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ONE SMALL RANDOMLY BLINKING DOT IN AN OTHERWISE DARK ENVIRONMEN--ETC(U)
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We raised seven kittens in the presence of a small, randomly blinking, dim light, in an otherwise dark room. We recorded receptive field (RF) properties of single neurons in primary visual cortex, comparing responses of the dot-reared kittens to normally- and dark-reared kittens from the same breeding colony. A substantial number of dot-reared kitten neurons preferred very small moving stimuli, though average RF field size was not significantly smaller than normal kittens'. Only rarely in normal or dark reared kittens

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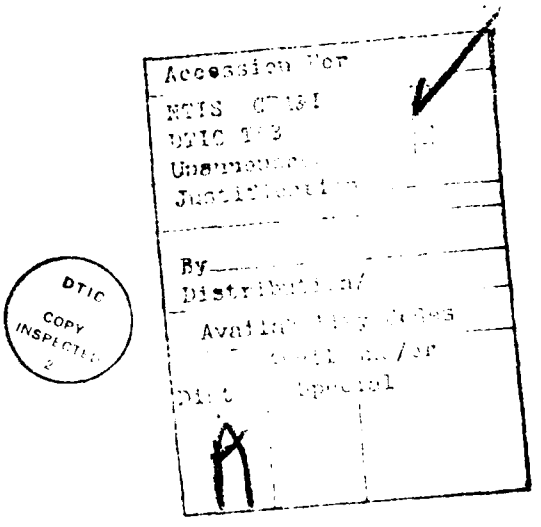
did we encounter neurons which preferred very small stimuli. Dot-reared neurons did not prefer ON-OFF stimulation to movement, even though their entire visual experience was with blinking (10 msec duration) not moving stimuli.

Compared to dark-reared kittens, there were many fewer non-visual units in the dot-reared sample. Like dark-reared neurons, units in the dot-reared kittens were rarely selective for the direction of movement of stimuli, whereas in our normally-reared sample most units were selective.

In the first five dot-reared kittens we noted significantly more binocular responses than in our control groups. We challenged the binocular system of two more dot-reared kittens by monocular deprivation (MD) in one animal and divergent strabismus in the other. Compared to MD and strabismic kittens reared in our normally lit colony, these two kittens had more binocular neurons, though not as many as the other dot-reared kittens. Because the dot-reared kittens also had good eye alignment compared to dark reared kittens, we conclude that viewing a solitary blinking dot may exercise a kitten's binocular fixation mechanisms in a way that enhances binocular interaction in visual cortex.



"One Small Randomly Blinking Dot in an Otherwise Dark Environment: Effects on Visual Cortical Neurons of Kittens"

By

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Summary. We raised seven kittens in the presence of a small, randomly blinking, dim light, in an otherwise dark room. We recorded receptive field (RF) properties of single neurons in primary visual cortex, comparing responses of the dot-reared kittens to normally- and dark-reared kittens from the same breeding colony. A substantial number of dot-reared kitten neurons preferred very small moving stimuli, though average RF field size was not significantly smaller than normal kittens'. Only rarely in normal or dark reared kittens did we encounter neurons which preferred very small stimuli. Dot-reared neurons did not prefer ON-OFF stimulation to movement, even though their entire visual experience was with blinking (10 msec duration) not moving stimuli.

Compared to dark-reared kittens, there were many fewer non-visual units in the dot-reared sample. Like dark-reared neurons, units in the dot-reared kittens were rarely selective for the direction of movement of stimuli, whereas in our normally-reared sample most units were selective.

In the first five dot-reared kittens we noted significantly more binocular responses than in our control groups. We challenged the binocular system of two more dot-reared kittens by monocular deprivation (MD) in one animal and divergent strabismus in the other. Compared to MD and strabismic kittens reared in our normally lit colony, these two kittens had more binocular neurons, though not as many as the other dot-reared

INTRODUCTION:

The developing kitten visual system, recorded at the single neuron level, has become the model par excellence for documenting the effects of experience on the subsequent responses of neurons, especially neurons in the primary visual cortex (reviews: Daniels & Pettigrew, 1976; Movshon & Van Sluyters, 1981). One line of research in this field can be seen as providing information about the minimal visual environment necessary to establish more responsiveness than the disrupted state caused by total deprivation (dark rearing). There have been two outstanding contributions:

(1) Dot Rearing. Pettigrew & Freeman (1973) and Van Sluyters & Blakemore (1973) reared kittens who viewed only small stationary dots. Kittens faced with this experience developed area 17 neurons which responded preferentially to small moving targets, a result virtually opposite to normally reared kittens, where cells grow to prefer elongated bars. The great majority of dot-reared cells also had none of the directional selectivity seen in cells of normal kittens.

(2) Strobe Rearing. Cynader et al. (1973) and Olson & Pettigrew (1974) were the first to raise kittens in strobe illumination. The brief stobe flashes provided "snapshots" of the environment but, because of their low frequency (2/sec or less), permitted no normal perception of movement. Neurons in kittens reared thus do not develop proper direction selectivity, though some do become particularly responsive to strobe itself, or ON-OFF flashes.

(summary continued)

kittens. Because the dot-reared kittens also had good eye alignment compared to dark reared kittens, we conclude that viewing a solitary blinking dot may exercise a kitten's binocular fixation mechanisms in a way that enhances binocular interaction in visual cortex.

Key Words. Visual Cortex--Development--Random Dot Stimulation--Receptive Fields--Binocularity

Compared to dark-reared kittens, dot- and strobe-reared kittens have fewer visually unresponsive units and less of the frustrating sluggishness characteristic of many neurons from the dark-reared group. It seems clear that dot and strobe stimuli provide kittens with some usable visual information, but certainly not enough to enable normal development. Questions can be raised about just what features of the strobe and dot experiences are essential for maintaining crude visual responsivemess, and about whether even less stimulation could do the same.

The randomly blinking dot stimulus. To explore these questions, we created a visual environment which combines features of the dot and the strobe paradigms. We arranged that in an otherwise dark cage a small (less than 1)spot of light would blink briefly (less than 10 msec on) at a random times averaging about 1 Hz. Like the strobe rearing situation, the conditioning would be ongoing all the time, with no need to transfer the kitten to a special chamber. The kitten viewing this would see the pinpoint pattern which the dot-reared kittens cited above saw, and would see the brief flashes of light which the strobe reared kittens saw. There are differences. Instead of many dots simultaneous in view, only one is seen, and that one dot blinks rather than providing sustained visual input. The blinking light is so dim it does not significantly illuminate any other part of the kitten's cage, and its blinking is not at a constant, predictable, rate. Altogether we felt that our dim, randomly blinking spot would provide less stimulation (although over many hours) than the orignal many-dot rearing or the strobe rearing. We wondered if it would provide enough stimulation to be different from dark rearing

for kitten cortical neurons.

We felt that if the single blinking dot could influence development of cortical neurons, it would do so like the many-dot environment: neurons would prefer small spots of light t larger targets. We wondered whether RF size would be normal and whether the ON-OFF blinking feature of the stimulus would enhance ON-OFF responses of cortical neurons. Because we were going to use a monochromatic 540 nm green LED as the light source for the stimulation, we also considered the possibility that blue-green color preferences might be affected (see Daw & Perelman, 1970 for a description of color coded cat LGN cells). Finally, because we attempting to generate a minimally effective stimulus, we decided to test whether such a stimulus would be able to shift ocular dominance in monocularly deprived or strabismic kittens.

To insure grounds for valid comparison we recorded, in the same lab, with the same visual stimuli and same standards for judgement of RF properties, from normally- and dark-reared kittens. The comparisons we make of our experimental and control results amplify and extend the previously cited work on dot and strobe rearing. We hope the data help establish single blinking dot rearing as an important paradigm to consider when constructing explanations for the development of the kitten's visual system.

MATERIALS AND METHODS

Animals. Litters of kittens resulted from our wild-type Tabby queens mating with our orange & white stud in our quarantined colony. After birth, but before eyelid opening, we transferred mother and kittens to the inner chamber of our ultra-flat black two chambered darkroom, if the kittens were to be dark reared or to view the blinking LED. Normally reared kittens remained in the main colony room, on a 12/12 light-dark cycle. All of the 13 kittens used in this study are listed in Table I.

Monocular occlusion and strabismus procedures. Left eyelid closure was performed under i.m. Acepromazine (3mg/kg) and Ketamine (25 mg/kg) anesthesia, supplemented by Chloroptic topical anesthetic. The nicitating membrane was stitched across the cornea, to the lateral lid margin. The lid margins were trimmed, then sutured together with 5-0 Prolene. We inspected daily for windows, and repaired any immediately.

Left medial rectus section was performed under the same anesthesia. The nicitating membrane and conjuntivia were retracted while the eyeball was rotated laterally just enough to reveal a dark stripe which coincided with the location of medial rectus insertion. The muscle was isolated by a blunt hook and the was cut completely. Antibiotic (chlorampenicol) was dropped in as the eyeball was allowed to relax to its new, divergent, position. A sham operation was performed on the other eyeball, including all procedures except actual cutting of the muscle. The two kittens which had the strabismus operation ended up with left eye deviation at the time of recording of 25° (K45)and 20° (K99).

Random Dot Stimulus Generation: Figure 1 shows the circuit we built to generate a pseudorandom bit stream which triggered a one-shot whose output controlled the illumination of a green (540 nm) LED. The 15-stage shift register produces a sequence which repeats itself every 32,767 clock pulses (Horowitz & Hill, 1980). Flash duration was 7 msec. Time between flashes ranged from 0.5 to 2.5 msec., average 1.1 sec. The green LED fitted onto one end of a 60 cm, 0.7 mm diameter fiber optic bundle, the other end of which was placed through a slot in a top corner of the dark room cage. Distance from the end of the LED to the center of the bottom of the cage was 40 cm. At 40 cm., the 0.7 mm light pipe subtended about 0.1° visual angle. Kittens could get as close as 25 cm. and as far away as 75 cm. The end of the light pipe was visible from virtually all parts of the cage. At feeding time each day the system was checked.

FIG. 1 HERE

In later experiments (K97, 99, 100), we used a Texas Instrument TMS 990/189 microcomputer board to emulate the 15 state sequencer, and we had seven LED's (without intervening light pipe) positioned at various slots around the top of the cage. Only one LED was on at any time. The LED's subtended about 0.6° of visual angle in these experiments.

By limiting current to the LED, we kept the illumination dim enough that no part of the cage, or any food or sawdust, or any kitten was visible to a human observer, even after 40 minutes of dark adaptation.

Single unit recording: Before removing a kitten from the darkroom, its eyelids were taped shit, to be opened as the first electrode penetration started a few hours later.

Under promazine (3 mg/kg i.m.) and ketamine (25 mg/kg i.m.) anesthesia we performed a tracheotomy and a veinous cannulation. We started a nitrous oxide (70% with 28% O_2 and 2% CO_2) ventilation anesthesia as we induced paralysis with 20 mg Flaxedil, i.v. Nitrous oxide was supplemented as needed by Nembutal, 2 mg/kg every 2-3 hours. We maintained paralysis with 12 mg/kg/hr Flaxedil. End tidal CO_2 was monitored with an Infrared Industries gas analyser. By adjustment of respirator stroke volume and inhaled CO_2 we kept the exhaled CO_2 at about 3.5%. The animal's temperature was kept at 38°c by a heating blanket in a feedback loop. We monitored ECG and EEG. If EEG showed signs of synchronous activity, we gave additional i.v. Nembutal. The animal was secured in a 30 kg custom made stereotaxic frame which angles the gaze 14° down from horizontal. Pupils were dilated with atropine and the corneas fitted with contact lenses of about 7.1 mm radius of curvature, which provided a slight positive correction. The retinas were inspected with an ophthalmascope. Retinal landmarks were either back-projected via tapetal reflection (Pettigrew et al., 1979) or each optic disc was viewed through the ophthalmascope and two observers marked its projection back onto the tangent screen.

A one centimeter oblong craniotomy was drilled, revealing the medial banks of both hemispheres, -2 mm posterior to A-P zero. A one cm high plastic chamber was cemented to the skull around the craniotomy. After tungsten hooks were used to tear the dura over the medial banks of the two post-lateral gyri, two tungsten-in-glass microelectrodes (Levick, 1972) were lowered into the hemispheres with a 2½ micron-per-step, microprocessor controlled, stepping motor system. The electrodes had 1-4 MΩ impedance at 500 Hz.

AC-coupled signals were led from the electrodes to two Analog Devices AD521 FET op amps one centimeter away. After local amplification, and positive feedback to cancel electrode capacitance, the two signals went to a switch, where one or the other could be selected for passage into a further amplification and filtering system. Included was an anti-log circuit for optimal separation of spike signals from electrode noise. (Barnett & Wingate, 1980). The resulting output was played over a speaker, displayed on an oscilloscope and available to a computer (MINC) for histograms correlated with stimuli.

After 36 hours of single unit recording the animal was killed with an i.v. injection of KCl solution. It was perfused through the aorta with 10% formaldehyde, and the skull was removed to allow inspection of the region of the electrodes' penetration. In four cases we processed 40 micron sections of the hemispheres to insure that we recorded from area 17.

Visual Stimuli: A stimulus fell into one of two categories--hand-held or automated. In the hand-held category were "noise cards", including Escher prints, and a clear plastic wand with a green LED embedded in the tip. This LED was flashed manually by a pushbutton connected to a battery, or flashed automatically by the same sequencer circuit which drove the darkroom LED.

The automated stimuli required a tangent screen for their imaging. The screen was maintained 114 cm (2 cm=1^{o}) away from the animal and images were back-projected onto it. A sheet of clear plastic held at a 45^{o} angle to the screen acted as a beam splitter to allow us to draw receptive fields on sheets of paper on a table in back of the screen. Our most primitive stimulus was a strobe

(Gen Rad model 1431). Beyond that, we had a pair of orthogonally mounted scanning motors with attached mirrors in an optical box above an overhead projector. On the focal plane of the projector was a "slit maker" mounted on a turntable (rotation of which was controlled by a stepping motor) and a shutter. A control box with a joystock allowed the experimenter to translate images and rotate them while watching the screen. The shutter was controlled by a footswitch.

In addition to its manual mode, the scanning motors, stepping motor and shutter could be controlled by a computer (Digital Equipment Corp. MINC) and this control could be synchronized with nerve spike histogramming. Speed, direction, on and off rates and interstimulus delay could all be programmed for repetitive presentation from one cell to the next. A second joystick controlled system was also available for "collision" and binocular stimulation experiments in conjunction with the first. This second stimulator had its own microprocessor (Intel 8085) controller for speed, direction, etc., so its activity would not tie up the main computing system.

All stimulation was done with dim background, about 10 cd/m^2.

Protocols, Classifications and Data Base: After isolating a unit and noting its depth in the penetration and spontaneous activity, a standard regimen was followed.

(1) If the cell were determined to be visual, then a receptive field for one eye was plotted: boundaries, regions of on-and-off response, and directional and speed preferences were noted.

(2) Judgements were made for these four response features:

a- speed preference

slow $< 1^\circ$/sec

1°/sec < moderate < 10°/sec

10°/sec < fast

b- size preference--whether the cell had a response to the hand-held LED, or whether a target in the range $1/2^{o}$, 1^{o}, 2^{o}, or 4^{o} produced a better response, or whether there was no preference for size at all. In the last case we would note the minimum size required to produce a response.

c- selectivity--we had three categories: Aspecific--responded equally well to movement in all directions; Immature--responded to all directions of movement but showed a clear preference for one axis or another (see Daniels et al., 1977). Selective--there existed one axis of movement which produced no response in the cell; usually this axis was orthogonal to the preferred direction. If a cell were visually responsive but too unreliable to be placed in one of the above categories, we labelled it "unclassifiable". → See Blakemore & Van Sluyters (1975) and Buisseret & Imbert (1976) for similar Categories

d- ocular dominance--we applied Hubel & Wiesel's (1962) seven category scheme. Group 1 was all contra, 7 all ipsi driven; a group 4 cell was driven, within a factor of two, equally well by both eyes; in groups 2 and 6 were cells with non-dominant fields so weak their boundaries could not be plotted reliably.

(3) Quantitative records. If we felt that a particular cell provided a good example of a typical RF feature, we would take the time to set up the repetitive automatic stimulus, and the window discriminator for spike detection, and collect the appropriate histograms to prove our case. Otherwise we would (4) turn to the other recording channel and record data from the other hemisphere. After that we would advance the electrode about 100 microns to establish a new recording site.

Each pair of recording sites would occupy us for about 1/2-1 hour. Before a cell could be declared "non-visual" we would listen for responses from various stimuli for at least fifteen minutes.

Because some of the RF features of random dot-reared kitten neurons were similar to LGN responses (see Daniels et al., 1977) we took special precautions to discard from the data base any units which fitted the following LGN criteria: (1) strictly monocular (2) better ON-OFF than movement responses (3) no preference for stimulus motion direction (4) small, less than 1 RF size (5) monophasic unstable waveform. About 4% of our recording sites qualified as LGN responses and were not included in subsequent analysis.

Table I summarizes the data base. From 13 kittens we recorded 615 cortical units.

RESULTS

Stimulus Size Preference. Because the random dot kittens saw only spots of less than 1° size, we were interested to compare the size preferences (if any) of their neurons to normal and dark-reared kitten neurons. A cell can show a preference for stimulus size if it is inhibited by larger stimuli. A milder form of size preference would be represented by the threshold for minimal size to evoke a response, if larger stimuli do not inhibit the cell.

Fig. 2 shows the striking difference in preference we recorded. Eighty-five percent of neurons from the random dot kittens preferred stimuli smaller than ¼ diameter; in normal kittens we recorded a preference around 2° ; visually responsive neurons of dark-reared kittens responded best to even larger targets--4° or more.

FIG. 2 HERE

Preferred size is less than or equal to receptive field (RF) area. In Fig. 3 we show that the RF areas of dot-reared kittens are not significantly less than those for normal or dark-reared. This implies that the dot size preference shown in 2 is not simply a result of RF areas shrinking. Fig. 4 shows a cell from a dot reared kitten which experienced strong surround inhibition. Note (1) this cell, unlike most from the dot-reared kittens, responded satisfactorily to a stimulus larger than 1° , and (2) the stimulus was moving, not flashed off and on.

FIG. 3 HERE

FIG. 4 HERE

Moving vs. Stationary flashed stimuli. Because the dot stimulus for the experimental kittens did not move, and flashed on and back off in 10 msec, there was no opportunity for the kittens to experience stimulus movement, either real or induced. We wanted to see if this limitation to flashed stimuli would alter the usual preferences of cortical neurons for moving instead of on-off stimuli.

As Fig. 5 shows, preference for movement was nearly as pronounced in dot-reared kittens as it was in normals. With respect to dark-reared kittens, the dot-reared animals showed more preference for moving stimuli. Fig. 6 shows examples of the responses to stimuli, moving and flashed, for a neuron from a random dot kitten. The neuron has virtually no response to the on-off presentation, but has a bidirectional response to slow movement of the same stimulus.

FIG. 5 HERE

FIG. 6 HERE

Along with the preference for moving stimuli, did the dot-reared kitten neurons develop the normal preference for direction of stimulus movement? No. In this regard they were much more like dark-reared kittens than normals. See Fig. 7. In fact we recorded a lower percentage of direction slective neurons in dot-reared kittens than dark-reared. The speed preferences of dot-reared neurons also approximated those of dark-reared kittens. Most preferred a slow (less than 1°/sec) movement, compared to a significant fraction of normal kitten neurons which respond well to speeds up to 100°/sec. (Movshon, 1975).

FIG 7 HERE

Compared to dark-reared kittens, dot-reared kittens had fewer non-visual neurons. See Fig. 7 again.

Ocular Dominance and Dot Rearing. We wondered whether viewing only a single, randomly-flashing dot would affect ocular dominance in binocularly viewing kittens. We knew that dark-rearing had little effect on the normally binocular complement of neurons in the visual cortex, but we also kn w that under special circumstances, (Daw & Wyatt, 1976) kittens with binocular viewing could develop two monocular populations of cortical neurons.

Our main results in this regard, presented in Fig. 8, suggest that dot-reared kittens can have more binocular neurons,

especially "group 4" (equally driven by both eyes) neurons, than normal or dark reared kittens. The last column of the data base, Table I, lists the percentage of group 4 neurons recorded from each individual kitten. For the dot reared kittens, values ranged from 29 to 63%, averaging 45%.

Our normal and dark reared control kittens show somewhat more monocularity (groups 1 and 7) than is usually reported. We feel this is due partly to our sampling procedure, in which we deliberately halt the electrodes every 100 microns and make a concerted effort to record from even small spike units. With our antilog amplifier (see Methods) we obtain good S/N audio with small units and are able with confidence to include their characteristics in our data base. Many of the small spike units were monocular (and see Shatz & Stryker, 1978). At any rate, with the same recording protocol we found fewer monocular units in our dot reared kittens (10% vs 40% in controls).

Surprizingly, we noted no significant binocular facilitation in the many binocular dot-reared neurons; response to stimulation simultaneously in both eyes was rarely greater than the sum of the two monocular responses.

Dot-reared kittens had good eye alignment, not the divergent strabismus often observed in dark reared kittens (Olson & Freeman, 1978). Figure 9 shows binocular eye alingment for the three kinds of kitten we are comparing here. While the dot-reared group had more variability than the normal or dark reared groups, the average for the dot reared group was about equal to the normal's. It is worth noting that the kitten (K94) with the smallest percentage of group 4 neurons also had the most divergent gaze of the blinking dot reared group.

FIG. 9 HERE

When we confronted the binocular system of two additional blinking dot reared kittens with monocular deprivation (K97) and divergent strabismus (K99) we found the differences to normal-light rearing shown in Fig. 10. The two kittens restricted to the single blinking dot environment had many more (33% vs 1%) group 4 neurons than identically treated controls reared in a normal 12/12 light dark cycle. These two random dot kittens did not, however, have as many binocular units as the original five dot kittens shown in Fig. 8. Note that there was some ocular dominance shift with MD K 97: no units were driven exclusively by the closed eye.

FIG. 10 HERE

Other aspects of the blinking dot stimulus. The stimulus was a monochromatic green LED, 545 nm. We noted no preferences (or differences in response) for this color, especially with respect to short wavelengths, such as has been seen in the LGN C-laminae (Daw & Perelman, 1970).

To generate the random sequence we used a pattern which would repeat itself about three times a day. When we tested segments of this particular pattern on neurons in the random dot kittens, we never saw a response to the pattern which was greater than the on-off response to a periodically repeated on-off pattern.

TABLE I HERE

Table I

DATA BASE

Kitten(Mother)	Sex	Visual Experience	(dot exp.– Onset age)	At Recording Age	At Recording Weight	Units	(non-vis)	Binoc. gp%
K80 (V)	M	Dot-reared single location	(37)days	84 days	680 gm	43	(4)	63 %
K93 (D)	M	Dot-reared single location	(25)	85	370	29	(4)	48 %
K94 (D)	F	"	(25)	92	460	40	(5)	29 %
K90 (C)	M	"	(51)	101	740	38	(3)	37 %
K97 (G)	M	Dot-reared MD Multi-locations	(20)	109	1000	33	(3)	36
K99 (G)	F	Dot-reared; strabismus Multi-locations	(20)	116	1500	37	(4)	30
K100 (G)	F	Dot-reared Multi-location binocular vision	(20)	118	900	61	(4)	57 %
K67 (F)	F	Dark-reared		37	420	52	(25)	15
K72 (G)	F	"		40	400	53	(12)	11
K55 (E)	M	Normal rearing		41	500	73	(2)	20
K56 (G)	F	"		41	450	40	(1)	35
K132 (F)	M	Monoc. dep. normal light		56	600	38	(3)	0 %
K45 (D)	F	Strabismus, normal light		40	500	75	(1)	1 %

DISCUSSION

Our results indicate that if a kitten's visual experience is limited to a small, briefly and randomly blinking spot, then most of its primary visual cortical neurons develop a preference for small stimuli moving inside a normally sized receptive field (RF). A preference for direction of motion does not occur. The neurons do not come to favor ON-OFF flashes of light, this in spite of the fact that the conditioning stimulus had no moving features and flashed so briefly (10 msec) that not significant retinal slip would occur.

In our five kittens who viewed the blinking dot stimulus with normal binocular vision we recorded a greater percentage of binocularly driven neurons than we recorded in normally reared kittens. We attribute this to the fact that the kittens could see only one dot at a time, and presumably got practice making aligned binocular eye movements to the solitary target. Supporting this notion, we found that eye alignment in the dot reared kittens was normal or slightly convergent, compared to the divergent strabismus we and others (Sherman, 1972; Olson & Freeman, 1978; Cynader & Mitchell, 1980) have often seen in dark-reared kittens. When we challenged binocularity in dot-reared kittens by raising two with monocular deprivation (MD) and strabismus, we still found many binocular neurons. This could mean that blinking dot did not provide sufficient visual content to the cortex to induce an ocular dominance shift or (at least in the case of the strabismic kitten) that dot's ability to enhance binocularity balanced strabismus' tendency to decrease it (and see Singer et al., 1979).

Limitations. In these experiments we are able to control precisely the absolute size, blink rate and duration, and luminance of the spot (and lack of illuminance of the surroundings). We could not control precisely the amount of time each kitten viewed the blinking dot, or with what parts of its retinas; nor did we monitor what eye movements each kitten made in response to the conditioning. Each of our kittens did, however, live with the dot stimulus continuously for several weeks. If the kittens were awake for 10 hr per day average then each accumulated about 500 hr opportunity to view the stimulus. This is a factor of 10 more time than the original random dot kittens (discussed below) and compares about equally with the conditioning time of the strobe-reared kittens (also discussed below).

Sample size. We recorded from enough units in our normally-reared and dark-reared control kittens, and from our five binocularly-reared dot animals to be certain of our main observations about differences in stimulus preference, RF size, ON-OFF responsiveness, direction selectivity and binocularity. An even larger sample (or one generated with computer assistance) could enable us to describe these differences more quantitatively. Taken together, the MD kitten and the strabismic kitten allow us to state confidently that ocular dominance cannot be shifted with the blinking dot conditioning, as it could in our control kittens reared in normal light, and in the kittens studied by others (MD: Wiesel & Hubel, 1963; Olson & Freeman, 1975; strabismus: Hubel & Wiesel, 1965; Van Sluyters & Levitt, 1979, for example).

ON-OFF responses. We were surprized that blinking-dot-conditioning seemed to have little effect on cortical neurons'

preference for moving versus stationary flashed targets. We knew that Daw & Wyatt (1976) had been able to change the direction preference of area 17 kitten neurons, by unidirectional rearing, and that Cynader et al. (1973) had found 13% of strobe reared kitten neurons to respond to strobe flashes only. Apparently selectively exercising ON-OFF circuits is not able either to increase the basic ON-OFF responses of cortex, or to diminish the responses to motion (other than to eliminate direction selectivity) in any significant way.

Comparison to results of previous dot-rearing. For ten years the brief reports by Pettigrew & Freeman (1973) and Van Sluyters & Blakemore (1973, and see Blakemore & Van Sluyters, 1975 p.691) have stood as the only documentation that cortical neuron receptive fields can be influenced by an environment restricted to small point sources of light. That work, in turn, serves with the stripe rearing research (Hirsch & Spinelli, 1970; Stryker & Sherk, 1975; Blakemore, 1977; Gordon et al. 1979; Van Sluyters, 1981 p.50 and see Movshon & as the only solid evidence that pattern vision can shape the responses of developing cortical neurons. The most important aspect of the shaping by dot experience, in their work and the work reported here, is the preference of cells for small spots moving anywhere in a normally sized RF. This is in contrast to the situation after normal development in which cells respond optimally to elongated bars moving in preferred directions (Hubel & Wiesel, 1962). Even in dark-reared kittens, those cells which remain visually responsive prefer larger than smaller stimuli--though without direction preference(Pettigrew, 1974).

With respect to the mechanism for the small size preference, Van Sluyters & Blakemore--who used fairly large dots, 1°-9°, for

conditioning--stated that cells "responded just as well to a spot" as to an elongated bar, whereas Pettigrew & Freeman found that "enlarging or lengthening the stimulus to match the field shape always led to a diminished response". Pettigrew & Freeman, like us, conditioned with small (less than 1°) spots. Seemingly, surround inhibition reveals itself more effectively after conditioning with very small spots.

Both of the 1973 reports are based on kittens which received about 50 hr each of conditioning. Data in their papers suggest about 20% of their units were not visually responsive. Our kittens, which averaged over 500 hr dot experience, had less than 10% non-visual units.

Only Blakemore & Van Sluyters (1975) mention any effect of dot-rearing on binocularity, and theirs was a <u>decrease</u> in the percentage of binocular units encountered, instead of the increase we saw with our five kittens. With many spots--none of which blink--in their conditioning cylinders, Blakemore & Van Sluyter's kittens were, presumably, less interested in fixating any particular spot, whereas our kittens' visual choice consisted of <u>only one blinking</u> spot, which may have compelled more episodes of binocular fixation. We are planning to test this notion by rearing kittens viewing two or more simultaneously blinking spots.

<u>Comparison to previous results of strobe rearing.</u> The previous reports of strobe rearing (Cynader <u>et al.</u>, 1973; Olson & Pettigrew, 1974;
Cynader & Chernenko, 1976; Pasternak & Movshon, 1980) emphasize a lack of directionally selective neurons in such kittens. Our blinking dot-rearing also produces such neurons. Strobe rearing seems

also to cause a significant minority of units to develop very good responses to flash stimuli, including the strobe flash itself. Without actually having recorded from strobe reared kittens in our lab, our impression is that ON-OFF responses, or responses to small blinking spots, in dot-reared neurons, is not much different from normal. Perhaps ON-OFF responses are difficult to change from their genetic predispositions unless the strong stimulus of full field strobe flash is used for conditioning.

The strobe rearing reports tend to compare the experimental animals with normally reared animals in order to draw distinctions but, as Movshon & Van Sluyters (1981) point out, comparison with dark-reared kittens may be more appropriate, because strobe- and dark-reared kittens have much in common. Strobe kittens do, however, have fewer non-visual units, and at higher strobe rates (8 hz, see Cynader & Chernenko, 1976) show good orientation selectivity. "Orientation selectivity"means preference for elongated bars over spots. Our blinking dot-reared kittens show the opposite (and also different from dark reared) preference, of small spots to any sort of larger target.

Binocularity. Strobe-reared kittens, unlike our blinking-dot reared kittens, have fewer binocular units than normal. Eye alignment in strobe reared kittens is also substantially abnormal (Olson & Pettigrew, 1974). It should be noted that even considering that our samples of neurons from normal and dark reared kittens (Fig. 8) have somewhat more monocularity than usually reported, our dot-reared kittens still exceed those usual values (Hubel & Wiesel, 1962) in percentage of binocular--especially gp 4--units.

The continuance of binocularity in dot-reared kittens with MD or strabismus presents us with the opportunity to increase the pattern complexity of subsequent dot-reared kittens, until we discover a boundary condition for disruption of binocularity. Such a condition will be able to be described in precise visual terms--spatial frequency composition, blink rate, number of independent dots, etc. With the data base of the present report as a starting point, dot-reared kittens should be able to continue contributing to our knowledge of development of the visual cortex. In fact, considering that external stimulation of visual cortex as an aid to the blind (Brindley & Lewin, 1968; Dobelle & Mladejovsky, 1974) results in point-like phosphene sensations, continued study of point source random dot effects in cortex may contribute to the design of visual prostheses.

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FIGURE CAPTIONS

FIGURE 1. Repeatable random sequence generator circuit. Outputs from the last two D-flip-flops of a 15-stage shift register are combined at an exclusive-OR gate then (1) fed back to be the input to the first flip flop, and (2) used to trigger (with rising edge) a one-shot timer with a 7 msec duration output. The one shot output drives a green (540 nm) light emitting diode (LED) with 20 mA of current. The sequence repeats every 32,767 clock pulses. The clock runs at 2 Hz. The LED flashes randomly with an average period of 1.1 sec. The system was constructed with integrated circuit chips powered by 200 mA of current at 5 volts.

FIGURE 2. Preferred stimulus size for visual cortex neurons from three kinds of kittens. Stimuli were circular targets of about 0.8 contrast. Responses were judged by listening to filtered spikes on an audio monitor. Stimuli were moved through receptive field (RF) at about 1 degree/sec while judgement was made. One of six categories ($<\frac{1}{4}^\circ$ thru $>4^\circ$ diameter) was selected. If response showed no preference for stimulus it was not included in data base. If response were equal over several categories, the middle category was selected. Sample size: Dot-reared -- 113 units with preferences, 37 without preferences, not shown. Normal -- 68 with, 12 without preferences. Dark reared -- 50 with, 31 without preferences. Note that 80% of dot-reared neurons preferred the smallest stimulus.

FIGURE 3. Receptive fields sizes for visual cortes neurons from three kinds of kittens. RF boundaries were determined by moving an optimally sized spot or bar in direction of preference (if any, see Fig. 7). Judgements were made by listening to audio monitor. RF shape was drawn for each neuron in the data base, and area measure-

ments, in $(deg)^2$, were computed after all data had been collected. For sake of display each area was placed in one of five categories (from less than 1 $(deg)^2$ to more than 16 $(deg)^2$). Approximately same number of samples as in Fig. 2 data base (cells with no size preference were excluded). All three kinds of kittens have about the same RF size distribution, with the dot-reared group having a somewhat lower average. Averages: Dot -- 5.6 $(deg)^2$; Norm -- 8.3 $(deg)^2$; Dark -- 8.2 $(deg)^2$.

FIGURE 4. Example of size inhibition in a dot-reared kitten neuron. This cell had a RF size of 18 deg^2 (3 X 6). When a 1° X 3° bar was swept 32 times back and forth through the field, at 1°/sec, the histogram on the left was generated (10 msec bins). When the size was increased to 1° X 8° the lack of response to the same 32 sweeps is shown on the right. Size inhibition of this sort for orientation selective units in visual cortex is usually labelled "hypercomplex". In this case the unit had no preference for stimulus direction, but did prefer movement to ON-OFF flashes.

FIGURE 5. Comparison of responses to moving vs stationary flashed stimuli for three kinds of kitten. Cells were grouped as: M -- clear preference for movement over flash; M=F -- responses to moving and flashed stimuli were the same, within a factor of two, as judged by listening to the audio monitor; F -- clear preference for flashed over moving stimuli; NV -- no visual response. In each case an optimally sized circular target (see Fig. 2) was used. If the cell showed a direction preference, that direction was used for movement. Sample sizes: Dot -- 213 units; norm -- 127 units; dark -- 114 units. Note that in spite of having been conditioned only by

flashing stimuli, the dot-reared neurons which prefered flash comprised only 20% of dot-reared population. Note also that 30% of dark reared neurons are not visualy responsive.

FIGURE 6. Example of stimulus movement preference in a dot-reared neuron. On the left is the response histogram for 32 sweeps of a $1\frac{1}{2}^{\circ}$ spot moved at 10°/sec through the receptive field (10 msec bins). On the right is the lack of response to the same size stimulus flashed ON and OFF at a 0.5 Hz rate 32 times. The unit had a broad preference for speed, responding from $\frac{1}{2}^{\circ}$/sec up to 30°/sec. No direction preference was seen in this unit.

FIGURE 7. Summary of selectivity categories for three kinds of kitten. A = aspecific, no preference for direction of stimulus movement; I = immature, unit responds to all directions but prefers one axis or direction by at least a factor of two; S = selective, unit does not respond at all to some direction of stimulus movement, usually orthogonal to preferred direction. As shown in the middle graph, normally reared kittens develop neurons 90% of which are selective. Dot-reared and dark-reared kittens have very few selective units. These samples do not list the nonvisual percentage, shown in Fig. 5.

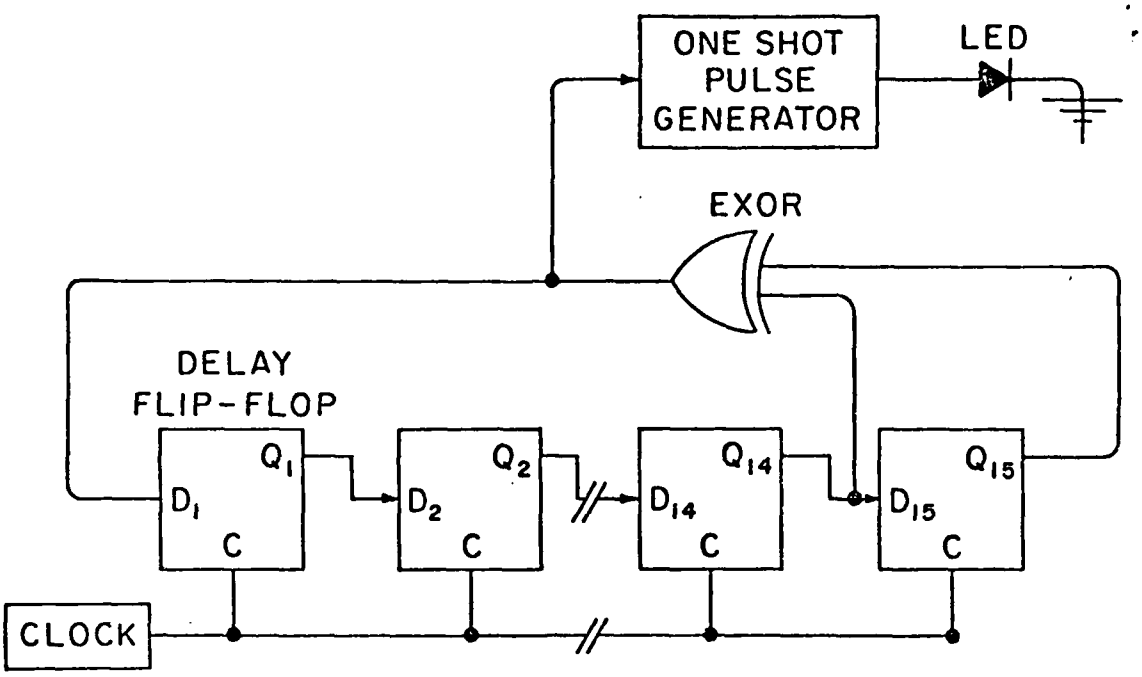
FIGURE 8. Summary of ocular dominance for three kinds of kitten. The seven category scheme of Hubel & Wiesel is used. Group 1 units are driven only by the contralateral eye, group 7 only by the ipsilateral eye, while group 4 units are, within a factor of two equally driven by stimulation through either eye. In every case, one eye is covered while the other is tested. We found more binocularity in our dot-reared kittens than in the normal or the dark-reared.

(More group 4's, fewer group's 1 and 7.) In each kind a slight contralateral bias is also seen.

FIGURE 10. Ocular dominance of strabismic and monocularly deprived (MD) kittens. Same seven group classification scheme is used here as in Fig. 8. On the right are ocular dominance graphs from two normally reared kittens recorded in our lab. They show the expected non-binocular distributions: U-shaped for the strabismic (unilateral medial rectus section) and one-sided for the MD (one week duration at six weeks of age). On the left are graphs from two dot-reared kittens given the same strabismus and MD (in the MD case, the duration was five weeks instead of one week). Both kittens showed significant numbers of binocular (group 4 especially) neurons. The dot-reared MD kitten had a shift to the opened eye, but not nearly as complete as the normally reared control.

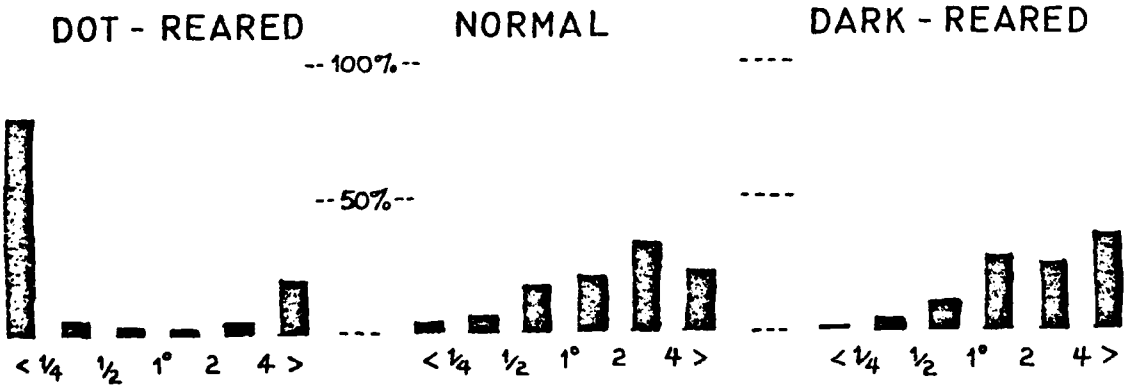
FIGURE 9. Binocular alignment for the three kinds of kitten. Alignment was determined at the time of recording, after paralysis had allowed the eyes to relax to a stationary gaze. Zero divergence would represent area centralae projecting straight ahead to the tangent screen, separated by the 3-4 cm inter-ocular distance. Non-zero divergence is the sum of the deviations of the two eyes' area centralae projections away from the (zero) expected gaze. The five binocular viewing random dot kittens have their respective alignments (including two cross-eyed cases) shown in circles on the top row. For the normal and dark-reared cases shown on the next two rows, we include additional measurements from six kittens used in other studies in our lab, in order to show data from five

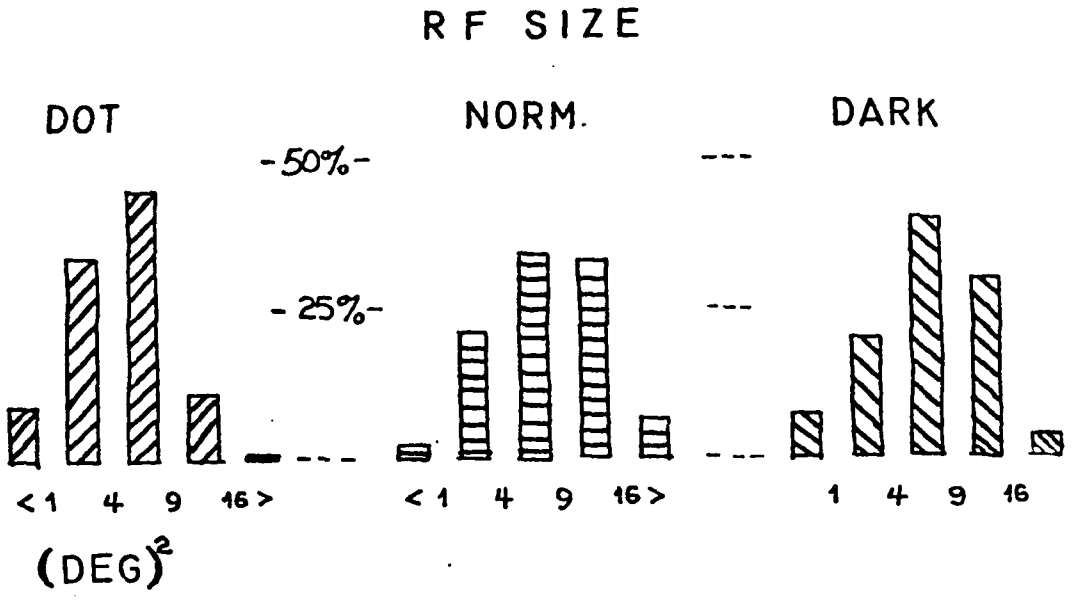
kittens for each category. Note the considerable scatter in the dot-reared group, and the resulting average alignment which is closest to zero of any of the three groups.

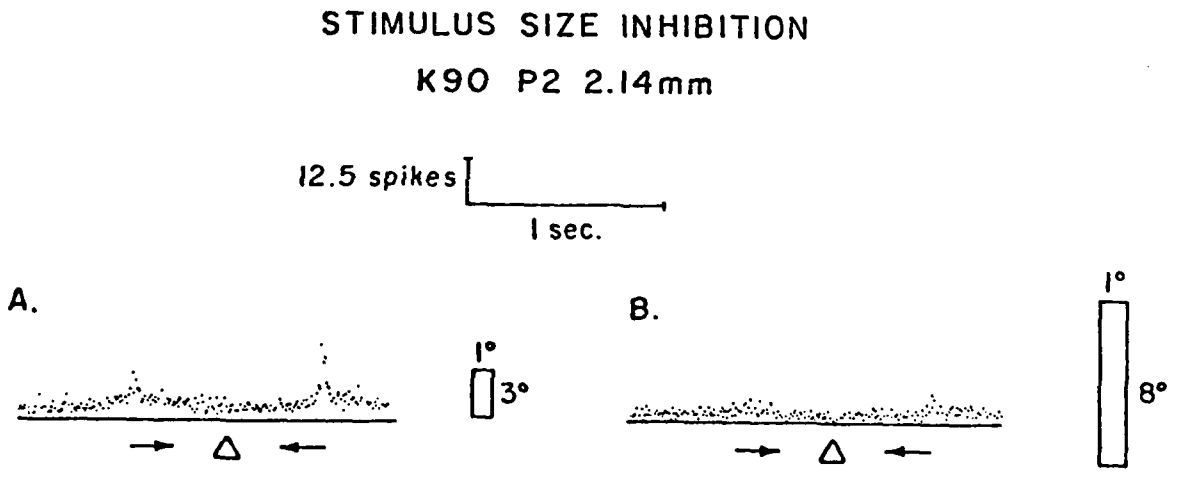


RANDOM REPEATABLE SEQUENCE GENERATOR

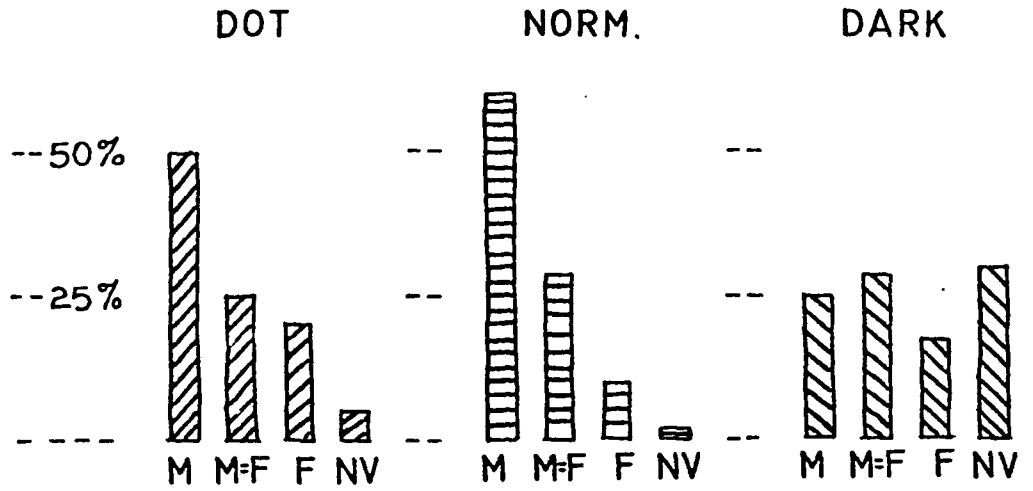
PREFERRED SPOT STIMULUS SIZE




RF SIZE
DOT
NORM.
DARK
-50%-
-25%-
< 1 4 9 16 >
< 1 4 9 16 >
1 4 9 16
(DEG)²

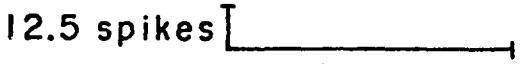

STIMULUS SIZE INHIBITION
K90 P2 2.14mm
12.5 spikes
1 sec.
A.
1°
3°
B.
1°
8°

MOVEMENT VS. FLASH



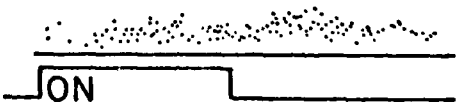
MOVEMENT FLASH

K94 P2 2.80mm

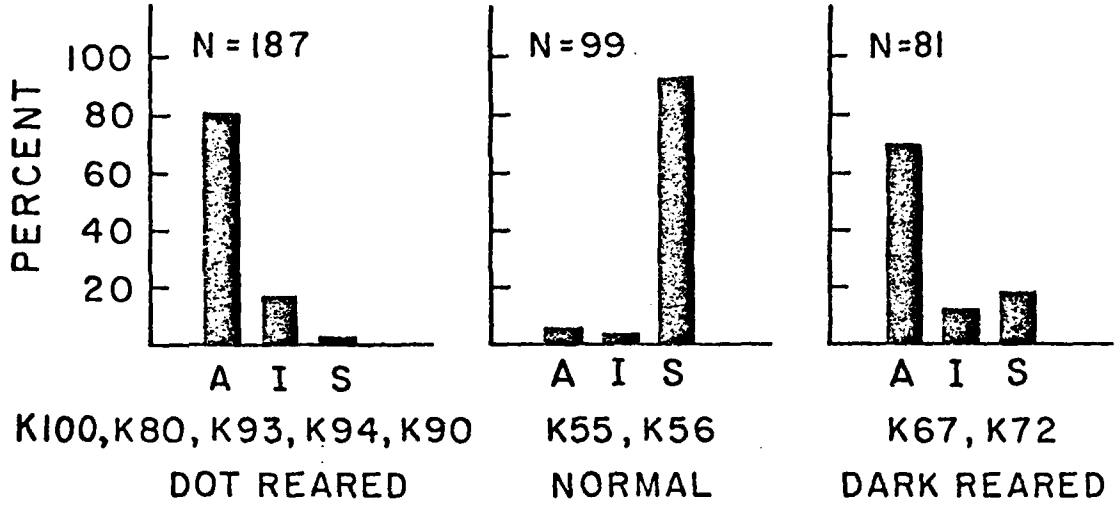


A.

B.



SELECTIVITY - SUMMARY

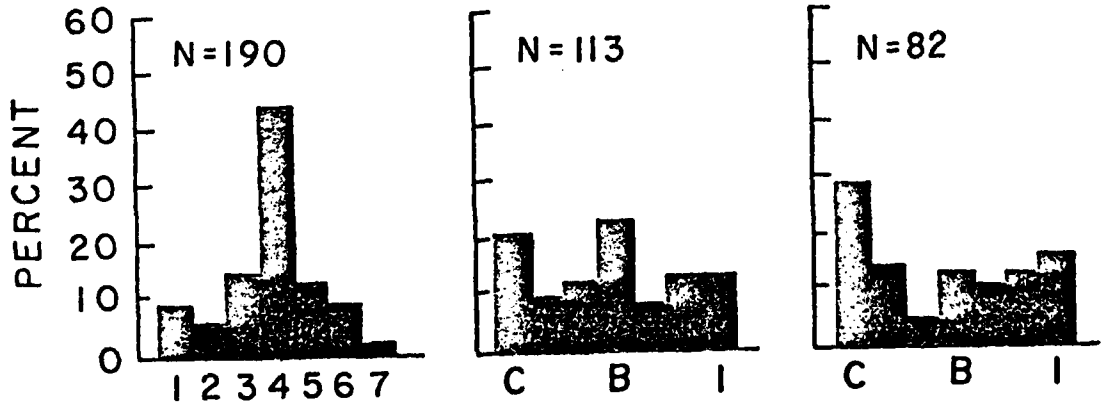


K100, K80, K93, K94, K90
DOT REARED

K55, K56
NORMAL

K67, K72
DARK REARED

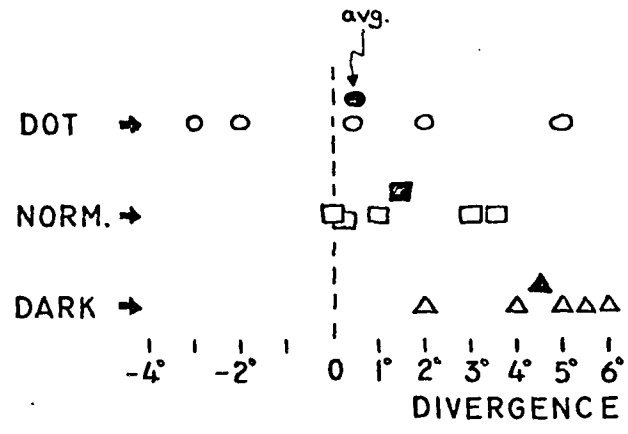
OCULAR DOMINANCE - SUMMARY

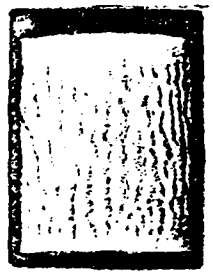


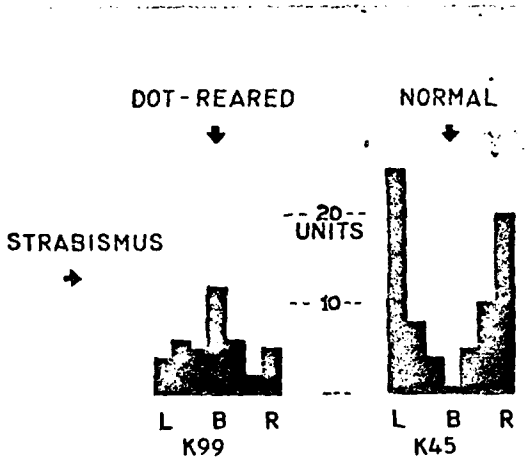
K100, K80, K93, K94, K90
DOT REARED

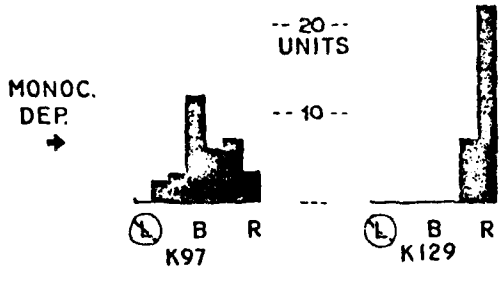
K55, K56
NORMAL

K67, K72
DARK REARED


BINOCULAR ALIGNMENT
avg.
DOT
NORM.
DARK
-4°
-2°
0
1°
2°
3°
4°
5°
6°
DIVERGENCE




DOT-REARED
NORMAL
STRABISMUS
20
UNITS
10
L B R
K99
L B R
K45


20
UNITS
MONOC.
DEP.
10
B R
K97
B R
K129