Behavior and Survival of American Cockroaches[1] Exposed to Different Ultraviolet and White Light Regimens[2]

JOHN B. GINGRICH

Pioneering Research Laboratory, U.S. Army Natick Laboratories, Natick, MA 01760

ABSTRACT

Periplaneta americana (L.) at different stages of development were exposed to 5 different light regimens for 24 h: UV vs. dark; "filtered" light (above 345 nm) vs. dark; UV vs. "filtered" light; white light vs. dark; and UV vs. white light (of equal intensity). Early instars avoided UV more quickly than "filtered" or white light, given the opportunity to escape into darkness. However, when forced to choose between UV and "filtered" or white light, early instars showed delayed avoidance or no avoidance. The same general pattern held for older instars except that avoidance responses occurred more quickly. When forced to choose between UV and white light of equal intensity, no avoidance occurred in any instar except the 5th. Mortality was greater than 90% in 1st to 5th-instar cockroaches regardless of the UV avoidance, though older instars required up to 1 month to reach 90% mortality, whereas in 1st and 2nd instars 100% mortality occurred within 4 days. Sixth and older instars exhibited very low mortality except in the UV vs. white light treatment where greater than 90% mortality occurred within 4 days.

Wharton (1971) found that adult male American cockroaches, *Periplenata americana* (L). were repelled by germicidal (UV) light. However, he described no statistical criteria for judging repellency, showed no relationship of cockroach age to repellency, did not study rate of response, and failed to separate UV repellency from that of visible light alone. Cohen et al. al. (1973) showed that within a given cockroach instar, those nearest the molt were most sensitive to the lethal effects of UV. In addition, they demonstrated that UV light of 254 nm produced the greatest mortality in the shortest time. The objectives of this study were to determine in cockroaches: (1) any relationship between age and avoidance of UV; (2) whether UV avoidance differed from that of visible light alone; and (3) the relationship, if any, between UV avoidance and mortality.

MATERIALS AND METHODS.—The emission characteristics of Sylvania 15-w germicidal lamps[3] were measured using an IL 600 research photometer[4] and a Cary 14 recording spectrophotometer[5]. The transmission characteristics of 3.2-mm plexiglass and Lexan® used in chamber construction for avoidance tests were similarly studied. Chambers were constructed of plexiglass and Lexan to inner dimensions of 30.5× 11.4×11.4 cm. Each chamber was divided into 2 equal compartments by a piece of plexiglass (or Lexan) that extended to 1.6 cm from the bottom, thereby leaving a 11.4×1.6 cm slit between the 2 compartments. The compartments were painted black, covered with clear plexiglass, or left uncovered to effect the following paired comparisons in the chambers: (1) UV vs. dark[6]; (2) UV vs. "filtered" light (above 345 nm) from germicidal lamps[7]; (3) dark vs. "filtered" light above 345 nm[7]; (4) dark vs. white fluorescent light[8]; (5) UV vs. white light of equal intensity[9]; and (6) white light of slightly different intensities.[10]. Newly-hatched cockroaches were removed every other day from dishes of oothecae and reared in separate containers so that cockroaches of a given age and instar could be used in tests at will. Prior to a test, 5 cockroaches were placed in each compartment, the 2 halves of each chamber being separated by a sliding door. The bottom of each chamber was covered with fresh absorbent toweling for each test and each compartment had a fresh vial of water (but no food) provided. Cockroaches were allowed to adjust to their new quarters for 1 h in darkness or red incandescent light[11] prior to removing the sliding doors and turning on the lights and the timer. Cockroaches were observed at regular intervals during the next 24 h, i.e. ¼, 1, 2, 3, 4, 5, and 24 h. The mean number of cockroaches in each compartment was calculated from 3 observations taken at 1-min intervals at each major time interval. A minimum of 3 replicates/instar was used and means for each test were subjected to χ^2 analysis. Avoidance was defined as the 1st time interval at which a significant χ^2 was obtained ($P<0.05$) after which no intervening intervals of nonsignificance were found. The instars tested were 1st, 2nd, 3rd, 4th, 5th, 6th and 7th, 8th and 9th, and adults. Upon completion of each test (i.e, after 24 h in the test chambers), cockroaches were placed in new rearing chambers, provided with food and water, and observed at daily and weekly intervals until mortality occurred (>50%). During this period they received normal lighting incidental to laboratory operations. The percent mortality at 24-h intervals (e.g. 24, 48, 96, 192 h, etc.) was recorded. Percent mortality was converted to probits, time of mortality was converted to logs, log time-probit (LTP) lines were plotted by the method of least squares, and 95% fiducial limits were derived with the aid of a computer.

[1] Orthoptera: Blattidae.
[2] Received for publication Apr. 23, 1973.
[3] Radiant energy at 254 nm = 86% of total light energy.
[4] International Light, Newburyport, Mass.
[5] Applied Physics Corp., Monrovia, Calif.
[6] UV half of compartment uncovered, dark half covered with plexiglass painted black. Radiant energy on UV side = 2820 ergs sec^{-1} cm^{-2}.
[7] Plexiglass or Lexan filters out 99.9% of UV below 345 nm and transmits 92% of light above 345 nm. With plexiglass used on the "filtered" side, radiant energy was reduced by ≈ 87% (86% UV and 1% of light above 345 nm).
[8] Source of white light was a 15-w Cool-White® light from General Electric.
[9] Two germicidal and 2 white lights (all 15-w) were used over opposite compartments, separated from one another by 3 ft × 3 ft-white poster board to prevent light crossover. Total radiant energy differential between the 2 compartments was less than 7%. Mean UV at 25 cm = 2840 ergs sec^{-1} cm^{-2}.
[10] One compartment covered with plexiglass thereby effecting ≈8% reduction of radiant energy on that side.
[11] Cockroaches responded randomly to a choice between darkness or red incandescent light.

Table 1.—Time (h) at which significant avoidance (X^2, $P < 0.05$) of cockroaches (by instar), occurred during exposure to 5 different light regimens: UV vs. dark, "filtered" (above 345 nm) vs. dark, UV vs. "filtered", white vs. dark, and UV vs. white (of equal intensity).

Instar	Avoided condition (compared condition)				
	UV (vs. dark)	"Filtered" (vs. dark)	White (vs. dark)	UV (vs. "filtered")	UV (vs. white)
1	2	5	5	5	None[a]
2	2	None*	4	24	None[a]
3	¼	¼	¼	5	None[a]
4	¼	1	¼	5	—
5	¼	¼	¼	2	3
6 & 7	¼	¼	¼	3	None[a]
8 & 9	¼	¼	¼	2	None[a]
Adults	¼	¼	¼	¼	None[a]

[a] Avoidance beyond 24 h not determined.

RESULTS AND DISCUSSION.—Large nymphs (8th and 9th instar) responded randomly to a choice between white light of slightly different intensities (≈8%), thus suggesting that small variations in light intensity do not affect cockroach behavior. In light-dark comparisons, 1st instars showed significant avoidance of white or "filtered" light (above 345 nm) only after 5 or more h of exposure (Table 1); 2nd instars behaved similarly. However, when given a choice between UV and darkness, both 1st and 2nd instars avoided the UV within 2 h (Table 1). First- and 2nd-instar cockroaches, therefore, appear to discriminate between UV and white light since the avoidance of UV occurs more quickly than avoidance of white light alone. When the choice was UV vs. "filtered" light, avoidance of UV required 5 to 24 h for 1st and 2nd instars respectively (Table 1), even though the intensity on the "filtered" side was 87% lower than on the UV side. Beginning with the 3rd instar, cockroaches avoided all kinds of light within ¼ h, except when forced to choose between UV and "filtered" light, in which case avoidance of UV was delayed up to 5 h. In general, the older the cockroach, the quicker the avoidance of the UV given a choice with "filtered" light (Table 1). However, when the intensities of UV and white light were equalized, avoidance of UV did not occur except in the 5th instar (Table 1). These findings suggest that cockroaches (particularly the 5th to 9th instars and adults) can discriminate between light of widely different intensities but are stressed by light of equal intensities to the point of random orientation. Stress in the above situation is further indicated by frequent crossovers between the 2 compartments.

Avoidance of UV is clearly reflected in the mortality data. The quicker the avoidance of UV within a given instar, the higher are the LT_{50} and LT_{90} values (Table 2). Also, when avoidance of UV in 2 successive instars was the same (e.g. 1st and 2nd, or 3rd and 4th instars), mortality was always lower in the older instars (Table 2). This concurred with the finding by Cohen et al. (1972) that sensitivity to the lethal effects of UV decreases in successive instars. The 1 exception was in the UV vs. white light test with the 5th instar which inexplicably avoided the UV within 3 h. The stressing effect of forcing cockroaches to choose between UV and white light of equal intensities is further indicated

Table 2.—Comparative LT values (time in h at which a given % mortality occurred) and slopes of LTP (log time-probit) lines calculated after exposing cockroaches by instar to choices of UV vs. darkness, UV vs. "filtered" (above 345 nm), or UV vs. white light (of equal intensity) for 24 hr. White vs. dark (controls) displayed no mortality.

Instar	LT 50 (Hrs)			LT 90 (Hrs)			Slope		
	UV vs. dark	UV vs. "filtered"	UV vs. white	UV vs. dark	UV vs. "filtered"	UV vs. white	UV vs. dark	UV vs. "filtered"	UV vs. white
1	29.6 ±7.2	9.8 ±0.9	<24	43.7 ±10.7	17.0 ±4.1	24–48	7.83	5.40	—
2	50.3 ±20.8	28.9 ±7.4	24.5 ±5.0	102 ±43.5	44.7 ±14.2	50.1 ±16.5	4.23	6.78	4.25
3	52.5 ±9.0	20.0 ±4.0	17.8 ±2.4	83.2 ±14.2	91.2 ±9.8	31.6 ±5.8	6.66	1.99	5.05
4	447 ±184	57.6 ±42.8	—	934 ±245	170 ±136	—	3.04	2.75	—
5	303 ±13	230 ±75	145 ±68	563 ±38	668 ±174	408 ±226	4.92	2.29	2.87
6 & 7	2400 ±1450	1780 ±1208	22.5 ±8.5	[a]	[a]	49.1 ±25.5	2.04	1.58	3.99
8 & 9	[a]	1660 ±1260	52.5 ±8.7	[a]	[a]	77.5 ±21.5	[a]	1.17	7.60

[a] Mortality within the duration of the instar too low to be calculated.

by the great reduction in LT_{50} and LT_{90} values in this treatment compared with all others (Table 2). The extremely low LT_{50} and LT_{90} values in stressed 6th- to 9th-instar cockroaches probably can be attributed to the nonavoidance of UV. However, since mortality rates are so high, the possibilities of a true stressing effect or of photopotentiation by white light as indicated by Beard (1973[12]) cannot be ruled out.

Since cockroaches can be expected to avoid UV unless stressed with white light, any practical application of UV in population suppression of cockroaches should take account of this factor. However, population suppression with UV should occur even without the stress of white light since young instars usually receive a lethal exposure prior to avoidance. To date, discussion on the mode of action of UV in killing cockroaches is largely speculative.

CONCLUSIONS.—Cockroaches in the 1st and 2nd instars avoid UV more quickly than "filtered" or white light when given the chance to escape into darkness. In older cockroaches, avoidance of all kinds of light (UV, "filtered", and white light) occurs so rapidly that no real differences were found. However, when given a choice of UV and white light of equal intensities, cockroaches displayed no avoidance except in the 5th instar. Mortality rates in 6th to 9th instars exposed to UV and white light of equal intensities were greatly increased. Any practical use of UV in cockroach population suppression should take account of the avoidance phenomena observed.

ACKNOWLEDGEMENT.—I gratefully acknowledge the support and advice of Drs. John J. Pratt, Gabriel R. Mandels, Louis M. Roth, and Mr. Samuel H. Cohen in the course of this research.

[12] R. L. Beard, 1973. Unpublished data.

REFERENCES CITED

Cohen, Samuel H., John A. Sousa, and Joseph F. Roach. 1973. Effects of UV irradiation on nymphs of five species of cockroaches. J. Econ. Entomol. 66: 859–62.

Wharton, O. R. A. 1971. Ultraviolet repellent and lethal action on the American cockroach. Ibid. 64: 252–5.

Reprinted from the
JOURNAL OF ECONOMIC ENTOMOLOGY