

The Effect of High Pressure Sodium Vapor Lamps on the Rat (42177)

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Abstract. The effect of high pressure sodium vapor lamps and daylight-simulating fluorescent lights on the growth, hematology, and behavior of Sprague–Dawley rats has been investigated. Rats weaned under the sodium vapor lamps had slightly heavier adrenals than those exposed to the daylight lamps when the two lighting systems were equalized either for total irradiance or for scotopic illuminance. However, no differences were observed in the tailflick response, hot plate response, or swimming endurance of rats housed under the two lighting conditions. No consistent differences were seen in the hemoglobin, red and white cell count, hematocrit, and mean cell volume between rats weaned under the high pressure sodium vapor lamps and daylight-simulating fluorescent lights. © 1985 Society for Experimental Biology and Medicine.

Light is an environmental factor that has a profound influence on growth and development in mammals (1). Lighting parameters that are considered important include spectral distribution, intensity, photoperiodicity, and duration of exposure (1, 2). Since laboratory experimental animals spend their entire lifetime under artificial lights it is important to understand the effect different lighting systems may have on them.

High pressure sodium vapor (HPSV) lamps are being increasingly used for indoor lighting purposes due to their higher efficiency and light output when compared with that of incandescent bulbs. However, Ozaki and Wurtman (3) have shown that rats raised under HPSV lamps weighed more during early development and had larger adrenal glands at necropsy than rats raised under daylight-stimulating (DS) fluorescent lamps. In these experiments the illuminances from both light sources were matched at 75 ft candles, which was considered to be a reasonably good laboratory lighting level. Subsequently, Corth (4, 5) has pointed out that, in the rat, vision is mediated solely by the rhodopsin-containing rods present in the retina. The footcandle meter, which measures photopic brightness, is therefore not an appropriate instrument to measure scotopic brightness as perceived by a nocturnal animal such as the rat. Thus, when rats are housed under either DS fluorescent or HPSV lamps that are equated photopically, they will perceive the fluorescent lights as being 3.1 times brighter (4, 5). Since rats normally

avoid bright environments (6), differences in the brightness of two lighting environments may produce differing degrees of stress.

We have now repeated the study of Ozaki and Wurtman (3) under two different lighting conditions. In the first experiment the exposure conditions were similar to those employed by Ozaki and Wurtman, except that instead of normalizing the illuminances of the light sources the total irradiances were kept the same. In the subsequent studies a number of changes were made in the lighting systems in order to isolate spectral distribution as the only variable. First, the scotopic intensities of the two light sources were equalized. Second, diffusers were employed to provide more uniform illumination and eliminate point sources. Third, the overall illuminances were reduced since rats normally avoid very bright environments (6). These modifications had the additional advantage that they also eliminated the possibility that the HPSV lamps were producing a thermal stress in the experimental animals (*vide infra*). Body and organ weights were measured under both exposure conditions; peripheral hematology and behavior were also monitored in rats weaned under the equal scotopic intensity conditions.

Methods. *Exposure protocols.* *Experiment 1.* Sprague–Dawley rats (males 98 days old, 425 g; females 70 days old 225 g) were obtained from Charles River Breeding Laboratories Inc. The rats were housed in an environmental chamber (9 × 12 × 8 ft) in which the temperature was maintained at 21°C and

the average relative humidity was 60%. Ten male and ten female rats were placed in racks (five per cage) illuminated by 2×4 ft surface lighting fixtures (Spectralite, Cat. No. S11244, Garco Lighting, Chicago, Ill.) containing four 40 W daylight fluorescent lamps (GE (Chroma 50 F40C50) and a single 15 W uv lamp (GE F15T8/BL). The ends of the lamps were covered with lead shields to eliminate possible emissions from the cathodes. The fixtures were equipped with aluminum egg crate louvers ($\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ in.) above which was an aluminum wire mesh which was electrically grounded. The fixtures were located 18 in. from the cage floors.

A second group of 10 male and 10 female rats was placed in cages (5 per cage) illuminated by high pressure sodium vapor lamps (GE Lucalox LU 150/55) housed in standard fixtures (GE Cat. No. C740G546). The lamps were located 54 in. from the cage floors.

Each group was provided light for 12 hr daily (6:00 AM–6:00 PM). The irradiances in the center of the racks were 478 and 461 $\mu\text{W}/\text{cm}^2$ for the daylight fluorescent and HPSV lamps, respectively. Because the irradiance of the fluorescent lamps decreased at the ends of the fixtures, the cages were rotated daily so that each cage received the same average amount of light during the experiment. Corncob bedding (Sanocel) was used throughout the study. The rats were allowed water and food (NIH 31 Rat and Mouse Ration) *ad libitum*. After 1 week, the rats were paired in single cages. The males were removed after a period of 18 days and the pregnant females were then monitored daily for litters. The date of each litter was recorded and the litters were standardized to four males and four females within a few days of birth. The male pups were sacrificed at 30 days of age. However, since Ozaki and Wurtman (3) raised their female rats until they were sexually mature, the females were not sacrificed until they were 70 days old. The body weights and weights of the heart, liver, spleen, testes, kidneys, and adrenals were determined.

Experiment 2. In a second experiment the illuminance of the daylight fluorescent light fixtures was adjusted to 10 ft. candles ($42 \mu\text{W}/\text{cm}^2$) by the removal of two lamps combined with the use of two aluminum mesh screens that had been painted flat black. The illumina-

nance of the HPSV lamps was changed to 30 ft. candles ($96 \mu\text{W}/\text{cm}^2$) by placing diffusers (sheet aluminum covered with Kodak White Reflectance Coating, No. 6080) above (30 in. diameter) and immediately below (8 in. diameter) the HPSV lamp.

Blood samples were collected from the tail veins of 28-day-old pups from three standardized litters in each lighting group. Red and white blood cell counts and hematocrit values were determined with a Particle Data Model 12 counter (Particle Data Inc., Elmhurst, Ill.). Hemoglobin levels were determined from the 1:500 dilution after completion of the white count. A hemolyzing agent (zap-oglobin II) was added to the dilution to convert hemoglobin to cyanmethemoglobin which was determined by optical absorption at 520 nm with a spectrophotometer (Gilford 250).

All pups were sacrificed at 30 days of age and their body and tissue weights determined.

Experiment 3. This experiment was similar to Experiment 2 except that peripheral hematology was performed on all of the pups when they were 26 days old. All pups were subjected to the tail flick (7) and hotplate (8) tests at 37 and 38 days of age, respectively. Five litters from each group underwent the swim endurance test (9) when they were 40 days old.

Behavioral tests. The tail flick (water) test determines the response of rats to a thermal stress. The tail of the rat is placed in water at

TABLE I. EFFECT OF LIGHTING ON REPRODUCTIVE PARAMETERS

| Reproductive parameter | Daylight | High pressure sodium vapor |
|------------------------------------|---------------------|---------------------------------|
| Experiment 1 | | |
| Litter size | 14.0 \pm 0.8 (10) | 14.2 \pm 0.6 (10) |
| Time to litter (days) ^a | 31.9 \pm 0.4 (10) | 32.6 \pm 0.5 (10) |
| Experiment 2 | | |
| Litter size | 13.2 \pm 0.3 (10) | 13.1 \pm 0.6 (10) |
| Time to litter (days) ^a | 25.2 \pm 0.4 (10) | 25.6 \pm 0.3 (10) |
| Experiment 3 | | |
| Litter size | 12.4 \pm 0.5 (9) | 13.9 \pm 0.8 (9) |
| % Male | 61.1 \pm 5.4 (9) | 44.3 \pm 6.0 (9) ^b |
| Time to litter (days) ^a | 25.3 \pm 0.4 (9) | 25.4 \pm 0.3 (9) |

^a Elapsed time between the pairing of the rats and the birth of the litters.

^b $P < 0.05$.

TABLE II. EFFECT OF LIGHTING ON ORGAN (mg/

| Experiment | Age (days) | Heart | | Adrenals | | Kidney | |
|--------------|------------|----------|----------------------|------------|-------------------------|----------|----------------------|
| | | Daylight | HPSV | Daylight | HPSV | Daylight | HPSV |
| Experiment 1 | | | | | | | |
| Males (40) | 30 | 450 ± 7 | 486 ± 6 | 10.8 ± 0.2 | 12.8 ± 0.2 ^a | 541 ± 4 | 551 ± 4 |
| Females (40) | 70 | 371 ± 5 | 375 ± 4 | 13.8 ± 0.2 | 15.0 ± 0.2 ^a | 381 ± 4 | 390 ± 3 |
| Experiment 2 | | | | | | | |
| Males (40) | 30 | 481 ± 6 | 490 ± 5 | 12.7 ± 0.2 | 14.1 ± 0.3 ^a | 672 ± 5 | 682 ± 6 |
| Females (40) | 30 | 489 ± 7 | 515 ± 6 ^b | 13.9 ± 0.2 | 15.7 ± 0.2 ^a | 680 ± 5 | 705 ± 6 ^b |

^a $P < 0.001$.

^b $P < 0.01$.

^c $P < 0.02$.

^d $P < 0.05$.

55°C and the latency time for the animal to remove its tail completely from the water is measured (7). Under the conditions employed in this test the animals showed no evidence of first or second degree burns.

The hotplate test also measures responsiveness to an aversive thermal stimulus. The rat is placed on a hotplate set at 60°C and the latency time for the animal to elevate one of its hindpaws with or without simultaneous licking is measured (8). Under the conditions employed in this test the animals showed no evidence of first or second degree burns.

The swim endurance test is a measure of physical effort. In this test the rat is allowed to swim freely in water until its head becomes submerged for a period of 5 sec. The total swim time is then recorded and the animal is removed quickly, dried, and returned to its cage (9).

Statistical analysis. The data were analyzed using a *t* test with $P < 0.05$ taken as statistically significant. All data are reported as the means ± standard error of the mean. Data from the tail flick and hotplate tests are assumed to be not normally distributed. These data were therefore also analyzed by a Kruksal-Wallis one-way ANOVA (11). However, since neither the ANOVA nor the *t* test showed any significant differences, only the *t* test data are presented in Table IV.

Light intensity and heat output measurements. Total irradiance was measured using an Eppley E-4 thermopile as previously described (10). For Experiments 2-3 both irradiance and illuminance were measured with an EG and G Radiometer-Photometer Model 550-1. To determine whether the HPSV lamps

(Experiment 2) were causing a thermal stress, a temperature probe (Vitek Model 101, Boulder, Co.) was inserted under the skin of a rat immediately after sacrifice. The rat was placed on the floor of a cage and its temperature monitored. The rat reached ambient temperature within 290 min and neither the rate of temperature change nor the final temperature was affected by the HPSV lamps.

Results. Reproductive parameters. The data in Table I indicate that the HPSV lamps had no significant effect on either litter size or time to litter. However, the time to litter was longer for both lighting systems under the higher intensity conditions used in Experiment 1. In Experiment 3, in which the sexes of the pups were recorded at the time of litter normalization, significantly fewer males were born to dams housed under the HPSV lamps.

Organ and body weights. When the total irradiances of the two lighting systems were the same, rats weaned under the HPSV lamps had slightly heavier adrenals (Experiment 1, Table II). In addition, male rats exposed to the HPSV lamps had slightly smaller livers. The difference in adrenal weights persisted even when the scotopic intensities of the two lighting environments were normalized (Experiment 2, Table II). In Experiment 2 significantly larger hearts and kidneys were observed among females housed under the HPSV lamps. Males exposed to the HPSV lights had smaller testes.

Hematology. Peripheral blood hematology was performed on selected pups in Experiments 2 and on all animals in Experiment 3 (Table III). In Experiment 2 the HPSV lamps caused a slight elevation of the red blood cell

100 g body weight) AND BODY WEIGHTS

| Spleen | | Liver | | Testes | | Body wt (g) | |
|----------|---------|-----------|------------------------|----------|----------------------|-------------|-------------|
| Daylight | HPSV | Daylight | HPSV | Daylight | HPSV | Daylight | HPSV |
| 344 ± 8 | 342 ± 7 | 4969 ± 65 | 4751 ± 72 ^d | 441 ± 4 | 430 ± 4 | 104 ± 2.0 | 106.3 ± 1.4 |
| 223 ± 5 | 217 ± 4 | 4106 ± 49 | 4091 ± 52 | — | — | 232 ± 4 | 247 ± 4 |
| 370 ± 6 | 367 ± 7 | 5610 ± 70 | 5500 ± 80 | 394 ± 5 | 373 ± 6 ^c | 98.1 ± 6 | 100.0 ± 2.2 |
| 357 ± 5 | 355 ± 5 | 6070 ± 70 | 6060 ± 80 | — | — | 89.9 ± 1.3 | 90.2 ± 2.0 |

count (males and females). Pups exposed to the HPSV lamps showed increased white cell counts in Experiment 3, although only the data for the male animals were significant. The white cell counts showed wide variability in all experiments possibly due to the incomplete lysis of red cells.

Behavioral tests. Ozaki and Wurtman (3) have suggested that rats weaned under HPSV lights may be exhibiting a stress response to the light spectrum. In Experiment 3 all animals were subjected to the tail flick and hotplate tests, while the swim endurance time was measured for five litters from each lighting group. No difference was noted in the responses of the two groups of pups to a thermal stimulus provided either by a hotplate or hot water (Table IV). Furthermore, there was no difference in the total physical effort of pups exposed to the two lighting environments as measured by the swim endurance test (Table IV).

Discussion. These studies have shown that rats born and reared under HPSV lamps have slightly heavier adrenals when compared with those of rats housed under daylight-simulating fluorescent lights. This difference was seen when the two light sources were equalized either for total irradiance (Experiment 1) or for scotopic brightness (Experiment 2). HPSV lamps and daylight-simulating fluorescent lights differ from each other in two important ways. First, they have markedly different spectral distributions (3). Second, the HPSV lamp emits infrared radiation (4). Since control experiments indicated that, under the conditions used in these experiments, the rats were not subjected to a measurable heatload from the HPSV lights, it must be concluded that the observed differences in adrenal weights are due to the spectral distribution of the HPSV lamps.

TABLE III. EFFECT OF LIGHTING ON PERIPHERAL BLOOD HEMATOLOGY

| Hematological parameter | Daylight | High pressure sodium vapor |
|--|------------|----------------------------|
| Experiment 2 | | |
| Hemoglobin (g/100 ml) | | |
| Male (12) | 14.6 ± 0.6 | 15.1 ± 0.3 |
| Female (12) | 14.4 ± 0.9 | 16.4 ± 0.8 |
| Red blood cells ($\times 10^{-6}/\mu\text{l}$) | | |
| Male (12) | 4.4 ± 0.2 | 5.1 ± 0.2 ^b |
| Female (12) | 4.6 ± 0.2 | 5.1 ± 0.2 ^a |
| Hematocrit (%) | | |
| Male (12) | 26.9 ± 1.0 | 30.0 ± 1.2 |
| Female (12) | 27.9 ± 0.9 | 29.0 ± 1.0 |
| Mean cell volume (μm^3) | | |
| Male (12) | 60.3 ± 0.5 | 58.5 ± 0.8 |
| Female (12) | 58.8 ± 0.9 | 56.7 ± 1.0 |
| White blood cells ($\times 10^{-3}/\mu\text{l}$) | | |
| Male (12) | 23.1 ± 3.3 | 22.9 ± 2.4 |
| Female (12) | 23.0 ± 4.7 | 25.8 ± 6.0 |
| Experiment 3 | | |
| Red blood cells ($\times 10^{-6}/\mu\text{l}$) | | |
| Male (36) | 3.9 ± 0.3 | 3.6 ± 0.1 |
| Female (36) | 3.8 ± 0.1 | 4.2 ± 0.3 |
| Hematocrit (%) | | |
| Male (36) | 24.5 ± 1.5 | 22.4 ± 0.8 |
| Female (36) | 23.9 ± 0.9 | 26.0 ± 1.6 |
| Mean cell volume (μm^3) | | |
| Male (36) | 61.3 ± 0.7 | 62.1 ± 0.44 |
| Female (36) | 62.3 ± 0.6 | 62.3 ± 0.6 |
| White blood cells ($\times 10^{-3}/\mu\text{l}$) | | |
| Male (36) | 17.7 ± 1.2 | 23.1 ± 1.7 ^b |
| Female (36) | 18.6 ± 1.6 | 23.2 ± 2.1 |

^a $P < 0.05$.^b $P < 0.02$.

TABLE IV. EFFECT OF LIGHTING ON BEHAVIORAL PARAMETERS^a

| Test | Time (secs) | |
|-------------------------------|-------------|-------------|
| | Daylight | HPSV |
| Swim endurance (swim time) | | |
| Male (20) | 149 ± 14 | 133 ± 12 |
| Female (20) | 135 ± 11 | 159 ± 14 |
| Hot plate (latency time) | | |
| Male (36) | 20.4 ± 1.2 | 22.0 ± 2.2 |
| Female (36) | 20.9 ± 2.0 | 19.4 ± 2.0 |
| Tail flick (latency time) | | |
| Male (36) | 3.33 ± 0.36 | 3.49 ± 0.36 |
| Female (36) | 2.84 ± 0.18 | 2.94 ± 0.17 |

^a Experiment 3 (see Methods).

Ozaki and Wurtman (3) have suggested that rats weaned under HPSV lamps may be exhibiting a stress response to the light spectrum. However, our behavioral tests failed to detect any statistically significant difference between animals in the two lighting groups. It is of course possible that the tests we employed were not sensitive enough to detect very subtle effects caused by exposure of the rats to the HPSV lamps.

The implications of our findings and those of Ozaki and Wurtman (3) for human health are not clear at the present time. There are, however, two reports which describe the response of pupils and teachers to the introduction of HPSV lamps into schools (12, 13). The symptoms which were reported mainly involved visual disturbances, such as eye strain and/or pain, eye fatigue, glare, color distortion, and headache. In both instances the HPSV lamps were eventually removed from the classrooms. These findings together with the animal data reported here and elsewhere (3) suggest that care should be taken when light sources containing grossly different spectral distributions, compared to natural daylight, are employed as general environmental lighting.

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