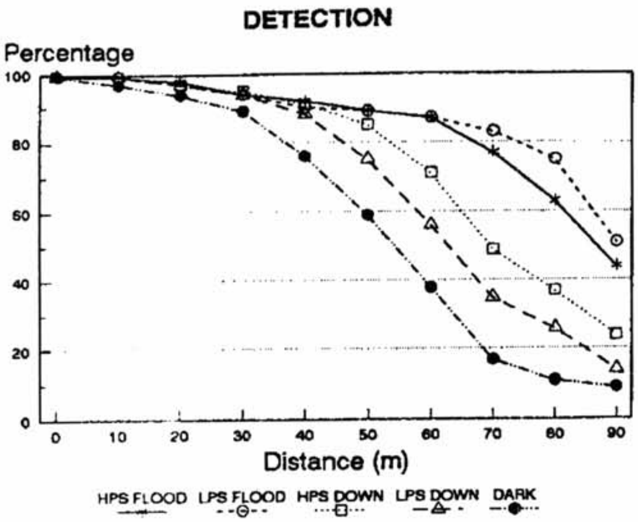


Figure 9 Percentage of guards detecting the intruder plotted against distance from the guards for each installation, when the intruder was walking along the centre line (Experiment 1).

The distances at which 50% of the guards detected the intruder for each of the lighting conditions are given in Table 2. There is little difference between the 50% distance and the mean distance except for the HPS FLOOD and LPS FLOOD installations where the 50% distance for detection is greater than the mean distance. The probable reason for this is the departure from a normal distribution that occurs for these lit installations, caused by the detection distance being limited to less than 100 m.

3.2 Distance for recognition of intruders when moving along the centre line

From the measured elapsed times and the associated video record, the distance from the centre of the group of guards at which each intruder was recognised by each guard could be quantified. An attempt was made to obtain this information for every lighting condition and every intruder on every night. However, an examination of the data for the DARK condition showed that recognition responses were frequently missing or incorrect, so these data were excluded from the statistical analysis. Also, data from three observers are rejected because they failed to indicate who they had recognised on their record forms. The data from the remaining fifteen observers for the four lighting installations were checked against the elapsed times and any notes made on the maps by each guard to eliminate any premature responses. The complete set of data was first analysed by a four-factor analysis of variance. This analysis revealed that there was no statistically significant effect of the two methods of selecting which intruder was used (randomisation with and without replacement). Therefore this variable was eliminated and the data analysed by a three-factor analysis of variance. Again, there is a pattern of statistically significant main effects and interactions. However, examination of the summary table (Table 3) using the two criteria adopted earlier shows that the lighting installations used have the greatest effect on distance for recognition. The magnitude of the effect can be seen in Table 2 which shows the mean distance at which recognition was claimed under each lighting installation. Tukey (HSD) tests for the mean distances for claimed recognition for each of the lighting installations showed that the mean distance for each installation was statistically significantly different from that for each of the other installations ($p < 0.01$).

The data used in the analysis of variance were the distances at which the guards claimed to recognise the intruder. By comparing the intruder marked on the guard's record sheet with the experimental record it is possible to eliminate all incorrect recognitions. The percentage of guards correctly recognising the intruder is shown plotted against distance in Figure 10. For comparison, the percentage of guards correctly recognising the intruder at different distances under the DARK condition is also given. For all lighting installations, the percentage of guards correctly recognising the intruder increases rapidly with decreasing distance, although as might be expected, recognition occurs much closer to the guards than detection. Also, it is evident that the HPS FLOOD and LPS FLOOD installations allow recognition to occur at greater distances than the HPS DOWN and LPS DOWN installations. It is also noticeable that under the four lit installations, almost 95% correct identification is eventually achieved but under the DARK condition, correct recognition only reaches 31%, a value only slightly greater than chance (25%). Table 2 shows the distances at which 50% of observers claimed to recognise the intruder and correctly recognised the intruder for each lighting instal-

Table 3 Analysis of variance summary table for distances at which the guards claimed to recognise the intruder, when the intruder was walking along the centre line (Experiment 1).

Source	Sum of squares	Degrees of freedom	Mean squares	F ratio	Significance	% variance explained
Guards	12 105.4	14	864.7	39.3	<0.001	10.4
A = Installation	18 109.6	3	6036.2	274.4	<0.001	72.6
B = Night	744.6	3	248.2	11.3	<0.001	3.0
C = Replication	1 758.4	7	251.2	11.4	<0.001	3.0
$A \times B$	3 417.8	9	379.8	17.3	<0.001	4.5
$A \times C$	3 712.1	21	176.8	8.0	<0.001	2.1
$B \times C$	3 339.4	21	159.0	7.2	<0.001	1.9
$A \times B \times C$	11 370.4	63	180.5	8.2	<0.001	2.2
Residual	39 193.7	1778	22.0			
Total	93 751.4	1919				

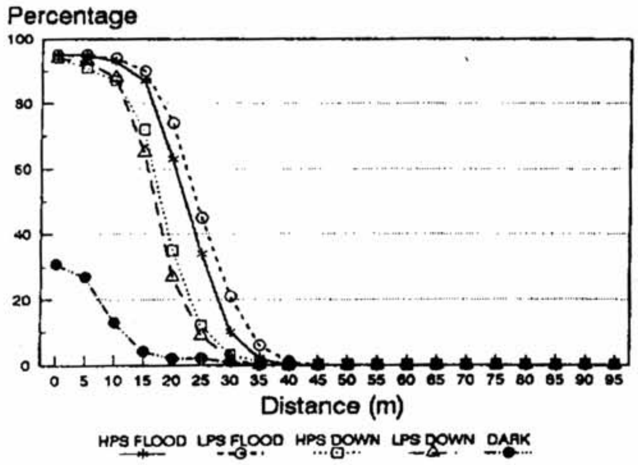


Figure 10 Percentage of guards *correctly* recognising the intruder plotted against distance from the guards for each installation, when the intruder was walking along the centre line (Experiment 1).

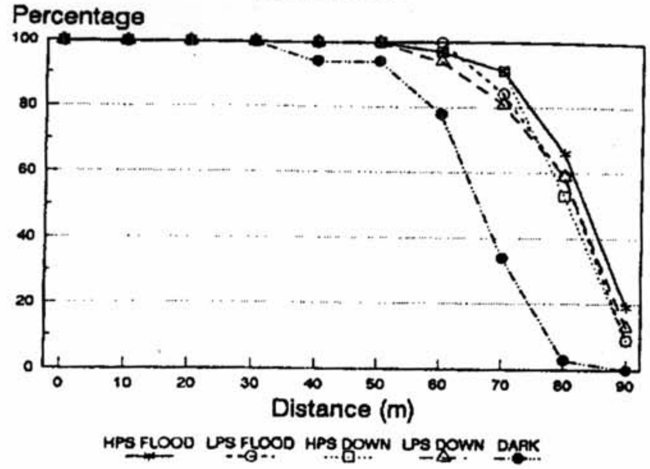


Figure 11 Percentage of intruders thinking they had been detected plotted against distance from the guards for each installation, when the intruder was walking along the centre line (Experiment 1).

lation. Also shown are the mean distances for claimed recognition for each lighting installation. An examination of Table 2 shows little difference between any of these measures.

3.3 Distances at which intruders considered they had been detected when walking along the centre line

From the video record and the associated sound track it was possible to obtain the distance from the guards at which each intruder believed he had been detected. The distances obtained were analysed by a two-factor analysis of variance. The summary table (Table 4) shows that, using the criteria adopted earlier, both the lighting installations and the nights are important variables. Tukey (HSD) tests for the differences between means showed that the mean distances at which intruders thought they had been detected in the DARK condition were significantly different than those under all the lit installations. There were no significant differences between any of the lit installations. The difference between the lit installations and the DARK condition is evident in the mean distances at which intruders thought they had been detected (Table 5).

Figure 11 shows the percentage of intruders under each lighting installation thinking they had been detected at various distances from the guards. Figure 11 reveals that for all the conditions there is a rapid rise in the percentage of intruders considering they had been detected with decreasing distance from the guards. All the lit installations follow a very similar trend but the DARK condition covers a range of distances closer to the observers. This is reflected in the distances at which 50% of intruders consider that they have been detected under each lighting condition (Table 5).

As for the difference between nights, the significant effect arises from the differences between the mean distance for the first night (72.2 m) and the mean distances for the other nights (77.3, 79.4, and 78.4 m for nights 2, 3 and 4 respectively). Tukey (HSD) tests for the differences between means showed that the mean distance at which the intruders believed they had been detected was significantly less on the first night than on nights 3 and 4 ($p < 0.05$). This change after the first night could be due to differences in visibility on different nights or to shifts in the criterion used by the intruders to judge when they had been detected, based on experience. Given the lack of difference between nights for the guards' tasks when the intruder was walking along the centre line the explanation based on a shift in criterion seems more likely to be correct.

3.4 Distances at which the intruders thought they had been recognised when walking along the centre line

From the video record and the associated sound track, it is possible to obtain the distance from the guards at which each

Table 4 Analysis of variance summary table for distances at which the intruders thought they had been detected when walking along the centre line (Experiment 1).

Source	Sum of squares	Degrees of freedom	Mean square	F ratio	Significance	% variance explained
Installation	7338.7	4	1834.7	21.8	<0.001	75.9
Night	1218.3	3	406.1	4.8	<0.01	16.8
Installation × Night	1112.6	12	92.7	1.1	†	3.8
Within cell	11794.4	140	84.3			
Total	21464.0	159				

† Not significant

Table 5 Mean distances at which the intruders considered they had been detected or recognised and the distances at which 50% of intruders considered they had been detected or recognised while walking along the centre line (Experiment 1).

Installation	Mean distance at which intruders thought they had been detected (m)	Distance at which 50% of intruders thought they had been detected (m)	Mean distance at which intruders thought they had been recognised (m)	Distance at which 50% of intruders considered they had been recognised (m)	Mean distance at which intruders identified the orientation of the Landolt ring (m)	Distance at which 50% of intruders identified the orientation of the Landolt ring (m)
HPS FLOOD	82.0	83.4	24.3	22.5	64.7	66.8
LPS FLOOD	80.3	81.8	27.9	23.8	61.4	61.6
HPS DOWN	79.9	80.6	22.3	22.5	59.7	62.4
LPS DOWN	78.4	82.0	24.7	23.1	62.4	66.8
DARK	63.5	65.3	6.0	6.7	6.4	6.4

intruder considered they had been recognised. However, the video records for nights 1 and 2 were over-written for the last few moments of movement and this was sometimes before the position where recognition was believed to have occurred. Therefore there was a significant amount of missing data on this aspect during nights 1 and 2 for the intruders' responses. The fault producing the over-writing was rectified after night 2 so the results for nights 3 and 4 were complete. The data for the distance at which each intruder thought he had been recognised are taken from nights 3 and 4 only. The data were analysed by a two-factor analysis of variance. The analysis of variance summary table (Table 6) shows that the only important variable was the lighting installations used. Tukey (HSD) tests for differences between means revealed that the DARK condition was significantly different from all the others. There were no significant differences between the lit installations. The difference in mean distance at which recognition was believed to have occurred for the lit installations and DARK condition is evident in Table 5.

The percentage of intruders who considered they had been recognised at different distances from the guards, for each installation, is shown in Figure 12. It can be seen that the response of the intruders rises rapidly with decreasing distance for all conditions, but there is a marked difference between the lit installations and the DARK condition, the latter covering a range of distances much closer to the guards. This difference is also evident in the distances at which 50% of intruders believe they have been recognised (Table 5). It is also interesting to note that for the DARK condition, 100% of intruders ultimately believe they have been recognised but in fact only 31% of guards had recognised the intruder correctly.

3.5 Distances at which intruders reported the orientation of the Landolt ring when walking along the centre line

From the video record and the associated sound track it is possible to obtain the distance from the Landolt ring at which each intruder reported its orientation. Because of the over-writing problem on the video record for nights 1 and 2 discussed in section 3.4, only the data for nights 3 and 4 will be examined. The data for these two nights showed that errors were rare; out of eighty reports only two were incorrect. The distance data for nights 3 and 4 were analysed by a two-factor analysis of variance. The analysis of variance summary table is Table 7. Using the criteria adopted earlier, the only important variable is the lighting installations used. Tukey (HSD) tests for differences between means revealed that the DARK condition was significantly different from all the lit installations. There were no significant differences between the lit installations. This pattern is evident in Table 5 which shows the mean distances at which the intruder reported the orientation of the Landolt ring under each lighting condition.

The percentage of intruders giving the orientation of the Landolt ring is plotted against distance in Figure 13. The large difference in distances between the lit installations and the DARK condition and the lack of difference between the

Table 6 Analysis of variance summary table for distances at which the intruders thought they had been recognised, when walking along the centre line (Experiment 1).

Source	Sum of squares	Degrees of freedom	Mean square	F ratio	Significance	% variance explained
Installation	4 113.8	4	1 028.5	36.3	<0.001	92.6
Night	2.5	1	2.5	<1.0	†	0.2
Installation × Night	204.2	4	51.1	1.81	†	4.6
Within cell	1 982.5	70	28.3			
Total	6 303.0	79				

† Not significant

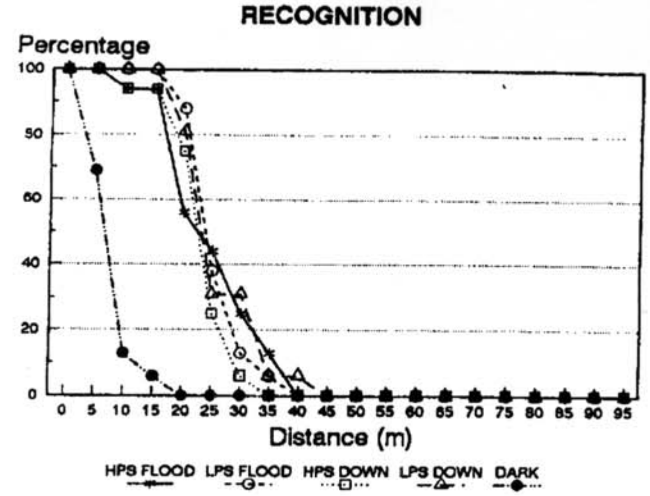


Figure 12 Percentage of intruders thinking they had been recognised, plotted against distance from the guards for each installation, when the intruder was walking along the centre line (Experiment 1).

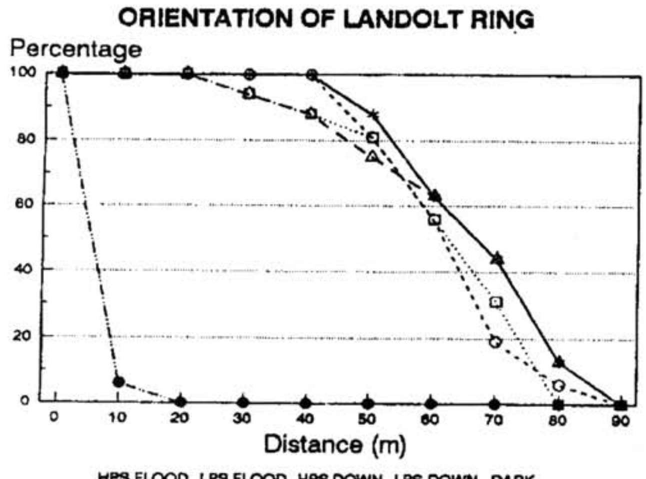


Figure 13 Percentage of intruders reporting the orientation of the Landolt ring, plotted against distance from the Landolt ring for each installation, when the intruders were walking along the centre line (Experiment 1).

lit installations is evident in Figure 13 and in Table 5 which shows the distance at which 50% of intruders reported the orientation of the Landolt ring.

For the lit installations, the average distance at which 50% of intruders identified the orientation of the gap in the Landolt ring is 64.4 m. Given this distance and the size of the gap in the Landolt ring, the corresponding visual acuity is 0.467 (2.14 minarc), a value which is not markedly different from the visual acuity of 1.62 minarc obtained in the laboratory by Conner and Ganoung[9] for Landolt rings of contrast 0.93 at a luminance of 0.2 cd m^{-2}.

4 Results of Experiment 2

4.1 Distances at which the intruders were detected when moving over the whole area in whatever manner they thought would minimise the likelihood of detection

The elapsed times for detection recorded on the event recorder were examined for multiple responses by a single guard. When multiple responses occurred, the position of detection marked on the map was also examined. In this way the correct response was identified and a complete set of correct elapsed times for detection was established. From these times and the associated video record, the distance from the centre of the group of guards where the intruder was detected by every guard was established. These distances were obtained for every lighting condition and every intruder on every night. The complete set of data was analysed by a three-factor analysis of variance.

Using the criteria adopted earlier, the analysis of variance summary table (Table 8) shows that the lighting installation is the most important variable, followed by night. Compared with these two, all the other factors and interactions are of little practical significance.

The mean distances for detection for the different installations are shown in Table 9. Tukey (HSD) tests of differences between mean distances at which detection occurred for each lighting condition showed that they are all significantly different from each other ($p < 0.01$) with the exception of the LPS DOWN installation and the DARK condition which are not significantly different.

Figure 14 shows the percentage of guards detecting the intruder plotted against the distance from the guards for each lit installation and the DARK condition. It is clear that the LPS FLOOD, HPS FLOOD and HPS DOWN installations all allow detection at greater distances than the LPS DOWN installation and the DARK condition. The distance at which 50% of guards detect the intruder under each installation is given in Table 9. A comparison of these distances with the mean distances for detection reveals little difference between these two measures of central tendency.

Table 7 Analysis of variance summary table for distances at which the intruders gave the orientation of the Landolt ring, when walking along the centre line (Experiment 1).

Source	Sum of squares	Degrees of freedom	Mean squares	*F* ratio	Significance	% variance explained
Installation	39901.9	4	9975.5	58.4	<0.001	96.0
Night	82.0	1	82.0	<1.0	†	0.8
Installation × Night	616.4	4	154.1	<1.0	†	1.5
Within cell	11955.9	70	170.8			
Total	52556.2	79				

† Not significant

Table 8 Analysis of variance summary table for distances at which the intruders were detected when moving over the whole area in whatever manner they considered would reduce the likelihood of detection (Experiment 2).

Source	Sum of squares	Degrees of freedom	Mean square	F ratio	Significance	% variance explained
Guards	139 576.4	17	8 210.4	28.2	<0.001	10.7
A = Installation	136 140.8	4	34 035.2	116.7	<0.001	44.2
B = Night	70 593.5	3	23 531.2	80.7	<0.001	30.6
C = Replication	8 494.0	3	2 831.3	9.7	<0.001	3.7
$A \times B$	33 730.8	12	2 810.9	9.6	<0.001	3.7
$A \times C$	27 026.2	12	2 252.1	7.7	<0.001	2.9
$B \times C$	5 364.1	9	596.0	2.0	†	0.8
$A \times B \times C$	86 917.7	36	2 414.4	8.3	<0.001	3.1
Residual	391 585.2	1343	291.6			
Total	899 427.7	1439				

† Not significant

Table 9 Mean distances at which the intruders were detected and the distance at which 50% of guards detected the intruder, when the intruder was moving over the whole field in any manner which would minimise the likelihood of detection (Experiment 2).

Installation	Mean distance for detection (m)	Distance at which 50% of guards detected the intruder (m)
l.OOD	58.9	60.4
LOOD	64.9	65.9
OWN	48.7	50.2
LPS DOWN	41.1	39.0
DARK	40.4	39.4

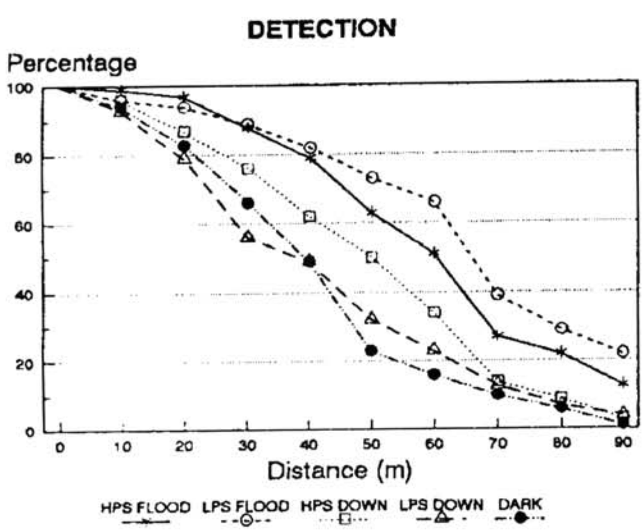


Figure 14 Percentage of guards detecting the intruder plotted against distance from the guards for each installation. The intruders could move over the whole area in whatever manner they considered would minimise the likelihood of detection (Experiment 2).

Table 10 suggests that there is a clear difference in the mean detection distance for nights 1 and 2 compared with nights 3 and 4. For nights 1 and 2 the mean detection distance over all the lighting installations was 57.8 m, but by nights 3 and 4 it had decreased to 43.9 m. This impression is supported by Tukey (HSD) tests on differences between means. Mean detection distances for nights 1 and 2 are not significantly different, neither are they for nights 3 and 4 but there are significant differences between nights 1 and 2 and nights 3 and 4 ($p < 0.01$).

Table 10 Mean distances for detection of intruders when moving over the whole field in whatever manner would minimise the likelihood of detection (Experiment 2) on different nights

Night no.	Mean distance (m)
1	57.3
2	58.4
3	43.5
4	44.2

It can plausibly be suggested that this shortening of the mean detection distance on nights 3 and 4 is due to a change in movement strategy by the intruders. Examination of the video records by the experimenter reveals that the manner of movement of intruders between the barriers could be crudely classified as crawling, walking or running. Table 11 shows the percentage of intruders on each night moving over the different parts of the field in these three ways. From Table 11 it could be seen that more intruders choose to run rather than walk or crawl between barriers on nights 3 or 4 than on nights 1 and 2.

Table 11 Percentage of intruders moving in a specified manner over parts of the field defined by the arcs of barriers (Experiment 2).

Night no.	Manner of movement	Start line to barrier at 67.5 m from the guards	Arc of barriers at 67.5 m to barriers at 45 m from the guards	Arc of barriers at 45 m to barriers at 22.5 m from the guards	Arc of barriers at 22.5 m to the line of guards
1	Crawl	100	90	55	0
	Walk	0	5	5	0
	Run	0	5	40	100
2	Crawl	100	100	65	0
	Walk	0	0	0	10
	Run	0	0	35	90
3	Crawl	75	60	20	5
	Walk	0	0	0	0
	Run	25	40	80	95
4	Crawl	80	65	20	5
	Walk	0	0	5	0
	Run	20	35	75	95

Table 12 Analysis of variance summary table for distances at which the intruders thought they had been detected when moving over the whole area in whatever manner they considered would reduce the likelihood of detection (Experiment 2).

Source	Sum of squares	Degrees of freedom	Mean square	*F* ratio	Significance	% variance explained
Intruder	1 100.5	3	366.8	2.96	<0.05	24.9
A = Installation	3 451.3	4	862.8	6.96	<0.01	58.6
B = Night	166.7	3	55.6	<1.0	†	3.7
A × *B*	748.2	12	62.4	<1.0	†	4.2
Residual	7 054.5	57	123.8			
Total	12 521.2	79				

† Not significant

4.2 Distances at which the intruders thought they had been detected when moving over the whole area in whatever manner they considered would minimise the likelihood of detection

From the video record and the associated sound track it was possible to obtain a distance from the guards at which each intruder considered he had been detected. The distances obtained were analysed by a two-factor analysis of variance. Using the criteria adopted earlier, the summary table (Table 12) shows that the important variable was the lighting installation used, although there was some difference between intruders. The mean distances at which the intruders consider they had been detected, for each lighting installation, are given in Table 13. Tukey (HSD) tests for the differences between means show that the distance at which the intruders considered they had been detected in the DARK condition was significantly less than under the HPS FLOOD, ($p < 0.01$) and LPS FLOOD ($p < 0.05$) installations and that the distance for the LPS DOWN installation was significantly less than for the HPS FLOOD installation ($p < 0.01$).

Table 13 Mean distance at which the intruders considered that they had been detected and the distance at which 50% of intruders considered they had been detected (Experiment 2).

Installation	Mean distance at which the intruders considered they had been detected (m)	Distance which 50% of intruders considered they had been detected (m)
HPS FLOOD	58.6	63.3
LPS FLOOD	49.0	48.1
HPS DOWN	47.9	46.7
LPS DOWN	47.5	46.7
DARK	37.9	40.7

Figure 15 shows the percentage of intruders under each lighting condition thinking they had been detected at various distances from the guards. For all the combinations there is a rapid rise in the percentage of intruders thinking they had been detected with decreasing distance from the guards, although there is a suggestion of a discontinuity between about 60 and 50 m for the lit installations. It is interesting to note that these distances are approximately those of two of the arcs of barriers behind which the intruder could rest in this experiment (Experiment 2). It may be that

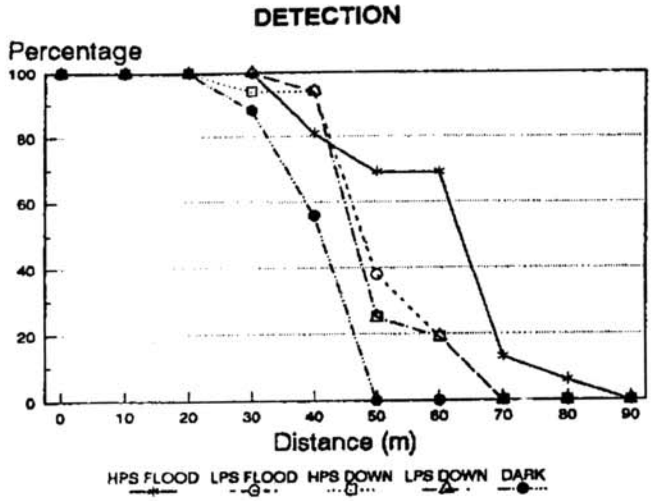


Figure 15 Percentage of intruders thinking they had been detected plotted against distance from the guards, for each installation when the intruders could move over the whole area in whatever manner they considered would minimise the likelihood of detection.

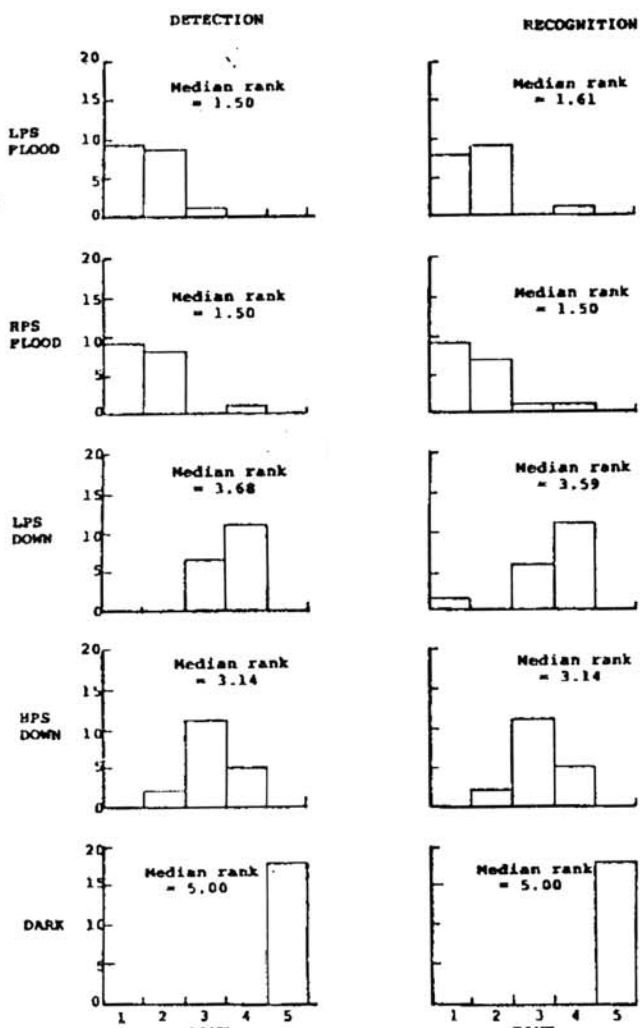


Figure 16 Frequency distribution of ranks for every installation for detecting and for recognising the intruders, given by the guards.

the intruders took the opportunity to report whether they thought they had been detected while resting behind the barriers. It should be noted that this bias could not occur in Experiment 1 because the intruder walked steadily down the centre line without resting or hiding behind the barriers, a factor which can plausibly be used to explain the much smoother slope of the cumulative frequency distributions in Experiment 1 (see Figures 11 and 12). The distances at which 50% of intruders consider they have been detected are given in Table 13.

5 Results of debriefing

The results obtained from the debriefing session using the questionnaires will be considered in two parts: responses from the guards and from intruders.

5.1 Subjective responses from guards

The first question asked the guards to rank the installations in the preferred order for (*a*) detection and (*b*) recognising the intruder. The frequency distributions of ranks obtained for each installation are shown in Figure 16 together with the median of each distribution. As might be expected, the DARK condition is ranked lowest by all the observers (rank 5) both for detection and for recognition. The lit installations are also ranked in the expected order with the HPS FLOOD and LPS FLOOD installations being considered better than the HPS DOWN and LPS DOWN installations both for detection and for recognition. Friedman non-parametric analysis of variance[8] showed that the differences in the distribution of ranks for the different installations were statistically significant ($p < 0.001$). Nemenyi tests[8] showed that the HPS FLOOD installation ($p < 0.01$), the LPS FLOOD installation ($p < 0.01$) and the HPS DOWN installation ($p < 0.05$) were significantly different from the DARK condition for both detection and recognition. The HPS FLOOD and LPS FLOOD installations were also significantly different from the LPS DOWN installation for both detection ($p < 0.01$) and recognition ($p < 0.05$). However, there was no significant difference between the HPS FLOOD and LPS FLOOD installations or between the HPS DOWN and LPS DOWN installations for either detection or recognition.

The second and third questions asked the guards to scale the installations from 0 to 100; the installation considered best for detection or for recognition was given a value of 100

Table 14 Mean scale values given for each installation by the guards and the intruders. For the guards the best lighting for detection and recognition is given the value 100 and the worst the value 0. For the intruders, the best lighting for avoiding detection or recognition is given the value 100 and the worst the value 0.

Installation	Mean scale values			
	Guards		Intruders	
	Detection	Recognition	Detection	Recognition
HPS FLOOD	85.7	87.1	5.0	5.0
LPS FLOOD	92.3	91.9	39.0	25.5
HPS DOWN	49.7	52.8	65.0	71.3
LPS DOWN	46.3	51.9	64.0	58.0
DARK	0.0	0.0	100.0	100.0

and the installation considered worst a value of 0. The mean scale values given for each installation are shown in Table 14. The pattern of mean scale values is almost identical to that produced by the median rankings obtained from the first question.

The fourth question asked the guards to rate the importance of various features of the experimental situation to their ability to detect and recognise intruders. This rating was made on a seven-point scale with the ends labelled 1 = unimportant, 7 = important. Figure 17 shows the distribution of ratings for detection. The distributions were ordered from most important to least important; median scale values greater than 3.5 were considered 'important' and those less than this value 'unimportant'. The important features for detection were the 'lights used to illuminate the field', 'contrast of the intruder against the barriers', 'contrast of the intruder against the field' and 'the lights in the background'. The first three features were expected to be important but the last requires some explanation. The lights referred to were two small street lights on a public road about half a mile distant. Occasionally an intruder would move so that he cut off the view of these lights from a guard. In hindsight, it would probably have been better to erect a screen to cut off the direct view of these lights but at the time they were considered too small or too distant to have any significance. This finding does suggest, however, the potential for enhancing the effectiveness of security lighting by providing some background lamps against which movement of an intruder can be detected.

The factors considered unimportant are audible cues from other guards, from the experiments communicating with the intruders, or from the intruders themselves. Even the occasional passing car which produced some stray light on the side of the field was considered unimportant. This confirms that it is the visual conditions which determine the ability of the guards to detect and recognise the intruders.

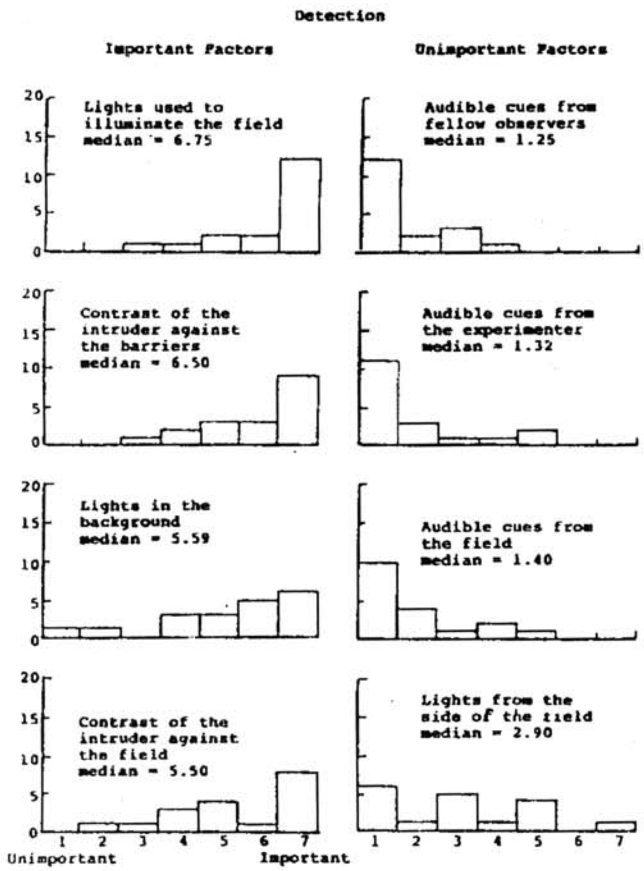


Figure 17 Frequency distribution of ratings of importance of various features of the experimental conditions to the ability to detect intruders. The ratings for each feature were made on a seven-point scale with the ends labelled 1 = unimportant, 7 = important.

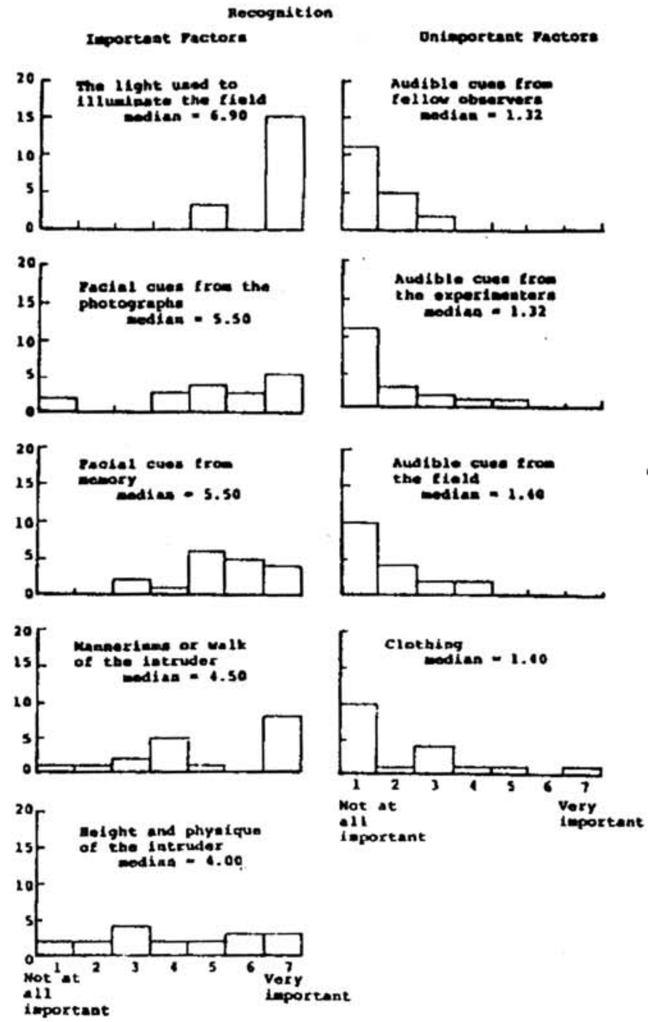


Figure 18 Frequency distribution of ratings of importance of various features of the experimental conditions to the ability to recognise the intruder. The ratings for each feature were made on a seven point scale with the ends labelled 1 = not at all important, 7 = very important.

Figure 18 shows the distribution of ratings for recognition. The distributions were ordered from most important to least important; median scale values greater than 3.5 were considered 'important' and those less than this value 'unimportant'. The important features were 'the lights used to illuminate the field', 'facial cues, either from the photographs supplied or from memory', 'mannerisms or the walk of the intruder', and 'the height and physique of the intruder'. All these factors might be expected to be important although an attempt had been made to select intruders of similar height and physique. Features considered unimportant were 'the audible cues from other guards, from the intruders and from the experimenters communicating with the intruders'. 'The clothing worn by the intruders', which was a standard uniform, was also considered unimportant for recognition. The fact that all these factors were considered unimportant supports the view that it is the visual conditions which are important in determining the guard's ability to recognise the intruder.

The fifth question asked the guards to rank order the four nights they experienced in order of darkness, the darkest night being ranked 1 and the lightest ranked 4. The median rank for each night was, night 1 = 3.5; night 2 = 2.4; night 3 = 2.2; night 4 = 2.4. Friedmann non-parametric analysis of variance[7] showed that there was no significant difference between the distributions of rankings obtained on the different nights. It can be concluded that all the nights were considered similar in their degree of darkness.

The sixth question asked the guards to rate how important they considered the weather to be in affecting their visual judgements. The assessment of the effect of the weather on visual judgement was similar on all nights, varying widely for different observers, some considering it important on all nights, others considering it unimportant. This observation is supported by an analysis of variance of the ratings. The differences between nights is not statistically significant but there are statistically significant differences between observers ($p < 0.001$).

The seventh question asked the guards which type of movement they found easier to detect, the walk down the centre line or the unknown movement by the intruder across the field, and why. Fourteen of the guards preferred the walk down the centre line because they knew where to look. The other four guards preferred the unknown movement because there was more time available to detect the intruder.

The eighth question asked the guards what search strategy was used when looking for the intruder when he was moving over an unknown route. Of the four options given, eleven guards said they searched the field continually in a systematic manner, six guards said they scanned the field in a random manner and one guard examined different areas in detail. None claimed to have looked in one direction until their attention was attracted to some definite position.

The ninth question asked if the guards found their attention wandering during each presentation, during each night, or on successive nights, and if they did by how much. Four guards said their attention wandered a little during some presentations, mainly those where the intruder could move in any manner he liked and chose to stay behind a barrier for a long period. Nine guards said they found their attention wandering a little at some time during each night, and seven guards said they found their attention wandered a little on successive nights. Such wandering of attention is inevitable during tasks involving prolonged attention in adverse conditions and it is a credit to the guards that they maintained their attention as well as they did.

The tenth and eleventh questions asked the guards if they had noticed any pattern in the order in which the intruders appeared. None of the guards had noticed any pattern.

5.2 Subjective responses from intruders

The first question asked the intruders to rank the five installations in the order in which they were best for (*a*) avoiding detection and for (*b*) avoiding recognition; the best installation for avoiding detection or recognition being ranked 1 and the worst 5. Figure 19 shows the frequency distributions of ranks given to the five installations by the four intruders. There was essentially no difference between responses for detection and recognition so they will be discussed here as one. As might be expected, the DARK condition is considered best. The LPS DOWN and HPS DOWN installations were considered next best and the HPS FLOOD and LPS FLOOD installations were considered least suitable for avoiding detection and recognition. As there were only four ranks for each installation it is not appropriate to carry out statistical tests on these data. At best these results can be considered indicative although they

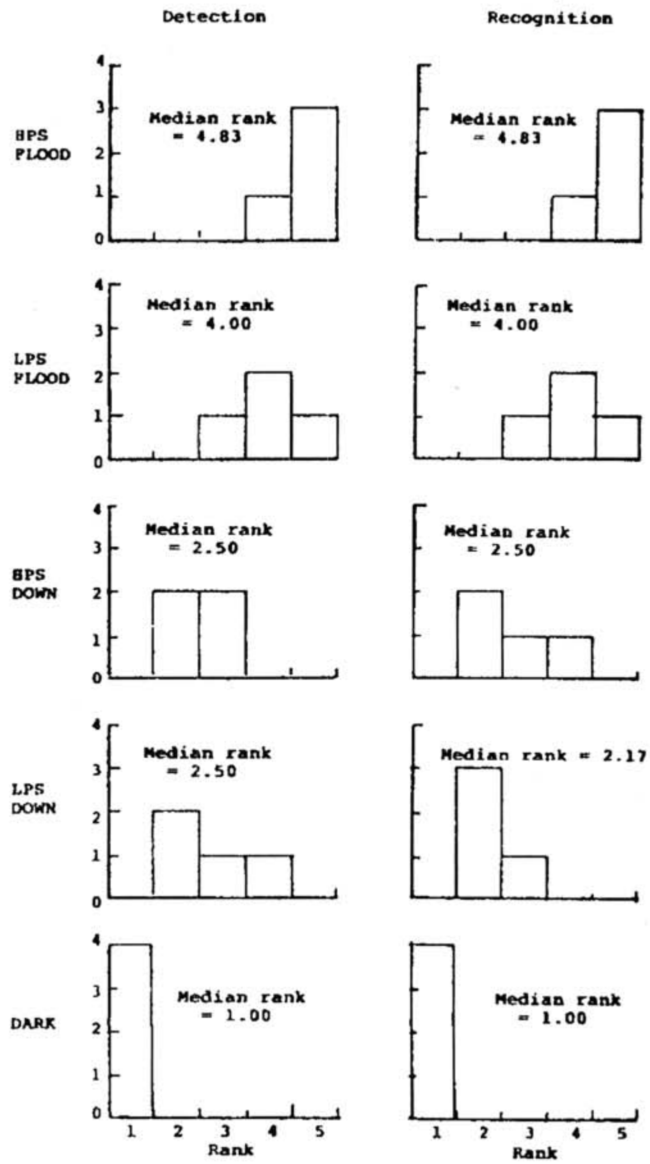


Figure 19 Frequency distribution of ranks for each installation for avoiding detection and recognition as given by the intruders.

are more or less consistent with the distances at which a constant percentage (e.g. 50%) of the guards detected and recognised the intruders under the different installations (see Figures 9 and 10).

The second and third questions asked the intruders to place the five installations from 0 to 100, where the installation considered best for avoiding detection or for avoiding recognition was given the value of 100 and the installation considered worst was given the value of zero. The mean values on these scales given by the four intruders for each installation are shown in Table 14. The scale values given by the intruders are almost the reverse of those given by the guards. However, there is one apparent difference between the guards and intruders' assessments, that is between the HPS FLOOD and LPS FLOOD installations. The intruders' results suggest that the HPS FLOOD installation is considered likely to make it more difficult to avoid detection and recognition than the LPS FLOOD installation. The guards' assessments imply little difference between these installations. This discrepancy suggests that the HPS FLOOD installation is a greater deterrent than the LPS FLOOD installation for the same illuminance. Unfortunately, the intruders' observations should only be considered as a suggestion because of the small amount of data available, although it is interesting to speculate that the HPS FLOOD installation may be considered more glaring than the LPS FLOOD installation by the intruders because of the smaller, brighter light source used (average luminance of luminaires on beam axis; HPS FLOOD = 191 000 cd m^{-2}, LPS FLOOD = 55 500 cd m^{-2}).

The fourth question asked the intruders to describe their preferred route and their preferred manner of movement when free to choose. The answers given are summarised in Table 15. It can be inferred that the preferred routes were idiosyncratic. There is no consistent pattern for the different installations. However, the preferred manner of movement does vary with the type of installation. For the DARK condition all the intruders preferred to run between the barriers but for the HPS FLOOD and LPS FLOOD installations the preferred movement was to crawl. The HPS DOWN and LPS DOWN installations were intermediate in this regard. It should be emphasised that these data were collected after the experimental work was completed, so the preferences relate to the preferred manner of movement developed over the four nights.

The fifth question asked the intruders to identify the cues they used to decide when they had been detected or recognised. All four intruders said that they used movement of the guards as a cue to when they had been detected or recognised. Without such cues the results may have been very different.

The sixth question asked the intruders to rank order the installations according to the ease of seeing the Landolt ring. The installation which made it easiest to see the Landolt ring was ranked 1 and that which made it most difficult was ranked 5. The rank orders given by the intruders for each installation are shown in Table 16. The intruders are consistent in assessing the DARK condition as the worst for seeing the orientation of the Landolt ring and the HPS FLOOD installation as the best. There is some disagreement among the intruders about the other installations. Such disagreements are to be expected given the slight differences between the lighting installations with respect to the distance at which the orientation of the ring can be seen (see Figure 13 and Table 5).

Table 16 Rank orders given by each intruder to the installations for the ease of seeing the orientation of the Landolt ring.

Installation no.	Intruder no. 1	2	3	4
HPS FLOOD	1	1	1	1
LPS FLOOD	2	2	2	3
HPS DOWN	3	4	3	2
LPS DOWN	4	3	4	4
DARK	5	5	5	5

Table 15 Preferred route and preferred manner of movement of the intruders when they could move over the whole area in any manner they thought would minimise the likelihood of detection (Experiment 2).

Preference	Intruder no.	Installation: HPS FLOOD	LPS FLOOD	HPS DOWN	LPS DOWN	DARK
Route	1	Down middle of field	Building side of field	Middle of field	Fence side of field	Fence side of field
	2	Building side of field	Middle of field	Fence side of field	Building side of field	Fence side of field
	3	Fence side of field	Building side of field	Fence side of field	Fence side of field	No preference
	4	Fence side of field	No preference	No preference	No preference	No preference
Manner of movement	1	Slow crawl	Slow crawl	Crawl on hands and knees	Slow crawl and run	Run
	2	Crawl	Crawl	Crawl and run	Crawl and run	Run
	3	Crawl on hands and knees	Crawl on hands and knees	Crawl on hands and knees	Crawl on hands and knees	Run
	4	Crawl	Run	Crawl	Crawl	Run

The seventh question asked the intruders to scale each installation on a scale of 0 to 100 for the ease with which it enabled them to see the orientation of the Landolt ring. The best installation is given the value of 100 and the worst 0. The scale values given by each intruder are shown in Table 17. Again, the disagreement surrounding the ranking of the LPS FLOOD, HPS DOWN and LPS DOWN installations is to be expected from slight differences between the installations with respect to the distances at which the orientation of the Landolt ring could be seen (see Figures 13 and Table 5).

Table 17 Value given to each installation for the ease of seeing the orientation of the Landolt ring by each intruder on a scale 0–100 where the best installation is given the value 100 and the worst the value 0.

Installation	Intruder no.			
	1	2	3	4
HPS FLOOD	100	100	100	100
LPS FLOOD	89	80	85	20
HPS DOWN	48	50	53	30
LPS DOWN	20	65	25	10
DARK	0	0	0	0

Questions eight and nine asked the intruders if they had ticed any pattern in the order in which they were used. ·ne of the intruders had noticed such a pattern.

(·ssion

6.1 Ljject of security lighting

The guards had three tasks:

1 To detect an intruder walking towards them along the centre line (Experiment 1).

2 To recognise the intruder walking towards them along the centre line (Experiment 1).

3 To detect an intruder who was trying to avoid detection and moving over the whole area (Experiment 2).

The results quantified how well the guards have performed these tasks in the absence of any form of lighting and with four types of perimeter security lighting.

These results show strongly that introducing security lighting improves intruder detection and recognition. In the DARK condition intruder recognition accuracy is only slightly better than chance (Figure 10). With every security lighting installation used, the recognition accuracy eventually approaches 95%.

Detection distance is greatly improved with security lighting. Table 18 compares detection distances for the different security lighting systems and for the DARK condition. In all but one case (LPS DOWN, Experiment 2) security lighting improves detection relative to the DARK condition. Often the improvement is substantial (e.g. 36.3 m with LPS FLOOD). It should also be noted that detection performance under the DARK condition was achieved with dark adapted guards. It is highly unlikely that the same performance could be achieved by a guard equipped with a torch (flashlight), or looking out from a lit gatehouse since he would not then be properly dark adapted. Clearly, security lighting has great advantages for detecting and recognising potential intruders.

6.2 Effect of illuminance

Given that having a perimeter security lighting installation improves the detection and recognition performance of guards, it is now necessary to consider what are the important factors in determining the distance at which detection and recognition occur. Knowledge of how the visual system operates suggests that there are three important aspects of the situation as regards detection: the size of the intruder, the contrast of the intruder against the background and the state of adaptation of the observer's visual system. The size of the intruder will increase as the intruder approaches the guard, but this increase will be the same for all the installations. As there are large and significant differences in detection distance between the installations, it is likely that the size of the intruder is not the only factor in determining the distance at which detection occurs. The other two

Table 18 Distance at which 50% of guards detected the intruder under the lit installations, for both types of movement, and the difference between these distances for the lit installations and the DARK condition.

Experiment no.	Type of movement	Measurement	Installation				
			HPS FLOOD	LPS FLOOD	HPS DOWN	LPS DOWN	DARK
1	Walking along the centre line	Distance (m)	86.8	90.6	69.7	62.8	54.3
		Difference in distance between the lit installations and the DARK condition	+32.5	+36.3	+15.4	+8.5	0.0
2	Route and manner of movement chosen by the intruder to minimise likelihood of detection	Distance (m)	60.4	65.9	50.2	39.0	39.4
		Difference between distance for lit installations and DARK condition	+21.0	+26.5	+10.8	−0.4	0.0

factors, the contrast of the intruder against the background and the state of adaptation of the observer's visual system, will both be influenced by the distribution of illuminances produced by each installation. This suggests that the vertical illuminances produced by the lit installations are likely to be important to the distance at which detection occurs.

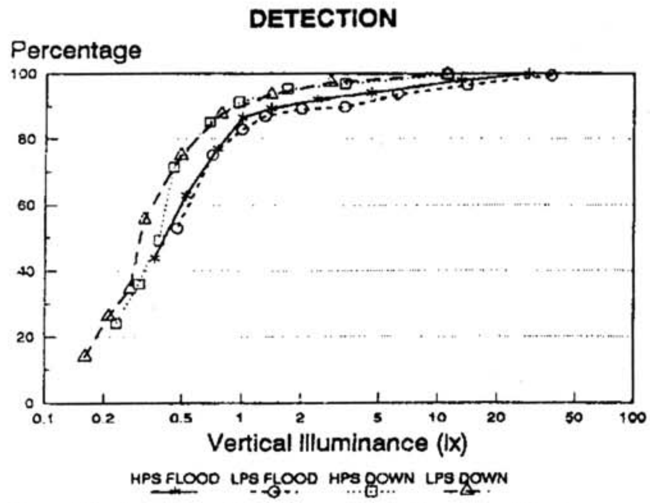


Figure 20 Percentage of guards detecting the intruder walking along the centre line, plotted against the vertical illuminance produced on the centre line at a given distance from the guards by each lit installation. The vertical illuminance starts at 10 m from the guards. At closer distances the vertical illuminances become very variable with position (Experiment 1).

The view is supported by Figure 20 which shows the probability of detection for an intruder walking along the centre line (Experiment 1) plotted againt the vertical illuminance produced along the centre line by each lit installation at various distances. A comparison of Figure 20 with Figure 9 shows that converting distance to vertical illuminance has considerably reduced the separation between the different lit installations, a fact which indicates the importance of vertical illuminance. However, a three-factor analysis of variance[8] applied to the log vertical illuminance associated with each distance at which detection occurred in Experiment 1 shows that even after converting distance to vertical illuminance there are still statistically significant differences between the lit installations (Table 19), the installation variable taking the major portion of the variance explained. Tukey HSD tests for differences between means showed that the major difference was between the FLOOD installations and the DOWN installations. This difference suggests that size probably does have some influence. Specifically, the FLOOD installations produce a given vertical illuminance at a greater distance from the guards than do the DOWN installations. This advantage will be offset somewhat by the smaller size subtended by the intruder at these greater distances. The net effect of the smaller size of the intruder will be to require a higher vertical illuminance for a given probability of detection for the HPS FLOOD and LPS FLOOD installations, which is the result shown in Figure 20.

This result is quantified in Table 20 which shows the vertical illuminances corresponding to the mean detection distance and the vertical illuminances associated with 50 and 90% probability of detection, for each of the lighting installations in Experiment 1. Although these vertical illuminances were

Table 20 Vertical illuminances under each lighting installation corresponding to the mean distance for detection and for 50% and 90% probability of detection for Experiment 1 and Experiment 2. These values were estimated by eye.

Experiment no.	Installation	Vertical illuminance (lx)		
		Mean	50% probability of detection	90% probability of detection
1	HPS FLOOD	0.51	0.40	1.6
	LPS FLOOD	0.61	0.47	3.2
	HPS DOWN	0.36	0.37	0.8
	LPS DOWN	0.31	0.31	1.0
2	HPS FLOOD	1.04	0.90	6.5
	LPS FLOOD	1.04	1.01	9.8
	HPS DOWN	0.67	0.63	7.4
	LPS DOWN	0.72	0.81	10.7

Table 19 Analysis of variance summary table for the vertical illuminances at which the intruders were detected when walking along the centre line (Experiment 1). The vertical illuminances have been subjected to a log transformation.

Source	Sum of square	Degrees of freedom	Mean square	F ratio	Significance	% variance explained
Guards	48.06	17	2.827	24.80	<0.001	22.9
A = Installation	24.47	3	8.157	71.55	<0.001	66.0
B = Night	0.12	3	0.040	<1.00	†	0.3
C = Replication	1.16	7	0.166	1.46	†	1.3
$A \times B$	3.42	9	0.380	3.33	<0.01	3.0
$A \times C$	5.91	21	0.281	2.47	<0.01	2.2
$B \times C$	4.61	21	0.220	1.93	<0.01	1.8
$A \times B \times C$	10.59	63	0.167	1.47	<0.05	1.4
Residual	246.97	2159	0.114			
Total	345.22	2303				

† Not significant

taken from Figure 20 by eye, it is still evident that the HPS FLOOD and LPS FLOOD installations consistently require a higher vertical illuminance than the HPS DOWN and LPS DOWN installations, for both the probability of detection criteria.

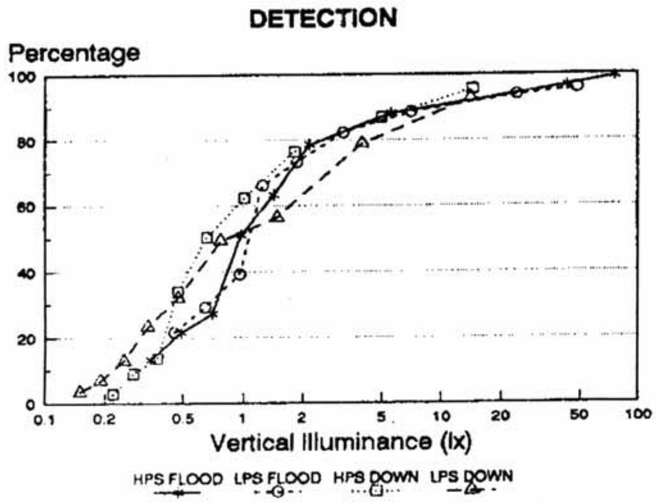


Figure 21 Percentage of guards detecting the intruder moving over the whole area in whatever manner he chose, plotted against the vertical illuminances produced by each lit installation. The vertical illuminance is the mean vertical illuminance produced on an arc at a given distance from the centre of the guards. The vertical illuminance starts at 10 m from the guards. At closer distances the vertical illuminances become very variable with position. (Experiment 2).

As for the detection of intruders when they move over the whole area in whatever manner they consider will minimise the likelihood of detection (Experiment 2), Figure 21 shows the percentage of guards detecting them plotted against the vertical illuminance produced by each installation. The vertical illuminance is the mean vertical illuminance on an arc of a specified radius and centred on the middle of the group of guards. Again, there is good agreement between the lit installations for the effect of vertical illuminance on the probability of detection, and comparison of Figures 14 and 21 shows a marked reduction in separation between the lit installations when vertical illuminance is used as the independent variable. A three-factor analysis of variance was carried out on the vertical illuminances associated with the distances at which detection occurred in Experiment 2, after log transformation. This showed that even after converting distance to vertical illuminance there was still a statistically significant difference between lighting installations but these differences were of little practical significance because the variance explained was slight (Table 21). Table 20 shows the vertical illuminances associated with the mean distances at which detection occurred and the vertical illuminances associated with 50% and 90% probability of detection, for Experiment 2. It is evident that vertical illuminance has a strong effect on the probability of detection, the variation between different installations probably being due to differences in intruder strategy.

Figure 22 shows the effect of plotting the probability of correct recognition against vertical illuminance on the centre line for the four lit installations (Experiment 1). In this case, changing the independent variable from distance to vertical

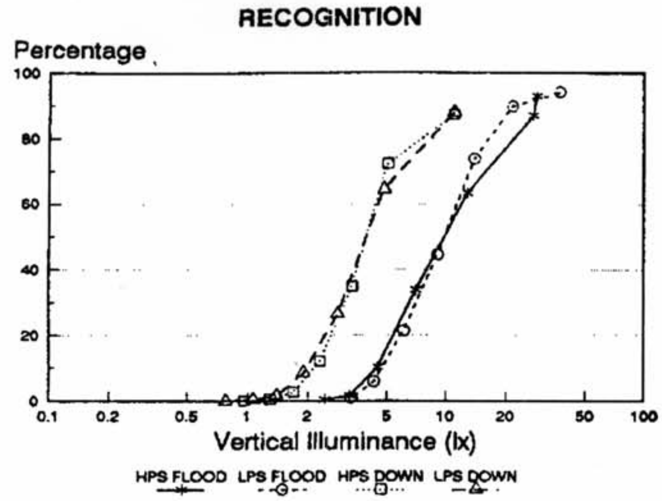


Figure 22 Percentage of guards *correctly* recognising the intruder walking along the centre line, plotted against the vertical illuminance produced on the centre line at a given distance from the guards by each lit installation. The vertical illuminance starts at 10 m from the guards. At closer distances the vertical illuminances become very variable with position. (Experiment 1).

illuminance does not result in a reduction in separation of the lit installations (cf Figure 10 and Figure 22). Rather, there is a clear difference between the DOWN installations and the FLOOD installations.† This difference can be explained by the limited distance at which recognition can occur. For recognition of faces and mannerisms of movement, the details that have to be resolved are smaller than those required simply to detect presence. This is why recognition always occurs much closer to the guards than does detection (see Figures 9 and 10). From Figure 10 it appears that the size of detail that needs to be resolved limits correct recognition to distances less than forty metres from the guards. At such distances the vertical illuminances produced by the FLOOD installations are increasing more rapidly than is the case for the DOWN installations. This will tend to enhance the difference in vertical illuminance between the FLOOD installations and the DOWN installations, for equal probabilities of correct recognition (Figure 22). How big these differences are can be appreciated from Table 22 which gives the vertical illuminances associated with the mean distance for correct recognition and with 50% and 90% probability of correct recognition.

Turning now to the question implied in the Introduction, 'What design criteria are needed for ensuring that perimeter security lighting allows guards to detect and recognise intruders?', the results shown in Figures 20 and 21 and in Table 20 suggest that vertical illuminance is a practical criterion. The appropriate value for this criterion appears to be related to the extent of the area to be guarded. The results shown in Figure 20 and Table 20 suggest that when the guard has to watch a limited area, then a vertical illuminance of 4 lx is sufficient to ensure 90% or greater probability of detection. However, when the guard has to watch a large area, the results in Figure 21 and Table 20 suggest that a vertical illuminance of 10 lx is required to ensure 90% or greater probability of detection.

† No analysis of variance has been attempted for this data because the failure to achieve 100 per cent correct recognition under any of the lit installations means that the data requried for such an analysis is incomplete.

Table 21 Analysis of variance summary table for the vertical illuminance at which the intruders were detected when moving over the whole area in whatever manner they considered would reduce likelihood of detection (Experiment 2). The vertical illuminances have been subjected to a log transformation.

Source	Sum of squares	Degrees of freedom	Mean square	F ratio	Significance	% variance explained
Guards	63.05	17	3.71	23.19	<0.001	18.3
A = Installation	3.13	3	1.04	6.50	<0.01	5.1
B = Night	30.33	3	10.11	63.19	<0.001	49.9
C = Replication	2.40	3	0.80	5.00	<0.01	3.9
$A \times B$	10.01	9	1.11	6.94	<0.001	5.4
$A \times C$	12.82	9	1.42	8.88	<0.001	7.0
$B \times C$	1.62	9	0.18	1.13	†	0.9
$A \times B \times C$	46.34	27	1.72	10.75	<0.001	8.5
Residual	169.81	1071	0.16			
Total	339.52	1151				

† Not significant

Table 22 Vertical illuminances under each lighting installation corresponding to the mean distance for correct recognition and for 50% and 90% probability of correct recognition (Experiment 1). These values were estimated by eye.

Installation	Vertical illuminance (lx)		
	Mean	50% correct recognition	90% correct recognition
HPS FLOOD	7.6	9.1	34.0
LPS FLOOD	8.8	9.3	21.8
HPS DOWN	3.9	3.8	—
LPS DOWN	3.4	3.7	—

As for recognition, the results in Figure 22 suggest that a vertical illuminance of 10 lx will also allow about 90% probability of correct recognition for the HPS DOWN and LPS DOWN installations. The higher illuminances apparently required by the HPS FLOOD and LPS FLOOD installations are artefactual in that they occur because of the limitation on the maximum distance at which recognition can occur due to the size of detail that needs to be resolved, as explained above.

Given the fact that perimeter security lighting almost always produces the highest illuminance at the perimeter and then shows a decline in vertical illuminance as distance from the perimeter increases, a vertical illuminance of 10 lx at the distance at which detection is required should ensure a high probability of detection and recognition. This illuminance is comparable with those recommended by Baker and Lyons[4] for perimeter lighting but is somewhat larger than those recommended in the USA for surveillance lighting[3]. However, it should be noted that the illuminance derived from the work described here is appropriate for perimeter security lighting, where the vertical illuminance decreases with increasing distance from the perimeter and where the guards are viewing the scene from the perimeter. This illuminance may not be appropriate where area floodlighting is used to provide a uniform illuminance over a large area because then the state of adaptation of the guard's visual system could be markedly different. Suitable illuminances for uniform area security lighting, such as might be used on lorry parks, remain to be established.

6.3 Effect of light source

The other question addressed by this research was whether low-pressure sodium and high-pressure sodium discharge lamps differ in terms of their effect on the detection and recognition of intruders. The probabilities of detection and recognition plotted against vertical illuminance are shown in Figures 20, 21 and 22 and the vertical illuminances associated with 50% probability of detection or recognition are shown in Tables 20 and 22. For all these results, the installations using the two light sources show very similar trends. Any differences between installations that do occur are between the FLOOD installations and the DOWN installations and are due to differences in light distribution rather than light colour. It can be concluded that low-pressure sodium lamps can be used for security lighting without any significant deterioration in the ability of observers to detect and recognise intruders.

This conclusion in turn raises the question of whether the light source colour is ever important in security lighting. In two circumstances it seems likely that light source colour will be important. The first is where colour is of significance in itself and is an essential element in recognition. For example, it may sometimes be necessary for a security guard to examine a pass handed in by someone in uniform. If the pass and the uniform are expected to be of a particular colour then it would be as well to use a light source in the area where the check will be made that will allow the guard to discriminate colour accurately.

The second area where light source colour may be important is more general in application and relies on an aspect of security which has not been considered in this experiment. The aspect is people's ability to describe an intruder or an assailant. People can be characterised on many different dimensions: sex, race, age, build, particular features, etc. and colour of clothing is one of them. A similar list of parameters could be drawn up for inanimate objects such as cars. How important the colour dimension is for such descriptions and how precise is the information noted is a matter of conjecture. However, what can be said with certainty is that using low-pressure sodium lamps for security lighting will make any colour description at best imprecise and at worst misleading. Until the question of the importance of colour in the description of people and objects is resolved it would be unwise to use low-pressure sodium discharge lamps if accurate descriptions of intruders or inanimate objects are considered important.

6.4 Subjective preferences

From the guards' preferences there is no doubt that they considered the lit installations to be superior to the DARK condition in enabling them to detect and to recognise intruders. This is in spite of the fact that the distances at which the guards detected the intruder when he might be moving over the whole area in any manner he chose (Experiment 2) showed little difference between the DARK condition and the DOWN installations. Further, the guards considered that the FLOOD installations, which produce higher vertical illuminances at greater distances than the DOWN installations, were better for detecting and recognising intruders, a belief supported by the distances for detection and recognition results (Figures 9, 10 and 14). The distribution of rankings also showed that there is no consistent difference between the guards' preference for installations of the same light distribution but using low-pressure sodium and high-pressure sodium discharge lamps. Again, this lack of difference between similar installations using the two lamp types is supported by the objective results once the vertical illuminances produced by each installation are taken into account (see Figures 20, 21 and 22). It can be concluded that the subjective preferences expressed by the guards are in general agreement with the objective results.

As for the intruders' preferences for the lighting installations, they are almost the reverse of those of the guards. The DARK condition is chosen by all the intruders as the best to avoid detection and recognition. While this choice is certainly supported by the reco[illegible]ion results and for detection when walking along the c[illegible]e line (Experiment 1), the advantage of darkness is not so clear-cut when the intruder could move over the whole area in any manner he liked (Experiment 2). Nonetheless, a clear preference for the DARK condition over the lit installations may be taken as evidence of the deterrent effect of security lighting. There is even a suggestion in the preference for the HPS FLOOD installation over the LPS FLOOD installation that the higher brightness of the HPS FLOOD luminaires may act as a deterrent. Unfortunately, because of the small number of intruders this observation must remain as a suggestion, although it is certainly one that deserves further study.

7 Conclusions

1 Under all lighting conditions, detection of the intruders occurs at greater distances than recognition.

2 Under all lighting conditions, detection occurred at greater distances when the intruder walked along a known path than when he was moving over a large area attempting to conceal his movements.

3 Compared with darkness, a perimeter security lighting installation would enable an intruder to be detected at a greater distance, no matter whether the intruder is moving along an expected path or attempting to conceal his movements.

4 The ability of guards to detect intruders is largely dependent on the vertical illuminance on the intruder, at least up to the maximum measured distance of 100 m.

5 An intruder walking along a known path will be detected 50% of the time if the vertical illuminance is approximately 0.4 lx. For 90% probability of detection, approximately 5 times as much light is required, i.e. 2 lx.

6 An intruder moving over a large area and attempting to conceal his movements will be detected 50% of the time if the vertical illuminance is approximately 1 lx. For a 90% probability of detection, 10 times as much light is required, i.e. about 10 lx.

7 Compared with darkness, a perimeter security lighting installation will allow more accurate recognition of faces.

8 The ability of guards to recognise intruders is dependent on both the vertical illuminance on the intruder and the distance of the intruder from the guard, at least up to the maximum measured distance of 100 m.

9 An intruder walking along a known path will be correctly recognised 50% of the time when the vertical illuminance is about 9 lx under the floodlighting installations, but only about 4 lx under the street lighting installations.

10 Low-pressure sodium discharge lamps are just as effective as high-pressure sodium discharge lamps in facilitating detection of intruders and recognition of faces. This conclusion assumes that colour is not an essential attribute of the object being detected or recognised. Whether colour is a significant dimension in people's ability to describe other people and objects and how light source colour would affect that ability remains to be established.

11 The preferences of guards and intruders for different lighting conditions are opposite and follow the objective effects of the lighting conditions on their ability to detect and recognise intruders or to avoid detection and recognition respectively.

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