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Effects of Sublethal, Cerebral X-Irradiation on Movement and Home-Range Patterns of Black-Tailed Jackrabbits

Lewis Nelson Jr.

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EFFECTS OF SUBLETHAL, CEREBRAL X-IRRADIATION ON MOVEMENT AND HOME-RANGE PATTERNS OF BLACK-TAILED JACKRABBITS

by

Lewis Nelson, Jr.

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Wildlife Biology

Approved:

Major Professor

Committee Member

Committee Member

Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

1970
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I am also grateful to Frederic H. Wagner for making this project available to me and acting as my major professor. His editorial comments on my thesis and suggestions concerning the data analysis have been especially helpful.

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ABSTRACT

Effects of Sublethal, Cerebral X-Irradiation
on Movement and Home-Range Patterns
of Black-Tailed Jackrabbits

by

Lewis Nelson, Jr., Master of Science

Utah State University, 1970

Major Professor: Dr. Frederic H. Wagner
Department: Wildlife Resources

Effects of sublethal, cerebral irradiation on movement and home-range patterns of black-tailed jackrabbits were studied in Curlew Valley, Utah, using radio-telemetry. Irradiation of 70 captive animals indicated that the LD$_{50(30)}$ was between 5,556 and 6,200 roentgens.

Nine wild, free-living experimentals were trapped in desert terrain, irradiated, transmittered, and released at the capture sites. Seven wild controls were treated similarly but were not irradiated. The field-irradiation dosage was 5,000 roentgens.

Tracking accuracy was determined by telemetering transmitters at fixed locations. Mean hourly movement was measured within 20-30 percent error and home ranges were measured with an error of less than 22 percent.

Experimentals had a mean hourly movement of 1,176.8 feet and controls 980.0 feet, significantly different at the .05 probability level. Experimentals had a bimodal
activity curve with peaks at 5:00 p.m. and 3:00 to 5:00 or 6:00 a.m. Controls displayed no such pattern.

Experimentals had a mean, daily home range of 66.1 acres and controls 34.1 acres, significantly different at the .05 probability level. Experimentals had a seasonal home range of 279.0 acres and controls 247.0 acres, not significantly different at the .05 probability level.

A probability index showing the frequency distribution of each animal's activity within 300-foot concentric, circular bands around a geometric center of activity showed similar distributions for both groups. The greatest concentrations of activity were within the innermost band for each group but experimentals had a slightly greater scatter of points in the outermost zone. These distributions were not significantly different at the .05 probability level.

Sublethal, cerebral irradiation appears to have increased activity levels of experimental animals but not changed those home-range characteristics involving the total area occupied and tenacity of site attachment. This increased activity may have resulted from inhibitory areas in the cortex which permitted greater expression of activity from the limbic system.

(70 pages)
INTRODUCTION

A considerable amount of work has been done on the effects of acute brain irradiation on learning, behavior, and physiological changes in mammals. Most of these studies dealt with domestic or wild-caught, captive animals (Arnold, 1962; Brizzee et al., 1962; Engel, 1967; Gerstner et al., 1956; Gerstner and Kent, 1957; Quinlan and Michaelson, 1964). Symptoms occurring at LD$_{50(30)}^{50}$ radiation levels included losses in weight, increased hunger, losses in motor coordination and equilibrium, decreased activity and exploration, hypotension, sluggishness, weakening of conditioned reflexes, higher respiration rates, transient vomiting, epileptiform seizures, and death.

The main behavioral change observed in animals irradiated at dosages below the LD$_{50(30)}^{50}$ level was hyperactivity (Davis and McDowell, 1962; Stahl, 1959). Other symptoms included losses in weight, increased hunger, increased maze learning and retention, and less discrimination learning (Arnold, 1962).

Only in recent years has the number of studies designed to analyze the effects of irradiation on the population dynamics, home range, and movement of free-living, wild animals been increasing (Allred, Beck, and Jorgensen, 1963; Dunaway and Kaye, 1961; French, 1965; Odum and Golley, 1963; Tanner, 1963; Tester et al., 1965; Tinkle, 1965).
The black-tailed jackrabbit (Lepus californicus) was chosen in this study as the subject for studying the effects of intense, sublethal brain irradiation on its movement and home-range patterns. The objective was to study (1) the distances control (nonirradiated) and irradiated animals moved during their daily activity periods, (2) the home ranges occupied by controls and experimentals each day and over a period of days, and (3) the degree of site attachment in the two groups.

Radio-telemetry was used to measure these behavioral parameters. This technique permitted continuous contact with animals in contrast to the irregular contacts based on trapping and the almost physical impossibility of getting visual observations of undisturbed animals.

Animal locations were determined at regular intervals from two permanent tracking stations by triangulation. This involved placing radio-transmitters, which produced pulsed signals at a constant rate, on jackrabbits and recording their location hourly with receivers. Bearings for each animal were determined from each tracking station, and the point where the bearings crossed was the implied location of the animal (triangulation point).

Distribution of the hourly location points provided an indication of the size and shape of the home ranges. Distances between hourly points were measured and averaged, giving an indication of the movement per animal per unit of time. These two measurements provided a convenient
means for comparing movement patterns of controls and experimentals.
THE STUDY AREA

The telemetry study area was located approximately 17 miles west and 5 miles south of Snowville, Utah, in Curlew Valley. It consisted of 2 square miles of Bureau of Land Management Land on the north slope of the Wildcat Hills. This area was at about 4,600 feet elevation and part of the Northern Desert Shrub Biome (Fautin, 1946). Sagebrush (*Artemisia tridentata*) was the dominant overstory shrub and halogeton (*Halogeton glomeratus*) the most common understory species. This area was chosen due to the homogeneous pattern of the sagebrush and two nearby knolls, which were ideal for radio-tracking stations. A more complete description of the area is given by Rusch (1965).
METHODS AND MATERIALS

Irradiation Procedures

Facilities and equipment

Radiation source. The radiation source was an Andrex (Picker), portable, X-ray machine which operated at 200 K.V.A. and 8 amperes. A metal frame was constructed to support the X-ray tube unit (Figure 1). During irradiation, a restraining box containing an animal was slid into a frame directly underneath the tube. The entire frame was enclosed by lead shielding.

Restraining techniques. The 17 x 9 x 8 inch restraining box was made of one-half-inch plywood. A one-third-horsepower ventilating fan was mounted at the rear of the restraining box. Openings in the box, in conjunction with the fan, permitted greater air circulation and reduced heat accumulation.

When an animal was placed in the box, its head protruded through an opening (Figure 2). The animal's head was held securely in the box by a notch under the chin and adjustable screw clamps on each side of the head. Pieces of cloth were placed in front of the adjustable screws to eliminate abrasion. The rear of the animal's body was not restrained. A metal sheet with a 0.75-inch lead plate containing a trapezoidal hole 0.825 x 0.825 x 0.393 inches,
Figure 1. Andrex portable X-ray unit used for irradiating black-tailed jackrabbits with metal supporting frame, lead shielding, and slide for restraining box.
Figure 2. Restraining box used to restrain black-tailed jackrabbits for brain irradiation.
the approximate shape and area of the top surface of the cerebral cortex, was slid over the animal's head to prevent an upward movement.

When the box was slid into the frame, the hole, and consequently the cerebral cortex, was centered in the path of the X-ray beam. Exposure of the rest of the animal to the X-ray beam was prevented by the lead plate. The scalp of the jackrabbit was shielded from damage by low-energy radiation by a .0254-inch diameter, circular copper filter placed inside the X-ray tube head attachment in the path of the radiation beam.

**Dosimetry.** Dosage rates were determined by a Victoreen 250-roentgen dosimeter, centered and taped at the bottom of the trapezoidal hole. This was the point where the X-ray beam was focused. The radiation dosages were measured and averaged for 0.5-, 1.0-, and 1.5-minute intervals. Cumulative dosages rose in a straight-line relationship with exposure time, 1 minute's exposure ranging from 140-156 roentgens. Dosimetry tables for longer periods of time and larger irradiation values were constructed from this basic information.

The area of the radiation beam at the bottom of the head was about three times larger than at its point of entry, as shown by placing photographic film under the head during exposure. Thus, other portions of the brain and some parts of the skin and skull were also irradiated.

In a vacuum, radiation diminishes with the square of the distance from the radiation source. Therefore, most
damage would occur in those areas closest to the radiation source. In this case, the cerebral cortex would be damaged the most.

**LD$_{50(30)}$ determination**

Animals used in determination of the LD$_{50(30)}$ value were obtained from the U.S. Bureau of Sport Fisheries and Wildlife Jackrabbit Research Station in Twin Falls, Idaho, and from Curlew Valley, northwestern Utah. They were transported to the Utah State University campus in burlap bags. After irradiation, they were placed in outdoor pens.

Five groups, consisting of 10 animals each, were exposed to cranial radiation dosages ranging from 1,389-6,945 roentgens. Two other groups of 8 and 12 animals were exposed to 6,200 and 6,800 roentgens. Irradiation and observation took place from September, 1966, through February, 1967.

Three 15 x 30 foot restraining pens were used to hold the irradiated animals during the observation period. These were equipped with food, water, hiding boxes, and brush piles. Pieces of cardboard along the sides with peep holes permitted observation of the animals without being seen.

An irradiation dosage below the LD$_{50(30)}$ level, but causing brain damage, was needed for the experimental animals used in the movement study. A field value of 5,000 roentgens was selected on the basis of the LD$_{50(30)}$ results reported below.
**Field irradiation procedures**

Jackrabbits were trapped on the study area with National, model 207, live traps set at intervals of 0.1 miles. When trapped, an animal was taken immediately to the X-ray unit. Test animals were irradiated, equipped with a radio-transmitter, and released at the capture site. Control animals were handled identically, including restraint in the X-ray machine, but were not irradiated.

**Radio Tracking**

**Transmission**

**Transmitter design.** The transmitter (Figure 3) had a pulse rate of 50-70 pulses per minute and a pulse length of 10 milliseconds. This gave a calculated battery life of 400 days. The transmitter unit weighed about 75 grams.

Transmitter components were covered with dental acrylic. The antenna loop was covered with a vinyl sleeve and fastened together at the back of the animal by a metal rivet. The transmitter was wrapped with electrical tape.

**Transmitter attachment.** A harness for mounting the transmitter on the animal was made of single-strand 16-gauge steel wire and covered with a vinyl sleeve. This harness consisted of a wire loop around the animal's neck attached to the transmitter by two wires, one along the back and one along the chest, and allowed the transmitter components to hang underneath the chest of the animal. A similar harness was used by Rusch (1965).
Figure 3. Schematic design of the modified Cochran and Lord (1963) transmitter used in the radio-tracking of black-tailed jackrabbits.
Reception

Two permanent tracking stations situated 9,900 feet apart were used to radio-track telemetered animals. Each station had a 70-foot tower, Hy-Gain 12-foot double yagi antenna, and Hammerlund HQ-145-A receiver. The antenna was moved by an antenna rotor. The rotor was operated by a control box equipped with a directional meter which gave the immediate compass direction the antenna was facing when oriented toward a transmitter signal. House trailers were used to house the receivers and control boxes. Power was supplied by a Kohler 2.5-MM-21, 2.5 kw, gasoline generator.

Tracking procedure. At hourly intervals from 5:00 p.m. to 8:00 a.m. during November and December, 1967, and January, 1968, compass bearings were taken from each tracking station for each animal. This was done by tuning the receivers to a particular frequency, which denoted a particular animal, so that the pulsed signals could be heard. The antenna was rotated clockwise until the signal could no longer be heard. The antenna bearing was then read directly from the control-box meter and recorded. The same procedure was repeated in the opposite direction. The midpoint between these bearings was assumed to be the animal's direction from the tracking station. The coincidence of the bearings from each tracking station gave the triangulated location of the animal. Earphones were used to eliminate distracting noises.
Accuracy checks. Eight rectangular transects containing 10 point locations each were established within the study area. They were arranged in two sets of four, nested transects (Figure 4) with a single, common origin. Each set contained a rectangular transect 225 x 150 feet with point locations 75 feet apart, a rectangle 450 x 300 feet and point locations 150 feet apart, one 675 x 450 feet and point locations 225 feet apart, and one 900 x 600 feet with point locations 300 feet apart.

Transmitters were placed at each point location of each transect. Three compass bearings were taken for each of these locations. Sightings were then taken with a surveyor's transit from the tracking stations for each transect point location.

Tracking station errors were determined by comparing surveyed with telemetered locations. These measurements provided information on the precision with which the animals' directions were being measured, and the gain in precision of 2-3 bearings over a single bearing.

Before radio-tracking animals each evening, a transmitter was placed in the tracking area at a known location. Two readings before and after each hour of tracking during the nightly observation period were taken on this transmitter from each tracking station. A comparison of the known transmitter location with the mean of these four readings gave the hourly bearing error for each tracking station. This angular correction was then added to, or
Figure 4. Four nested rectangular transects used in determining radio-tracking station bearing errors and showing the varied distances and rectangular arrangements.
subtracted from, each telemetered animal location. Such hourly corrections were necessary due to antenna misalignments by short-term wind or torque pressures.

**Computer Processing of Data**

A computer program was written to convert all triangulated animal locations to X and Y coordinates. They were then plotted to scale by animal number and date on an I.B.M. 1627 X-Y plotter. These plots were used to determine movement and home-range patterns.
RESULTS

**LD$_{50}(30)$ Determination**

The mortality data from irradiation suggest that the LD$_{50}(30)$ value lies somewhere between 5,556 and 6,200 roentgens (Table 1). Animals irradiated at higher dosages exhibited losses in motor coordination, decreased activity, reduced exploration, sluggishness, and death. Animals irradiated at lower dosages displayed none of these symptoms. On the basis of these results, a 5,000-roentgen dosage was selected for the experiment with free-living animals.

Free-living rabbits irradiated at 5,000 roentgens and used in radio-tracking on the study area were observed directly after irradiation and sometimes during retrapping. No immediate effects were observed from radiation.

**Radio-Tracking Accuracy**

The potential errors inherent in determining animal locations with radio-bearing taken from fixed tracking stations have been explored by Heezen and Tester (1967). Although they discussed these errors in detail, I felt it desirable to recapitulate the basic problems in the context of my own study. I considered this necessary because the results and implied effects of experimental manipulation
Table 1. Cerebral cortex X-ray dosage rates and mortality levels for irradiated black-tailed jackrabbits

<table>
<thead>
<tr>
<th>Exposure time in minutes</th>
<th>Dosage rates in roentgens</th>
<th>Number of animals</th>
<th>Deaths in 30 days</th>
<th>Percent mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>1389</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>18</td>
<td>2778</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>27</td>
<td>4167</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>36</td>
<td>5556</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>40</td>
<td>6200</td>
<td>12</td>
<td>8</td>
<td>67</td>
</tr>
<tr>
<td>43</td>
<td>6800</td>
<td>8</td>
<td>6</td>
<td>75</td>
</tr>
<tr>
<td>45</td>
<td>6945</td>
<td>10</td>
<td>6</td>
<td>60</td>
</tr>
</tbody>
</table>
depend on the technique providing dependable data. The errors I encountered appeared to be qualitatively the same as those discussed by Heezen and Tester but quantitatively different because of differences in (1) equipment, (2) distances between tracking stations, and (3) the magnitude of the parameters being measured.

**Geometric errors inherent in telemetry**

**Bearing error.** The basic approach in telemetry is reading compass bearings on a transmitter signal from two receiving stations by the use of directional antennas. The point at which the two bearings cross is the implied location of an animal. With successive locations taken at regular time intervals, it is possible to trace the rate and direction of movement; and with a collection of such locations over a period of time, it is possible to delineate the general area of an animal's activities.

The bearings taken from any one receiver are seldom measured without error. Readings taken on a signal will be inaccurate due to wind pressures on antennas, voltage variations in the power source, equipment inaccuracies, variation in signal strength from the transmitters, temperature changes, and human errors. Each bearing taken on an animal must therefore be considered an estimate of the true direction of the animal, that true direction falling within a margin of error on each side of the bearing obtained. This error will henceforth be termed the "bearing error."
Bearing errors for each receiving station were determined from the fixed, rectangular transects. With eight transects, each with 10 point locations, and three receiver bearings taken on each point location, 240 bearings were available from each tracking station for comparison with the transit-derived directions. On the average, the receiver bearings deviated from the true direction by 1 degree and 36.8 minutes for one station and 2 degrees and 22.7 minutes for the other. The linear magnitude of the bearing error (distance between implied direction of signal and angular deviation) depended on the distance between the transmitter and receiver, increasing as that distance increased (Table 2).

**Position error.** When two simultaneous bearings are taken on an animal, the point at which they cross is the implied location of the animal. The lines representing the bearing errors on each side of the two signals also cross, forming an error polygon (Figure 5) which represents the area in which the animal, on the average, actually occurs. The size and form of this error polygon determine the precision with which an animal's location can be ascertained with any given telemetry facility. The resulting inaccuracies fall under two general forms which shall be discussed here as "position error" and later as "elongation bias."

As the linear width of the bearing error increases at increasing distances from the receiver, so too does the error polygon increase in size (Figure 5). Thus, the
Table 2. Linear magnitude of a 1-degree bearing error at varying distances from the receiver

<table>
<thead>
<tr>
<th>Distance from tracking stations</th>
<th>1-degree bearing error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.25 miles</td>
<td>23 feet</td>
</tr>
<tr>
<td>0.50 miles</td>
<td>46 feet</td>
</tr>
<tr>
<td>0.75 miles</td>
<td>69 feet</td>
</tr>
<tr>
<td>1.00 miles</td>
<td>92 feet</td>
</tr>
<tr>
<td>1.25 miles</td>
<td>115 feet</td>
</tr>
<tr>
<td>1.50 miles</td>
<td>138 feet</td>
</tr>
<tr>
<td>1.75 miles</td>
<td>161 feet</td>
</tr>
<tr>
<td>2.00 miles</td>
<td>184 feet</td>
</tr>
</tbody>
</table>
Figure 5. Error polygons of hypothetical animal locations resulting from receiver bearing errors and transect and radio-tracking areas.
determination of animal locations is subject to increasing inaccuracies at progressively greater transmitter-receiver distances, and the distance between successive animal locations can be magnified by this progressively greater error. Heezen and Tester (1967), using a system of transects at varying perpendicular distances from the baseline (an imaginary line drawn between tracking stations) stated,

... the apparent total area occupied by an animal increases as the random plots are moved outward from the baseline. This is a direct result of increase in the size of the error polygon as distance from the baseline increases. Because only the peripheral points are considered in calculating area, the chances for an increase are greater than for a decrease; that is, if due to error only one or two recorded perimeter points fall farther out than the true points and all the rest fall farther in, it is possible that the area of the plot will still increase. ... The increases in total distance travelled follow about the same graphic patterns as those for total area. (Heezen and Tester, 1967, p. 130)

The same trend is evident in the observation on my own transects. The areas enclosed in Transects 1 and 5, the 225 x 150-foot rectangles, was 0.8 acres. The area enclosed by the telemetered locations on Transect 5 (closest to the receivers) was 2.7 acres, a magnification of 3.4. The telemetered area for Transect 1 was 5.9 acres, a magnification of 7.4. The mean, telemetered distance on these two transects was 254 and 294 feet, respectively. With the actual distances 75 feet, the respective magnifications were 3.4 and 3.9.

The significance of these errors depends on the receiver-transmitter distances and the magnitude of the
parameters being measured. The potential error in denoting a single location of an animal is a function of the size of the error polygon, the errors increasing at greater receiver-transmitter distances. Where animal activity is described by some parameter measuring the distance between, or spatial relationship of, two or more locations of an animal, the relative error in measuring this parameter is a function of the size of the parameter.

A location 1.5 miles from each receiver might have an error polygon with a 400-foot diameter. On the average, the maximum linear error will be 200 feet (distance between the center and perimeter of the polygon). If two successive, true locations of an animal were 1,000 feet apart, these points could appear to be from 600-1,400 feet apart, a potential error of ±40 percent. If two such true locations were 2,000 feet apart, they could appear to be from 1,600-2,400 feet apart, a potential error of ±20 percent.

The transect results bear out this pattern. In Transects 5 and 6 (Figure 5), with test points at 75- and 150-foot intervals, the mean distance between points was overestimated by 158 percent. In Transects 7 and 8, with test points 225 and 300 feet apart, the mean distance was overestimated by 66 percent. The same pattern exists in determining the area occupied by a scatter of points. The areas enclosed by Transects 5 and 6 were 0.8 and 3.1 acres and were overestimated by 161 percent. Transects 7 and 8, with areas of 7.0 and 12.4 acres, were overestimated by 22 percent.
Most of the telemetered animals were located proximal to Transects 5-8. Among the parameters used to measure their activity were the distances between successive, hourly locations (mean hourly movement) and the areas occupied by the hourly locations taken over a period of one day (daily home range) or several days (seasonal home range). Mean hourly movement values varied from 600-1,700 feet and averaged about 1,000 and 1,200 feet for the two treatments. An increase in transect interpoint distances of 2.3 (75 and 150 to 225 and 300 feet) reduced the error margin by 58 percent (158 to 66 percent). The approximate 4.2 increase in distances between the hourly jackrabbit locations and the 225- and 300-foot transect distances could reasonably be expected to result in at least a further 58 percent reduction in the error margin. Hence, the error in measuring distances between hourly jackrabbit locations could conceivably have been 20-30 percent.

Jackrabbit home ranges varied from 9-175 acres each day and averaged 35 and 66 acres for the two groups. The error in measuring these could well have been below the 22-percent error in measuring the 7- and 12-acre areas of the two larger transects.

**Elongation bias.** Heezen and Tester (1967) showed that the shape of the error polygon varied with the position of the transmitter relative to the receivers. At locations close to the baseline, the polygon became elongated parallel to the baseline (Figure 5). This disappeared at progressively greater distances from the baseline until, when
each line between transmitter and receivers formed a 45-degree angle with the baseline, the polygon was square or rectangular. At successively greater distances, the polygon became elongated perpendicular to the baseline. Distortion was largest close to, and at great distances from, the baseline.

These distortions occurred at locations over the midpoint of the baseline. Locations to either side of the midpoint placed the telemetered subject closer to, and at greater angles with, one of the receivers, but farther from the other and at a smaller angle. As either end of the baseline was thus approached, the error polygon took on a vertical elongation (Figure 5).

These patterns implied that distortion was potentially least in a zone surrounding the intersection of the two bearings that formed 45-degree angles with the baseline. Over the midpoint of the baseline, telemetered points took on an artificial horizontal scatter where the bearing lines formed angles less than 45 degrees, and a vertical scatter at points above the intersection of the 45-degree lines. At points above the ends of the baseline, the scatters tended to be vertical.

At points below the intersection of the 45-degree lines, and for short distances to either side of the center of the midline, the tendency to vertical elongation negated the horizontal elongation which occurred. For example, the polygon formed by intersecting 30-degree error lines had a horizontal dimension approximately twice
its vertical. When the intersection was moved parallel
to the baseline one-fourth of the distance from its center
to its end, the ratio of horizontal to vertical dimension
of the error polygon declined to 3:2.

These elongation tendencies may be seen in my own
data. Transects 1-4 were located near the intersection of
the 45-degree bearing lines (Figure 5). If, for each
transect, the distance between the two telemetered points
farthest apart horizontally was divided by the distance
between the two points farthest separated vertically, the
mean of the four quotients was 1.0. The horizontal scat-
ter was equal to the vertical scatter and no elongation
bias was implied.

Transects 5-8 were approximately at the intersection
of the 45.0- and 22.5-degree bearings (Figure 5). When
the maximum horizontal dimension of the telemetered points
for each transect was divided by the maximum vertical
dimension, the mean of the four quotients was 0.9. Here
again, the results suggested no elongation bias.

Data on the telemetered rabbits showed evidence of
elongation bias. The rabbits were studied in an area
slightly to left of center of the baseline and from 600-
3,000 feet perpendicular to the baseline (Figure 5). Some
daily point scatters for each animal were measured for the
greatest horizontal and vertical dimensions, as above with
the transects. The greatest horizontal distance for each
scatter was divided by the greatest vertical distance, and
the resulting quotients were grouped and averaged according to 200-foot intervals from the baseline (Table 3).

The point scatters of animals tracked close to the baseline (600-1,200 feet) were elongated horizontally 4.5-6.2 times the vertical. This declined until, possibly at distances beyond 1,400 feet, and certainly beyond 2,000 feet, the quotient stabilized at about 2. Most of the telemetered animals were in this latter range. Although the animals over the center of the baseline were in an area where a 2:1 distortion could be expected, the animals to the left of center approached a zone with less distortion. It was uncertain whether the average 2:1 ratio obtained in these animals reflected a true home-range elongation, as Rusch (1965) concluded of Curlew Valley jackrabbits, or whether elongation bias was responsible. The fact that the elongation was always parallel to the baseline makes me suspect the latter alternative.

**Number of readings per animal**

The accuracy with which an animal's location can be determined can be improved by taking several readings and averaging them. This increased accuracy is partly a function of the animal's movements during observation. If, during several consecutive readings on an animal, it moved substantially, any gain in precision would be negated by that movement.

To test the increased precision made possible by repeat readings on the stationary transect points, the
Table 3. Elongation of some daily home ranges as a function of the distance from the baseline

<table>
<thead>
<tr>
<th>Perpendicular distance from baseline to animals (feet)</th>
<th>Sample size</th>
<th>Total horizontal distance of home range (feet)</th>
<th>Total vertical distance of home range (feet)</th>
<th>Elongation factor (horiz./vert.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-600</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>601-800</td>
<td>4</td>
<td>16,080</td>
<td>2,600</td>
<td>6.2</td>
</tr>
<tr>
<td>801-1000</td>
<td>7</td>
<td>23,920</td>
<td>4,320</td>
<td>4.5</td>
</tr>
<tr>
<td>1001-1200</td>
<td>3</td>
<td>11,000</td>
<td>2,440</td>
<td>4.5</td>
</tr>
<tr>
<td>1201-1400</td>
<td>5</td>
<td>16,320</td>
<td>5,680</td>
<td>2.9</td>
</tr>
<tr>
<td>1401-1600</td>
<td>5</td>
<td>14,280</td>
<td>6,960</td>
<td>2.1</td>
</tr>
<tr>
<td>1601-1800</td>
<td>7</td>
<td>23,720</td>
<td>9,680</td>
<td>2.5</td>
</tr>
<tr>
<td>1801-2000</td>
<td>4</td>
<td>8,280</td>
<td>3,200</td>
<td>2.6</td>
</tr>
<tr>
<td>2001-2200</td>
<td>6</td>
<td>20,360</td>
<td>9,040</td>
<td>2.3</td>
</tr>
<tr>
<td>2201-2400</td>
<td>4</td>
<td>18,640</td>
<td>9,600</td>
<td>1.9</td>
</tr>
<tr>
<td>2401-2600</td>
<td>3</td>
<td>6,520</td>
<td>3,720</td>
<td>1.8</td>
</tr>
<tr>
<td>2601-2800</td>
<td>3</td>
<td>10,480</td>
<td>6,200</td>
<td>1.7</td>
</tr>
<tr>
<td>2801-3000</td>
<td>1</td>
<td>4,640</td>
<td>2,000</td>
<td>2.3</td>
</tr>
</tbody>
</table>
average bearing error involved in one, two, and three readings was determined. The mean errors for one, two, and three triangulations were 1 degree and 36.6 minutes, 1 degree and 30.6 minutes, and 1 degree and 24.8 minutes, respectively. None of the means were significantly different ($t = P > .05$).

Since accuracy was not significantly increased from 1-3 readings, only one triangulation was taken on each animal per hour. This reduced operator fatigue and permitted more frequent animal readings.

**Simultaneity of readings**

The coincidence of reading times during triangulation was accomplished by using synchronized watches and communication over Heathkit GW-32 citizens'-band transceivers. Some reading-time lags still occurred because of losses in communication between stations, difficulty in locating animals, equipment problems, and human variation. Since these time lags probably incurred some error due to shifts in animal positions, some consideration was given to the amount of time lag that could be tolerated.

Time lags ranged from 0-32 minutes between bearings on individual animal triangulations. The data were divided into two groups: those taken with time lags of 0-3 minutes, and those with time lags of 4-6 minutes. The means of the two groups were not significantly different ($t = P > .05$). Triangulations with lags of more than
6 minutes were discarded and those readings with a time lag of 6 minutes or less were retained.

**Conclusions on accuracy**

Tracking precision depended on a combination of factors, including the variation in bearing errors, locations of animals relative to the receivers, and the magnitude of the parameters being measured. The transect data suggested that the error margin may be 20-30 percent or less. Some elongation bias was possible, though not definitely known to be present.

In general, controls and experimentals, and males and females, were uniformly distributed within the study area. In view of the errors and biases which might have been present, the measured parameters may at best have been reasonable approximations. At the worst, they were wide of the mark and can only be considered as indices. Since controls and experimentals were reasonably well paired with respect to location, it was assumed that errors and biases present were comparable between the two groups.

**Influence of Radiation on Home Range and Movement Patterns**

**Mobility indices**

**Mean hourly movement.** In the absence of continuous records on an animal's location, I used the mean distance between successive pairs of hourly locations as an index to the extent and rate of movement, a parameter hereafter
termed the "mean hourly movement." This is not a measure of total movement since measurement between successive points must be a straight line, and an animal's movement will not necessarily be linear.

Mean hourly movements of controls and experimental were calculated for the period of time each animal was radio-tracked (Table 4). The number of days each animal was observed varied from 2-23 with the total number of animal nights and hourly means among controls and experimental fairly comparable. An F-test showed heterogeneous variances between the two groups (tests for homogeneity were performed before all t-tests). The means of the two groups were significantly different ($t = P < .05$). The experimental animals had a mean hourly movement 20.1 percent greater than the control animals.

An analysis of mean hourly movements was made by sexes and treatments (Table 4). The means for both sexes of control and experimental animals were significantly different ($t = P < .05$). The experimental males had a mean hourly movement 26.2 percent greater than the control males. The experimental females had a mean hourly movement 18.4 percent greater than the control animals.

The means of control males and females were significantly different ($t = P < .05$). The males had a mean hourly movement 19.4 percent greater than the females.

The means of experimental males and females were significantly different ($t = P < .05$). The males had a
Table 4. Mean hourly movement, standard deviation, and number of hourly moves of individual animals by sex and treatment

<table>
<thead>
<tr>
<th>Anim. No.</th>
<th>No. hourly moves</th>
<th>( \bar{X} ) hourly movement (feet)</th>
<th>Std. dev.</th>
<th>Anim. No.</th>
<th>No. hourly moves</th>
<th>( \bar{X} ) hourly movement (feet)</th>
<th>Std. dev.</th>
<th>Anim. No.</th>
<th>No. hourly moves</th>
<th>( \bar{X} ) hourly movement (feet)</th>
<th>Std. dev.</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

**Males**

<table>
<thead>
<tr>
<th>Control animals</th>
<th>Experimental animals</th>
<th>Combined males</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 76 1157.1 867.8</td>
<td>24 49 1435.7 1246.8</td>
<td>— — —</td>
</tr>
<tr>
<td>22 81 951.2 702.2</td>
<td>27 124 1400.4 1154.1</td>
<td>— — —</td>
</tr>
<tr>
<td>25 95 1294.1 978.5</td>
<td>34 10 591 655.4</td>
<td>— — —</td>
</tr>
<tr>
<td>26 75 815.6 789.0</td>
<td>36 72 1299.9 1034.5</td>
<td>— — —</td>
</tr>
</tbody>
</table>

Subtotals/mean 327 1067.6 843.6 255 1347.1 1119.4 582 1190.1 937.2

**Females**

<table>
<thead>
<tr>
<th>Control animals</th>
<th>Experimental animals</th>
<th>Combined females</th>
</tr>
</thead>
<tbody>
<tr>
<td>23 103 681.7 602.6</td>
<td>28 61 579.4 535.3</td>
<td>— — —</td>
</tr>
<tr>
<td>30 174 879.5 756.3</td>
<td>29 58 1717.3 1014.2</td>
<td>— — —</td>
</tr>
<tr>
<td>31 56 1329.4 802.6</td>
<td>32 180 1024.3 846.4</td>
<td>— — —</td>
</tr>
<tr>
<td>33 22 1148.9 734.4</td>
<td>35 46 953.7 618.6</td>
<td>— — —</td>
</tr>
</tbody>
</table>

Subtotals/mean 333 894.0 718.6 367 1058.5 701.3 700 980.2 709.1

**Combined controls**

660 980.0 812.6

**Combined experimentals**

622 1167.8 991.2

**Grand total and mean**

1282 1075.5 839.0
combined mean hourly movement 27.3 percent greater than the females.

**Diel movement patterns.** Diel movement variations were determined by studying the mean, hourly movement values during the hours of observation. These results (Figure 6) showed two periods of high activity in the experimentals already underway at 5:00 p.m. and again from about 3:00-5:00 a.m. The control animals showed no such pattern, with the generally lower level of activity fairly constant from 5:00 p.m. to 8:00 a.m.

Subdividing the data by sexes and treatments showed roughly the same patterns although the movement rates were lower in females than males (Table 4). Both male and female controls showed fairly constant levels of movement while male and female experimentals both displayed increased activity in evening and early morning.

**Home-range patterns**

The space in which an animal carries out its daily activities has for many years been termed its "home range." The problems of describing and developing techniques for the measurement and description of the home range have been reviewed by Sanderson (1966). The techniques used by most authors are of two general types: (1) delineation of the area encompassed by an imaginary line connecting the outermost points of an animal's activity; and (2) conception of the home range as a bivariate probability phenomenon in which the probability of finding the animal
Figure 6. Activity patterns of control and irradiated animals in relation to time of day.
increases with proximity to some geometric or focal center of the animal's locations over a period of time. Parameters used for comparison in the latter case are one or more arbitrarily selected probability belts about the geometric center.

**Daily home range: perimetric representation.** Rusch (1965) observed that black-tailed jackrabbits in Curlew Valley occupied slightly different, but overlapping, areas each day. On the basis of his central-tendency representation, he termed these areas the "daily average ranges," and collectively over a period of time the "seasonal average range." A central-tendency representation for daily movement patterns was not attempted in this study because the mean number of hourly fixes per animal per day was only 8. A perimetric representation was, however, where at least 5 locations were taken for an animal in any one day. The outermost points were connected and the enclosed area was measured.

The resultant daily home ranges were averaged for each animal (Table 5). The number of animal nights were comparable for control and experimental animals. The daily home-range means of control and experimental animals were significantly different ($t = P < .05$). The experimentals had a mean, daily home range 90.5 percent greater than the controls.

An analysis of daily home ranges was made by sexes and treatments (Table 5). The means for both sexes of
Table 5. Mean daily home range, standard deviation, and nights of radio-tracking for individual animals by sex and treatment

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Males</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Control animals</td>
<td></td>
<td></td>
<td>Experimental animals</td>
<td></td>
<td></td>
<td></td>
<td>Combined males</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>17</td>
<td>22.8</td>
<td>29.0</td>
<td>24</td>
<td>10</td>
<td>53.3</td>
<td>18.7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>22</td>
<td>13</td>
<td>25.6</td>
<td>14.0</td>
<td>27</td>
<td>15</td>
<td>65.7</td>
<td>54.7</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>25</td>
<td>17</td>
<td>40.9</td>
<td>28.8</td>
<td>34</td>
<td>2</td>
<td>9.3</td>
<td>11.1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>26</td>
<td>8</td>
<td>31.6</td>
<td>28.8</td>
<td>36</td>
<td>9</td>
<td>100.1</td>
<td>71.9</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>
| Subtotals/means | 55 | 33.6                      | 25.4      | 36        | 67.7 | 68.7                      |           | 91        | 47.1 | 36.7

|           | Females |                           |           |           |         |                           |           | Combined females |         |                           |           |
|-----------|---------|---------------------------|-----------|-----------|--------|---------------------------|-----------|                   |         |                           |           |
|           | Control animals |                           |           | Experimental animals |         |                           |           |                   |         |                           |           |
| 23        | 13     | 26.6                      | 16.1      | 28        | 8      | 14.7                      | 11.9      | —         | —     | —                         | —         |
| 30        | 20     | 29.5                      | 15.0      | 29        | 9      | 175.4                     | 130.0     | —         | —     | —                         | —         |
| 31        | 9      | 84.7                      | 48.1      | 32        | 23     | 50.8                      | 39.0      | —         | —     | —                         | —         |
|           | Subtotals/means | 42 | 40.4                      | 25.1      | 53        | 64.9                      | 82.5      | 95        | 54.1 | 47.6

|           | Combined controls |                           |           | Combined experimental |         |                           |           | Grand total and mean |         |                           |           |
|-----------|                   |                           |           |                       |         |                           |           |                       |         |                           |           |
| 97        | 34.7               | 25.2                      |           | 89        | 66.1  | 72.3                      |           | 186        | 50.7 | 42.5


control and experimental animals were significantly different \( (t = P < .05) \). The experimental males had a mean, daily home range 101.5 percent greater than the control males. The experimental females had a mean 60.6 percent greater than the control females.

Control females had a mean, daily home range 20.2 percent greater than the control males. Experimental males had a mean, daily home range 4.3 percent greater than experimental females. These differences were not significant \( (t = P > .05) \).

**Seasonal home range.** When all of the telemetered locations accumulated over a number of days for an individual animal are plotted, something approaching the total area it occupies during that period is depicted. The mean number of fixes per animal during the observation period was 111. These samples are adequate for both perimetric and central-tendency representation of the seasonal home range. Such plots were made for each animal.

The areas enclosed by lines connecting the outermost points of the scatters for each of the 16 animals studied (Table 6) averaged 247.0 acres for the controls and 279.0 acres for the experimental. The means of the two groups were not significantly different \( (t = P > .05) \).

The same analyses subdivided by sexes (Table 6) showed a greater mean for the females in each treatment, and an average for all individuals of 215.7 acres for the males and 314.2 acres for the females. The means of the two groups were not significantly different \( (t = P > .05) \).
Table 6. Seasonal home ranges of individual control and experimental animals derived by connecting the outermost points of all triangulated locations and measuring the enclosed areas

<table>
<thead>
<tr>
<th>Animal number</th>
<th>Seasonal home range (acres)</th>
<th>Animal number</th>
<th>Seasonal home range (acres)</th>
<th>Seasonal home range (acres)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control males</td>
<td>Experimental males</td>
<td>Combined males</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>236.0</td>
<td>24</td>
<td>200.1</td>
<td>—</td>
</tr>
<tr>
<td>22</td>
<td>149.3</td>
<td>27</td>
<td>339.9</td>
<td>—</td>
</tr>
<tr>
<td>25</td>
<td>219.2</td>
<td>34</td>
<td>49.7</td>
<td>—</td>
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<tr>
<td>26</td>
<td>195.0</td>
<td>36</td>
<td>336.7</td>
<td>—</td>
</tr>
<tr>
<td>Subtotals</td>
<td>799.5</td>
<td>926.4</td>
<td>1725.9</td>
<td></td>
</tr>
<tr>
<td>Means</td>
<td>199.9</td>
<td>231.6</td>
<td>215.7</td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>37.7</td>
<td>137.7</td>
<td>93.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control females</td>
<td>Experimental females</td>
<td>Combined females</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>299.2</td>
<td>28</td>
<td>90.9</td>
<td>—</td>
</tr>
<tr>
<td>30</td>
<td>253.2</td>
<td>29</td>
<td>736.0</td>
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<tr>
<td>31</td>
<td>377.0</td>
<td>32</td>
<td>329.1</td>
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<td></td>
<td></td>
<td>33</td>
<td>177.3</td>
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<tr>
<td></td>
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<td>35</td>
<td>250.9</td>
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<tr>
<td>Subtotals</td>
<td>929.4</td>
<td>1584.2</td>
<td>2513.6</td>
<td></td>
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<tr>
<td>Means</td>
<td>309.8</td>
<td>316.8</td>
<td>314.2</td>
<td></td>
</tr>
<tr>
<td>Std. Dev.</td>
<td>62.6</td>
<td>250.3</td>
<td>192.2</td>
<td></td>
</tr>
</tbody>
</table>

Combined controls Combined experimentals Grand total and mean

| Grand totals | 1728.9 | 2510.6 | 4239.5 |
| Means        | 247.0  | 279.0  | 265.0  |
| Std. Dev.    | 44.9   | 196.1  | 146.0  |
A probability index similar to that described by Harrison (1958) was calculated (Table 7). This index was constructed to measure the degree to which an animal concentrated its activities around a geometric center of activity, or distributed it throughout its home-range area.

A seasonal geometric center of activity for each animal was determined by computing mean X and Y values for all of its telemetered locations. Eight, concentric circular bands, each 300 feet wide, were drawn around these geometric centers and the number of hourly locations for each animal occurring within each band counted. These data were separated into control and experimental animal groups and the percentage of locations in each band (probability index) calculated for each group (Table 7).

Since the area of each band increased as some function of the radius, it seemed desirable to view the number of locations in each band on a per-unit-area basis. Consequently, the number of locations in each band was divided by the area of the band and expressed as number of locations per 1,000 square feet (Table 7).

The two distributions are quite similar. The largest number of locations per unit area occurs in the 0-300 foot band for controls and experimentals. These values are not directly comparable because of a difference in sample size. What is comparable is that both groups spent more time per unit area in the innermost band. Activity dropped by about a fourth or third in the second band, and thereafter
Table 7. Number of locations per unit area, and probabilities of control and irradiated jackrabbits occurring at varying distances from the geometric center of their home ranges

<table>
<thead>
<tr>
<th>Feet from geometric center of home range</th>
<th>Number of telemetered locations</th>
<th>Number of locations per 1,000 sq. ft.</th>
<th>Cum. number of locations</th>
<th>X percent in strip</th>
<th>Cum. probab. index in percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control animals</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-300</td>
<td>102</td>
<td>.36</td>
<td>102</td>
<td>11.03</td>
<td>11.03</td>
</tr>
<tr>
<td>300-600</td>
<td>206</td>
<td>.24</td>
<td>308</td>
<td>22.27</td>
<td>33.30</td>
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<tr>
<td>600-900</td>
<td>172</td>
<td>.12</td>
<td>480</td>
<td>18.59</td>
<td>51.89</td>
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<td>900-1200</td>
<td>142</td>
<td>.07</td>
<td>622</td>
<td>15.35</td>
<td>67.24</td>
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<td>1200-1500</td>
<td>94</td>
<td>.04</td>
<td>716</td>
<td>10.16</td>
<td>77.41</td>
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<tr>
<td>1500-1800</td>
<td>76</td>
<td>.02</td>
<td>792</td>
<td>8.22</td>
<td>85.62</td>
</tr>
<tr>
<td>1800-2100</td>
<td>56</td>
<td>.02</td>
<td>848</td>
<td>6.05</td>
<td>91.68</td>
</tr>
<tr>
<td>2100-2400</td>
<td>39</td>
<td>.01</td>
<td>887</td>
<td>4.22</td>
<td>95.89</td>
</tr>
<tr>
<td>2400</td>
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<td>—</td>
<td>925</td>
<td>4.11</td>
<td>100.00</td>
</tr>
<tr>
<td>Totals</td>
<td>925</td>
<td></td>
<td>925</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>

| Experimental animals                    |                                  |                                      |                         |                   |                             |
| 0-300                                   | 76                               | .27                                  | 76                      | 8.80              | 8.80                        |
| 300-600                                 | 167                              | .20                                  | 243                     | 19.33             | 28.13                       |
| 600-900                                 | 146                              | .10                                  | 389                     | 16.90             | 45.02                       |
| 900-1200                                | 117                              | .06                                  | 506                     | 13.54             | 58.56                       |
| 1200-1500                               | 97                               | .04                                  | 603                     | 11.23             | 69.79                       |
| 1500-1800                               | 64                               | .02                                  | 667                     | 7.41              | 77.20                       |
| 1800-2100                                | 68                               | .02                                  | 735                     | 7.87              | 85.07                       |
| 2100-2400                                | 46                               | .01                                  | 781                     | 5.32              | 90.39                       |
| 2400                                    | 83                               | —                                    | 864                     | 9.61              | 100.00                      |
| Totals                                  | 864                              |                                      | 864                     | 100.01            | 100.00                      |
by about half in each additional band in what appeared to be roughly a bivariate normal distribution of points.

The cumulative probability index depicted the two groups in comparable parameters. The two distributions were similar, with roughly half of all locations falling within the innermost three bands. The major difference is a larger scatter of points beyond the outermost zone in the experimentals. This excess attenuated slightly the entire distribution of experimentals in comparison to that for the controls. The distributions were not significantly different at the .05 probability level according to the Chi-Square Goodness of Fit.

**Stability of the home-range locus.** Parameters designed to measure the area in which an animal carries out its life activities have been compared. Another test is the degree to which these areas remain fixed at a given site. Conceivably, two animals could occupy about the same area but one could gradually shift its area of activity while another could remain fixed.

The comparison of seasonal home ranges has provided a preliminary test of this possible difference. If one of the groups was gradually shifting its locus of activity, the points constituting its seasonal home range would occupy a larger area and not be concentrated about a geometric center, as appeared to be the case.

As a final test, geometric centers of daily home ranges were calculated for each animal. It was assumed
that an animal which was gradually moving its locus of activities would display a linear shift in these daily centers, and that the area enclosed by a line connecting all of the daily centers would be greater than that for an animal remaining fixed in a localized area. Two such areas, along with the daily home ranges on which they are based, are shown in Figures 7 and 8 and Table 8.

The mean of the areas for seven controls was nearly the same as for the eight experimentals (34.1 and 33.7, respectively). The differences were not statistically significant ($t = P > .05$).
Figure 7. Relationship between daily home ranges and area encompassed by a line connecting the centers of the daily home ranges for a control jackrabbit.
Figure 8. Relationship between daily home ranges and area encompassed by a line connecting the centers of the daily home ranges for an irradiated jackrabbit.
Table 8. Areas enclosed by lines connecting the outermost geometric centers of daily home ranges for control and experimental animals (cf. Figures 4 and 5)

<table>
<thead>
<tr>
<th>Animal number</th>
<th>Control animals</th>
<th>Experimental animals</th>
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<tr>
<td></td>
<td>Area within home-range centers (acres)</td>
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</tr>
<tr>
<td>21</td>
<td>53.8</td>
<td>24</td>
</tr>
<tr>
<td>22</td>
<td>30.6</td>
<td>27</td>
</tr>
<tr>
<td>23</td>
<td>9.7</td>
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</tr>
<tr>
<td>30</td>
<td>54.0</td>
<td>33</td>
</tr>
<tr>
<td>31</td>
<td>34.8</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>239.0</td>
<td>269.7</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Means</td>
<td>34.1</td>
<td>33.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>15.7</td>
<td>24.9</td>
</tr>
</tbody>
</table>
DISCUSSION

Objectives

The objective of my study was to compare movement, activity, and home-range patterns of control and experimental animals. Any differences would presumably be due to brain damage from irradiation.

Parameters Used in Measurement

Indices of linear movement in animals were determined by measuring distances between consecutive hourly locations. By averaging these distances, I could estimate an animal's mean hourly movement for each day of observation or the mean over a period of days.

Home range

Characteristics. An animal's movements involve some degree of activity localization or site orientation. Seton (1909) stated that animals have home areas or home regions. Burt (1940, p. 25) further delineated the home-range phenomenon when he defined it as "That area about its established home which is traversed by the animal in its normal activities of food-gathering, mating, and caring for the young." This site orientation is often expressed as a concentration of activity around some focal point or geometric center (Harrison, 1958; Rusch, 1965).
The daily and seasonal home ranges for an animal may or may not be one and the same. He may traverse his entire home-range area each day (Lechleitner, 1958), or he may move over somewhat different areas each day which collectively constitute the region he occupies over a period of time (Rusch, 1965; Tester and Siniff, 1965).

Measurement parameters used in this study. Sanderson (1966) reviewed 13 methods or parameters for expressing the home-range phenomenon in animals. Basically, they constitute variants of two concepts: (1) the delineation of an area encompassed by an imaginary line connecting the outermost points of an animal's activity, and (2) the conception of home range as a bivariate probability phenomenon in which the probability of finding an animal increases with proximity to some geometric or focal center of the animal's locations over a period of time.

The daily, minimum-area method of determining home-range was used in my study and calculated by plotting hourly locations of each animal during each day of radio-tracking, connecting the outermost locations, and measuring the enclosed areas. Thus, home range was determined for each day each animal was radio-tracked. The seasonal, minimum home range was derived by the same procedure except all locations for the entire tracking period were used. I assumed, when using the minimum-area method for calculating home range, that the animals had travelled beyond the outermost constructed lines. Hence, the derived home
range may have been a conservative estimate of the true home range.

The objective of my study involved relative comparisons of home-range size for the two treatments, and, for this purpose, absolute estimates of home ranges for control and experimental animals were not necessary. However, in order that my observations might make a broader contribution to a knowledge of jackrabbit home-range size, I selected the minimum-area method. This was selected because of ease of measurement, and because it tended to negate the overestimation inherent in the telemetry system. In this way, I hoped that the estimates would not only provide a basis for comparison, but also something approaching an estimate of true home-range size.

Probability belts were used to measure the seasonal concentration of activity around the geometric center of activity. The geometric center was determined for each animal by averaging all X and Y coordinates derived from the angular location bearings. This gave a mean X and Y coordinate and a corresponding geometric center of activity. Successive circular bands of 300-foot radius were drawn around this geometric center and the number of point locations in each band counted. This, then, described the concentration of activity at increasing distances from the geometric center.

The stability of site attachment, and the possible effects of radiation thereon, were measured to determine
the degree to which the actual area occupied by an animal was fixed. Conceivably, an animal could localize its movement within a daily home range, but daily home ranges could shift progressively so that the animal's location in the landscape actually drifted. This possibility was explored by plotting the geometric centers of the daily home ranges of each animal, connecting the outermost centers, and measuring the enclosed areas.

**Radiation Effects**

As stated earlier, the main behavioral change observed by other workers in domesticated and wild-caught captive animals irradiated at dosages below the LD$_{50}(30)$ level has been hyperactivity (Davis and McDowell, 1962; Stahl, 1959). Assuming that a similar change would occur in free-living wild animals, one would expect such animals to express their hyperactivity by modification of their movement, activity, and home-range patterns. Such seems to have been the case in this study.

**Movement and activity patterns**

The mean hourly movement of experimental animals, both separated by sexes and with sexes combined, was significantly different from the control animals at the .05 probability level. Experimental males had a greater mean hourly movement (1347.1 feet) than the control males (1067.6 feet). Experimental females had a greater mean hourly movement (1058.5 feet) than the control females
(894.0 feet). The combined, mean hourly movement of experimental animals was greater (1176.8 feet) than the control animals (980.0 feet). A significant difference at the .05 probability level was found between the mean hourly movement of control males and control females and between experimental males and experimental females.

Experimental animals displayed a distinct bimodal activity curve, the activity peaks occurring at about 5:00 p.m. and 3:00-6:00 a.m. Control animals displayed a more constant level of activity. No pronounced activity peaks occurred in the latter from 5:00 p.m. to 8:00 a.m.

**Home-range patterns**

Vorhies and Taylor (1933) found home ranges of jackrabbits several miles in diameter and daily movements of 1-2 miles from food to shelter. Orr (1940) observed many of the animals feeding at distances up to 1 mile from suitable cover. These observations are not surprising because the extent of an animal's movements and home range are affected by the pattern of the habitat (Lechleitner, 1958; Sanderson, 1966; Vorhies and Taylor, 1933).

Jackrabbit home range in areas having a good inter-sperision of food and cover has been studied by others. Lechleitner (1958) found home ranges to be less than 50 acres, and that they were affected by the juxtaposition of food and cover. French, McBride, and Detmer (1965) calculated home ranges to be less than 40 acres. Rusch (1965) determined home ranges to be less than 35 acres.
Vorhies and Taylor (1933) also found that no major daily movement occurred where food and shelter were in close proximity.

My study area was selected for its homogeneity of the sagebrush habitat, thus insuring that food and cover were available to the animals in a confined area. This allowed a more representative comparison of my data with other studies where food and cover were well interspersed. The control animals in my study had a mean, daily home range of 34.7 acres, closely paralleling the daily home ranges reported by Lechleitner (1958), Rusch (1965), and French, McBride, and Detmer (1965).

The mean, daily home range of experimental animals, both separated by sexes and with sexes combined, was significantly different from the control animals at the .05 probability level. Experimental males had a mean, daily home range of 67.7 acres and control males a mean of 33.6 acres. Experimental females had a mean, daily home range of 64.9 acres and control females a mean of 40.4 acres. The combined mean, daily home ranges of experimental animals was greater (66.1 acres) than the control animals (34.7 acres).

One might expect that the seasonal home ranges of irradiated animals would be greater than the control animals because of the greater mean, daily home ranges of the experimental animals. This was not the case in this study. Differences between seasonal home ranges of control and irradiated animals were not significant at the
.05 probability level. Experimental males had a mean, seasonal home range of 231.6 acres and control males a mean of 199.9 acres. Experimental females had a seasonal home range of 316.0 acres and control females a mean of 309.8 acres. The combined experimental animals had a seasonal home range of 279.0 acres and combined controls a mean of 247.0 acres. Further, connecting the outermost points of the daily geometric centers of activity suggested that both control and experimental animals had fairly constant, non-shifting centers of activity. The means of these areas for control and experimental animals were 34.1 and 33.7 acres, respectively. The differences were not statistically significant at the .05 probability level.

Seasonal distributions of experimental and control animals within the concentric, probability belts were not statistically different at the .05 probability level using the Chi-Square Goodness of Fit. Both groups of animals had a greater number of locations in the bands nearest the geometric center, on a per-unit-area basis, the number decreasing with increasing distance at about the same rate in both classes.

Conclusions

Hyperactivity, as manifested by larger hourly movements and daily home ranges, suggested that modification of the brain occurred in irradiated animals. That modification could have been through irritation of areas that generate
activity or through damage to areas that regulate activity. The areas of basic arousal, emotions, and drives are located in the limbic system, which is made up of portions of the mid- and hind-brain. Areas of inhibitory control are located in the cerebral cortex. They prevent or regulate the intensity of action generated in the limbic system (Barnett, 1963).

The greatest modification of the brain probably occurred nearest the radiation source. The brains of irradiated animals were not examined. Since the area of the brain closest to the radiation source was the cerebral cortex, and since this was the site of inhibitory activity, it seemed likely that the hyperactivity may have been caused by a disruption of inhibitory function which permitted a greater expression of general activity from the limbic system.
SUMMARY

The effects of acute, sublethal cerebral irradiation on movement and home-range patterns of free-living, black-tailed jackrabbits were studied in Curlew Valley, Utah. Radio-telemetry was utilized to record hourly locations of control and irradiated animals from 5:00 p.m. through 8:00 a.m. during November and December, 1967, and January, 1968.

Experimental irradiation of 70 captive animals indicated that the LD$_{50(30)}$ was somewhere between 5,556 and 6,200 roentgens. Since brain damage without death was desired, an arbitrary value of 5,000 roentgens was selected for irradiating free-living animals.

Nine experimentals were trapped on a northern Utah desert study area, irradiated, radio-transmitters placed around their thoraxes, and released at the points of capture; seven controls were treated similarly, including containment in the X-ray unit, but not irradiated.

Since movement was to be followed by triangulating periodically on each transmitter signal from two receivers 1.9 miles apart with directional antennas, accuracy of the receiver system was tested by (1) triangulating on transmitters placed at known, fixed locations, and (2) comparing repeat readings on the same locations. Accuracy varied as a function of the equipment, location
of animals in relation to the baseline (imaginary line drawn between the two tracking stations), and magnitude of the parameters being measured. Average errors for the two receivers were 1 degree 36.8 minutes and 2 degrees 22.7 minutes. Greatest accuracy was attained when the signal was located by receiver bearings which formed 45-degree angles with the baseline. Variability increased parallel to the baseline with the location of sites close to it, and increased perpendicular to the baseline at more distant points. Distances between pairs of points were measured within 20-30 percent error; home-range areas were measured with an error of less than 22 percent. Three consecutive bearings did not materially improve precision over one.

Each animal was triangulated upon hourly, the readings from the two stations taken as nearly simultaneously as possible. Where more than 6 minutes elapsed between the two readings, the data were discarded.

Experimental irradiated animals had a mean hourly movement (mean distance between successive pairs of hourly locations) of 1,176.8 feet and control animals 980.0 feet. Experimental males had a mean hourly movement of 1,347.1 feet and control males 1,067.6 feet. Experimental females had a mean hourly movement of 1,058.5 feet and control females 894.0 feet. Control males and control females differed in mean hourly movement by 173.6 feet.
Differences between these groups were statistically significant at the .05 probability level.

Experimental animals displayed a distinct bimodal activity curve with peaks in the early evening already underway at 5:00 p.m. when observations were begun each day, and again from about 3:00 to 5:00 or 6:00 a.m. Control animals showed no such pattern, with the generally lower level of activity fairly constant from 5:00 p.m. to 8:00 a.m.

Experimental animals had a mean daily home range (calculated by connecting the outermost location points and measuring the enclosed area) of 66.1 acres and control animals 34.7 acres. Experimental males had a mean daily home range of 67.7 acres and control males 33.6 acres. Experimental females had a mean daily home range of 64.9 acres and control females 40.4 acres. Differences between these groups were statistically significant at the .05 probability level. There was no significant difference between control males and control females or between experimental males and experimental females.

Experimental animals had a seasonal home range of 279.0 acres and control animals 247.0 acres. Experimental males had a seasonal home range of 231.6 acres and control males 199.9 acres. Experimental females had a seasonal home range of 316.8 acres and control females 309.8 acres. These differences are short of statistical significance at the .05 probability level.
A probability index using 300-foot concentric circular bands, and expressed on a locations-per-unit-area basis, showed similar distributions for both experimental and control animals. The greatest concentration for both groups occurred within the 300-foot zone. Activity in each additional band declined, dropping by about a fourth or third in the second band, and thereafter by about half in each additional band. Experimental animals had a larger scatter of points than control animals beyond the outermost zone. The distributions were not significantly different at the .05 probability level according to the Chi-Square Goodness of Fit.

The stability of the home-range locus was tested for experimental and control animals by calculating the geometric centers of daily home ranges, connecting the outermost points of the scatter of these centers, and measuring the enclosed area. The mean of these areas was 33.7 acres for the experimental animals and 34.1 acres for the control animals. These differences were not statistically significant at the .05 probability level.

Irradiation appears to have increased the activity levels of experimental animals, including movement over a larger area each day. But the area of movement over a period of several days was similar in the experimentals and controls indicating that the total home range size and the general area of the terrain occupied by an animal was unchanged by irradiation. Hyperactivity has been observed
previously in captive brain-irradiated animals and is probably due to a disruption of inhibitory areas in the cerebral cortex which permitted a greater expression of general activity from the limbic system.


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