VISUAL DETECTION OF X-RAYS IN THE RHESUS MONKEY

Thomas Chaddock and James C. Smith, paper read at Radiation Research Society Meeting,

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It has been demonstrated in our laboratory that X-rays can be used as conditioned stimuli with pigeons, rats, and monkeys. Typically a 10 to 20 second radiation exposure is terminated with a brief electric shock and the animal is conditioned to stop some ongoing response at the onset of the X-ray exposure. Rats and monkeys will learn this suppression response in 10 to 25 pairings of the irradiation and shock.

Much research has been conducted which indicates that olfaction is involved in the immediate detection of ionizing radiation. Dinc and Smith, using rats, and Taylor using Rhesus monkeys, demonstrated that an intact olfactory system is necessary for an immediate behavioral response to X-rays. These studies showed that animals which had been trained to suppress ongoing responding at the onset of X-ray exposure, lost this conditioned suppression response after ablation of their olfactory bulbs or sectioning of the olfactory tracts. Furthermore, animals that had this olfactory surgery prior to suppression training could not learn the suppression response at all.

It is also well established - in fact as far back as Roentgen in 1869 - that humans report a visual sensation to X-ray exposure. These X-ray-produced visual phosphenes, which occur only in a dark adapted eye, have been obtained with dose rates as low as 0.5 mr/sec.

The purpose of the present study was to investigate whether or not anosmic Rhesus monkeys could detect X-rays visually. The reason no evidence for visual detection was seen in previous studies is that all animals were well light adapted. In the present study all data was obtained in total darkness.
The subjects in the present experiment were Rhesus monkeys whose ages were approximately 3 to 4 years and weighed between 10 - 13 pounds. All subjects were housed in individual home cages where water was continuously available and they were maintained at approximately 90% of their normal body weights. All Ss were made anosmic prior to training by surgery in which the olfactory tracts were cut bilaterally.

The behavioral technique used in these studies was a modified version of conditioned suppression. Essentially this technique is a classical conditioning paradigm whereby a conditioned stimulus is paired with shock and superimposed on an ongoing operant baseline. Fig. 1 illustrates the technique.

The top line represents time in 10 sec. units. The animal is deprived of food and trained to press a lever for food pellets. Typical responding early in training can be seen on line A. By carefully scheduling the presentation of reinforcement on a variable time basis, a stable rate of responding can be obtained, as shown in line B. If the animal is given a brief electric shock while responding, the smooth rate of responding can be suppressed, as seen in line C. At this point in training a conditioned warning stimulus, in this study X-ray, is presented just prior to electric shock. After several pairings of the X-ray warning stimulus and shock, the animal becomes conditioned to the shock and complete or almost complete suppression of responding occurs, as seen in line D.

If one samples the behavior of the animal for a comparable period of time prior to the onset of the warning stimulus, baseline responding can be obtained to compare with responding during the warning X-ray stimulus as seen in line E. This suppression
can then be quantified in the manner described by Hoffman, as seen in line F. One can see from this equation that if complete suppression occurs during the warning stimulus the ratio is 1.00, and if no suppression occurs, the ratio is 0.00.

Control trials were also administered during each daily experimental session in order to insure that the animal was responding to the X-ray beam and not to some artifact associated with its onset. These trials consisted of operating the X-ray machine in the same fashion as used in the X-ray trials, but the beam was directed away from the animal. When the suppression ratio was applied to control trials, there were no artifacts and since the animal responded at a uniform rate, these trials yielded ratios near zero in value. Control trials were never terminated with shock.

Since it has been shown by Garcia that for immediate X-ray detection the head of an animal was the most sensitive, and since the L.D. 50/30 is much greater for head only exposure than for whole body exposure, a marked decrease in lethality can be attained by head only exposure.

Head only exposure is accomplished for the monkey by restraining the animal in a standard primate chair which slides into an acoustical chamber, Fig. 2. The outside of the acoustical chamber and one side of the primate chair were lined with lead which shielded the animal's body from the X-rays. A circular port, 8 inches in diameter, was cut in the lead shielding on the side of the chamber perpendicular to the animal's head. The X-ray tube was operated in the horizontal position and was aligned with the port, thus permitting head-only exposure to the X-rays.

In this apparatus, the monkey pressed a lever and a pellet
dispenser was used to deliver food reinforcements on a variable time schedule. Shock was administered by an AC shock generator and was presented to the subject across the chair seat and a brass foot plate.

Programming of the behavioral schedules was accomplished by standard relay switching and timing circuits located in the X-ray control room. Two of the animals used in this study were trained to suppress to X-rays prior to having their olfactory tracts cut. Following surgery these animals were tested in a well illuminated chamber and showed no suppression. These 2 monkeys and 2 other anosmic monkeys were then trained in complete darkness.

In Fig. 3 the dose rate threshold curves are plotted for 4 separate monkeys. All animals were trained to reliably suppress to the onset of 60 mr X-rays. Mean suppression ratios were computed daily for X-ray and control trials. When criterion suppression behavior was obtained, the dose rate was systematically reduced until threshold was reached. Threshold was defined as a mean suppression ratio of 0.50.

The criterion for lowering the dose rate was:

(1) a mean S.R. of 0.80 or greater on the X-ray trials with a mean S.R. of 0.20 or less on the control trials, or

(2) four consecutive daily sessions at one dose rate with the suppression ratio for the control trials at 0.20 or less.

As seen here, at 8 mr/sec all animals show reliable suppression whereas at 3 and 4 mr/sec the mean suppression ratio has dropped off appreciably. It is interesting to note that olfactory thresholds are the same. Control trials if plotted would show a mean suppression rate of approximately 0.20.
Following threshold determination, dark adaptation curves were obtained using the house-light, a 30 volt bulb, as the source of illumination. After giving two trials with the light on, the light was turned off and X-ray trials were presented at various intervals following its termination. Two different dose rates (60 and 6 mr/sec) were utilized for this study and four sessions (each session containing 5 X-ray trials) of dark adaptation were presented at each dose rate. Mean suppression ratios were computed for each interval in the dark and for the control trials.

Figs. 4, 5, 6, and 7: none of the animals showed any suppression behavior while fully light adapted. However, after the lights have been turned out the animals ability to detect the X-rays is a function of the dose rate of the X-ray and the amount of time spent in the dark. As one can see, most Ss give high suppression ratios after 6 minutes of dark adaptation with the 60 mr/sec dose rate, whereas with the 6 mr/sec stimulus the animals require approximately 9 to 12 minutes in the dark before reliable detection is obtained.

In summary, the data indicates that there is a visual component to the immediate detection of X-rays. In the previous olfactory studies, visual detection may be ruled out due to the present data which indicates that detection is impossible in well light-adapted animals.
Suppression Ratio (S.R.) = \frac{Pre R's - During X-ray R's}{Pre R's}