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The possible induction of diabetes insipidus in chicks by regulated light regimes

Cindy Cox Wilson

To the Graduate Council:

I am submitting herewith a thesis written by Cindy Cox Wilson entitled "The possible induction of diabetes insipidus in chicks by regulated light regimes." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Animal Science.

Robert L. Tugwell, Major Professor

We have read this thesis and recommend its acceptance:

H. V. Shirley Jr., W. D. Barber

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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and recommend its acceptance:

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THE POSSIBLE INDUCTION OF DIABETES INSIPIDUS IN CHICKS BY REGULATED LIGHT REGIMES

A Thesis

Presented for the

Master of Science

Degree

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Cindy Cox Wilson

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ABSTRACT

Diabetes insipidus is caused by the lack of water reabsorption in the kidneys. Water reabsorption is regulated by the antidiuretic hormone. Experimentation has resulted in the concept that the production of the avian antidiuretic hormone (arginine vasotocin) occurs in the neurosecretory nuclei of the hypothalamus. This hormone is stored in the posterior pituitary until its release is stimulated by light. The purpose of this experiment was to evaluate the effects of three light regimes (i.e., (1) 24-hours light, (2) 12-hours light: 12-hours darkness, and (3) 24-hours darkness) upon the production of diabetes insipidus in cockerels measured by water consumption.

The results of the experiment indicated that there was a significantly greater water consumption in the constant light and constant darkness regimes. The production of an extremely watery diarrhea coupled with the differences in water consumption in these two regimes led to the conclusion that diabetes insipidus can be produced by altering the light regime of birds.

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CHAPTER I

INTRODUCTION

All living things inhabit a world filled with rhythmic changes; rhythmic alteration is characteristic of all biologic life. In the natural habitat, organismic rhythms are strictly 24 hours in length; they are "locked" or "entrained" to this pattern by the daily light-dark cycles generated by the rotation of the earth on its axis. When plants or animals are placed under constant conditions, the rhythm persists; however, the length of the period is slightly longer or shorter than 24 hours. Halberg (1959) defined this time period as circadian (circa, about; dies, day), i.e., about a day in length.

Prior work showed that circadian rhythms may not be established in constant illumination or constant darkness. Further work has shown that the absence of a circadian rhythm due to constant light or constant darkness will result in abnormal hormone balances. One such hormone affected is arginine vasotocin, the antidiuretic hormone (ADH) of birds. Previous experimentation at The University of Tennessee indicated that diabetes insipidus may be produced under constant light regimes. The purpose of this experiment was to evaluate the possibility of inducing diabetes insipidus by regulation of the light regimes.

CHAPTER II

REVIEW OF LITERATURE

Definition of Terms

The terms "rhythm," "cycle," and "periodicity" were used indiscriminately in the past. Kleitman (1949) attempted to separate and define these terms by restricting "rhythm" to regularly recurring quantitative changes in some variable biological process. According to Kleitman, "Two conditions are necessary to make such a recurring stage into a rhythm: (a) it must be extrinsic in origin, depending upon a regular change in the environment, such as light or temperature, usually associated with terrestrial or cosmic periodicity, developing in each biological system de novo; and (b) when fully established, it must persist for some time, even when the environmental changes are absent. Except that the regulating system need not be nervous, a rhythm may be likened to a conditioned response, which is also individually acquired and depends on an extrinsic reinforcement for its establishment, yet will persist for a shorter or longer period of time in the absence of such reinforcement."

Park (1940) subdivided "rhythms" into two categories; "exogenous" rhythms which were a direct response to physical changes in the environment and which did not persist when conditions were kept constant and "endogenous" rhythms which continue under constant conditions.

Endogenous rhythms have been correlated with environmental changes

even though they were not necessarily a direct response to them. Halberg (1953) offered the idea of an innate endogenous rhythm synchronized by changes in environmental factors such as light or temperature. Since the rhythm was not a direct response to these environmental influences, such factors were referred to as "synchronizers." Cloudsley-Thompson (1952) used "clues" and Aschoff (1954) used Zeitgeber (time-giver) to indicate a corresponding term.

Kleitman used the term "cycle" to represent repetitive series of events or successive changes of state, each with the characteristic feature that the sequence of occurrence instead of the duration tended to be constant.

Periodicity, like rhythm, was described (Kleitman, 1949) as being directly dependent on environmental changes. However, it showed no persistence of variation when environmental conditions were made uniform. The regularity, or lack of it, was a result of the variation with which it was coupled.

For future use, the terms "rhythm," "cycle," and "periodicity" are regarded as synonymous (Cloudsley-Thompson, 1961) when applied to biological phenomena.

Historical Development

A majority of the behavorial and physiological properties of an organism show rhythmic variation with a daily repetition. Although some of these rhythms may be driven by the external environment, an increasing body of evidence indicates that most of the daily rhythms appear to be endogenous and are merely synchronized by the environment

(Aschoff, 1965). Under natural conditions the 24-hour period is synchronized with the period of the earth's rotation by means of periodic factors in the environment called Zeitgebers. The day-night changes in light and temperature are the most dominant factors.

Many organisms, in addition to daily or circadian rhythms, also exhibit seasonal rhythms. Garner and Allard (1920) discovered that daylength was involved in the control of seasonal morphogenesis. This discovery initiated extensive experimental work in photoperiodism and eventually led to the conclusion that daylength was primarily responsible for the timing of the seasonal responses of many plants, insects, and animals.

Many instances have been recorded which indicate that light is a synchronizing agent of circadian rhythms and that it furnishes organisms with a reliable clock by which physiological functions may be scheduled. Laboratory studies have shown 24-hour rhythms in most animals. These rhythms were expressed as locomotor activity (Johnson, 1926), oxygen consumption, ovulation (Aschoff, 1955), or in changes in the constituents of the blood (Halberg and Howard, 1958), excretory products (Lobban, 1960), or body temperature (Halberg and Visscher, 1954).

Specifically, a lighting regimen was shown to be responsible for controlling the timing of eosinophil rhythms as well as activity rhythms in mice and other experimental animals (Halberg and Howard, 1958). A shift in the timing of daily periods displaced the daily rhythm. Halberg, et al. (1951), also demonstrated a circadian rhythm in the eosinophil level of circulating venous blood of normal males.

This rhythm persisted under conditions of limited and unlimited activity. Webb and Brown (1959) were not able to find this rhythm in the blood of patients with hypopituitarism or a history of bilateral adrenalectomy.

Light partially or completely inhibits movement and other activities in some animals. Euglena ceased to exhibit a rhythm of photostatic sensitivity in continuous light (Bruce and Pittendrigh, 1954); the activity of Convoluta ceased in continuous light (Bohn, 1903); fireflies did not flash in continuous light (Perkins, 1931). Brett (1955) found that continuous light suppressed the emergence rhythm in Drosophilia.

Among the vertebrates, there are many examples of inhibitory effects of constant light or darkness. Constant illumination inhibited the color of the lamprey (Young, 1935). The ability of the lizard to change color was abolished by continuous light (Rahn and Rosendale, 1941). Continuous illumination was responsible for the decreased nocturnal activity of the rat (Slonaker, 1907; Richter, 1922). It was discovered, however, in wild mice (Johnson, 1926), voles (Davis, 1932), dancing mice (Wolfe, 1930), and bats (Griffin and Welsh, 1937) that constant darkness did not abolish a previously established diurnal activity rhythm. In mice reared in continuous darkness from birth, a diurnal activity rhythm was not developed (Wolfe, 1930). Sollberger (1965) stated that under constant lighting conditions, there can be no synchronizing action of a circadian rhythm. Individuals maintained under constant conditions often do not exhibit any circadian rhythms.

Although light intensity appeared to have a noticeable effect on circadian rhythms, it seemed that the alteration of light and darkness

was the primary factor that determined the form of the rhythm (Harker, 1958).

Galbraith and Simpson (1905) reported the following characteristics of diurnal temperature variations in birds: (1) dependence on activity habits; (2) higher temperatures in females than males; (3) greater diurnal range in the smaller birds. Other investigators (Hilden and Stenback, 1916; Baldwin and Kendeigh, 1932) reversed the diurnal body temperature rhythm of birds by inverting the light-dark cycle.

There is extensive literature on the physiological events related to the sex cycle. Bissonnette (1936) reviewed the literature on sexual photoperiodicity usually displayed by seasonal breeders. In most cases, the increased proportion of daylength during the spring was responsible for gonadal development in both sexes. Bissonnette (1938) also demonstrated that the gonadal stimulating effect of light upon the ferret was accomplished through the eyes. Further investigation revealed that impulses from the eyes were transferred to the anterior lobe of the hypophysis.

In 1954, Fraps experimented with estradiol benzoate injections into regularly ovulating hens. Fraps concluded that the neural mechanism, which was thought to control the release of ovulation-inducing hormone, follows a 24-hour rhythm in its response to other excitatory hormones.

Shaw (1933) discovered a 24-hour rhythm in the number of polymorphonuclear leucocytes in pigeons. Kramer (1952) and Hoffman (1954)

demonstrated the existence of a "biological clock" in birds which was used for celestial navigation. Investigators (Hoffmann, 1953; Matthews, 1955) later found that this "clock" was dependent upon the light-dark cycle.

Bunning (1972) stated that diurnal light-dark cycles were the most important synchronizers of circadian rhythms in animals. He further stated that it seemed that light never affected the circadian clock directly but through complicated pathways. "In vertebrates it affects the clock via light-reception in the eye."

The mechanism of photoperiodic gonadal response has been studied extensively (Benoit, 1957). Receptors seemed to be both retinal (Hamner, 1963, 1966) and encephalic (i.e., hypothalamic and rhinencephalic). Other essential elements are neurosecretory cells in the supraoptic-paraventricular nuclear complex of the hypothalamus and their neurosecretion-bearing axons which extend to the glandular layer of the median eminence of the hypothalamus. Lesions in the supraoptic-paraventricular nuclei (Benoit, 1957) caused gonadal atrophy and the disappearance of neurosecretory material from the median eminence.

Although light focused directly on the hypothalamus or the pituitary evoked gonadal response in the duck (Benoit, 1957), light radiations acted primarily through the eye, which in turn stimulated the hypothalamus to produce neurohormones (Scharrer, 1964) from its neurosecretory cells which acted on target organs.

It has been demonstrated many times that light exerts a major influence on the reproductive functions of many vertebrates. Workers

have found that light stimulates the diurnal rhythm of hormonal secretions affecting these functions (Donovan and Harris, 1956; Fiske, 1941). They also found that the presence of an intact pituitary was necessary (Hill, 1933; Benoit, 1935). Critchlow (1963) stated that, "The integrity of the hypophyseal portal vessels is essential to the response to extra illumination."

It is generally accepted that synthesis and release of pituitary hormones exhibits a marked circadian rhythm. Data obtained by Retiene, et al. (1968), and Retiene and Schulz (1970) indicated that the rhythm of hormones such as adrenocorticotrophin (ACTH), vasopressin or vasotocin (ADH), corticosteroids, and thyrotrophic hormone (TSH) was completely synchronized and characterized by a peak prior to the onset of activity. Other researchers (Levinson, et al., 1941; Halberg, et al., 1959) discovered that the onset of activity was stimulated by light. Experiments were conducted (Calhoun, 1945; Calhoun, 1946; Fiske and Leeman, 1964; Sollberger, 1965) that indicated that the circadian rhythms of hypophyseal hormones were abolished in continuous light.

The Antidiuretic Substance

The occurrence of an antidiuretic substance in the avian neurohypophysis has been known for more than half a century (Sturkie, 1965). Sturkie (1965) demonstrated antidiuretic activity in the hypothalamus of the chick embryo at the ninth to tenth day of incubation. This antidiuretic substance was found to be arginine vasotocin whose primary function as the antidiuretic hormone (ADH) in chickens (Sturkie, 1965)

was upon epithelial cells of the distal portion of the renal tubule. ADH was responsible for the reabsorption of water by these epithelial cells.

Researchers (Scharrer and Bargman, 1954; Utiger, 1968; Sturkie, 1965) established the concept that vasotocin is a neurosecretory product which is produced by the paired supraoptic and paraventricular nuclei of the hypothalamus and travels through the neurosecretory tract to be stored in the median eminence and the neural lobe of the bird's hypophysis (Farner and Oksche, 1962). A deficiency in the secretion of ADH is considered to be the cause of diabetes incipidus (DI) (Dalling, 1966).

Diabetes insipidus refers to a condition characterized by polydipsia and polyuria with an inability to concentrate the urine or to conserve water (Wheeler and Adelson, 1964; Dalling, 1966). Since an animal is usually not born with this disease but rather develops it later in life, it was presumed (Lazarow, 1949) that metabolic and environmental factors influenced the onset of DI. It was discovered that there were a variety of functional disorders (Wheeler and Adelson, 1964) that underlie this condition: (1) the destruction of normal sites of ADH production, (2) the failure of ADH production for an unknown reason, (3) a primary renal tubular ADH unresponsiveness associated with other renal tubular defects, (4) polyuria secondary to copius fluid intake, and (5) the lack of normal ADH release in response to plasma hyperosmolality (hypothalamic DI) (Dunson, et al., 1972).

Other experimental work indicated that DI could be induced by the partial (Verney, 1947) or total removal of the posterior pituitary (Richter, 1934-35). Destruction of the hypothalamo-hypophyseal tract or lesions made in the hypothalamus also resulted in DI.

Generally a pattern of urine excretion is formed after the ADH balance is upset: (1) immediate diuresis reaching a maximum within four days, (2) an interphase of approximately 12 days with a normal urine flow, and (3) permanent polyuria (Laslo and de Wied, 1966; Coggins and Leaf, 1967; Brook, Radford, and Stacy, 1968).

CHAPTER III

METHODS AND MATERIALS

Rhode Island Red cockerels obtained from a local hatchery were used in this experiment. At one day of age, the chicks were placed in each of five sections of the three electrically heated brooders and allowed feed and water ad libitum. The temperature in the brooders was maintained at 90°F for one week and dropped 5°F each week thereafter until 70°F was reached.

Three light regimes were utilized: 24-hour (24-hr.) light, 12-hours light:12-hours darkness (12:12), and 24-hours (24-hr.) darkness. The light regimes were maintained in separate rooms; each regime represented a different treatment and each was replicated five times. The experimental units (plots) were single compartments. The results were evaluated with the analysis of variance for a completely randomized design.

Chicks were grown for a period of six weeks. They were fed and watered at random times during each 24-hr. period to eliminate the possible establishment of a circadian rhythm. Feed (Table 1), a chick starter mash, and water were weighed and consumption was measured daily.

Water consumption was measured by determining the quantity necessary to restore the original level in the container. This measurement was considered to be equivalent to water consumption after

TABLE 1

EXPERIMENTAL DIET

Feedstuff	Amount
Yellow corn	63.80
Alfalfa meal, 17%	2.50
Fish meal	2.50
Soybean oil meal, 50%	25.50
Ground limestone	0.60
Defluorinated rock phosphate	1.50
Salt	0.48
Manganese sulfate	0.02
Vitamin mix	0.02
Coccidiostat premix	2.50
Calculated analysis:	
Crude protein, %	21.54
Productive energy, C/lb.	943
Methionine, %	0.408
Cystine, %	0.313
Calcium, %	0.960
Phosphorus, %	0.692
Available phosphorus, %	0.449
Manganese, mg./lb.	31.2
Vitamin A, I.U./lb.	5349
Vitamin D, I.C.U./lb.	340
Riboflavin, mg./lb.	3.01
Niacin, mg./lb.	27.78
Pantothenic acid, mg./lb.	6.67
Choline, mg./lb.	718.0

determining that the evaporation rate was negligible in all three treatments.

In past experimentation with diabetes insipidus in poultry, the inception of the disease was measured by the amount of urine production in surgically altered birds. Since birds with diabetes insipidus must exhibit a significantly increased water consumption, it was decided to use water consumption in surgically unaltered birds as the primary data source.

CHAPTER IV

RESULTS AND DISCUSSION

I. RESULTS

Water Consumption

Means of the water consumption within each treatment were compared by analyses of variance. These means and the resultant F ratios are given in Table 2.

During the first two weeks, water consumption differed at the .05 probability level. Birds in the 24-hr. light regime consumed significantly more water than those birds in either of the other two treatments. The birds subjected to 24-hr. darkness drank more water than the 12:12 regime.

During the second two week period, the birds in the 12:12 group again drank less water than the other two groups of birds; however, this difference was not significant.

During the final two-week period, the birds in 24-hr. darkness consumed more water than the birds in the 12:12 group. The birds in 24-hr. light were intermediate to, but not significantly different from, the other two treatments.

The total water consumption during the six weeks period also differed significantly, whether based upon a per bird or per gram bird weight basis. Both measurements were significantly greater for the 24-hr. darkness and the 24-hr. light than for the 12:12.

TABLE 2

MEANS AND F RATIOS FROM ANALYSIS OF VARIANCE COMPARISONS OF WATER CONSUMPTION BY COCKERELS EXPOSED TO DIFFERING LIGHT REGIMES

Measurement	Treatment Mean			F Ratio
	24-hr. Light	12:12	24-hr. Dark	
Milliliter of water per bird				
First two weeks[1]	605.4[a]	426.1[c]	510.4[b]	26.40***
Second two weeks[2]	917.8	843.5	975.1	2.21
Third two weeks[1]	1710.9[ab]	1444.3[b]	1927.5[a]	5.78*
Total (six weeks)[1]	3250.2[a]	2709.8[b]	3328.6[a]	6.55*
Milliliter of water per gram bird weight				
Total (six weeks)[1]	5.54[a]	4.37[b]	5.50[a]	8.60*

[1]Means not followed by the same letter were judged different at the .05 probability level using Duncan's New Multiple Range.

[2]Means for water consumption during the second two-week period were not significantly different at the .05 probability level.

*,***Denote significance at the .05 and .001 probability levels, respectively.

Feed Consumption

Means of the feed consumption from each treatment were compared by analyses of variance. These means and the resultant F ratios are given in Table 3.

During the first two weeks, the birds in 24-hr. darkness consumed significantly more feed than either the birds in 24-hr. light or 12:12. The birds in 24-hr. light ate more feed than the birds in 12:12; however, this difference was not significant.

The birds in 24-hr. darkness were significantly different from the other two treatments during the second two weeks. The birds in the 24-hr. light group consumed a greater amount of feed than did the birds in the 12:12 regime; however, this difference was not significant.

During the third two weeks, the means of feed consumption were found to be significantly different at the .05 probability level. Birds in the 24-hr. light regime consumed significantly more feed than those birds in either of the other two treatments. The birds in the 12:12 regime ate more feed than the birds in constant darkness.

The total feed consumption during the six week's period showed that birds in 24-hr. light consumed significantly more feed than birds in either of the other two treatments. This relationship held true on both a per bird and a per gram bird weight basis.

Physical Symptoms

Birds grown in 24-hr. darkness excreted a yellowish-white liquid fecal material in large quantities. Closer examination revealed that there was comparatively little solid waste material, just the liquid

TABLE 3

MEANS AND F RATIOS FROM ANALYSIS OF VARIANCE COMPARISONS OF FEED CONSUMPTION BY COCKERELS EXPOSED TO DIFFERING LIGHT REGIMES

Measurement	Treatment Mean			F Ratio
	24-hr. Light	12:12	24-hr. Dark	
Gram of feed per bird				
First two weeks[1]	567.6[b]	502.6[b]	674.0[a]	31.61***
Second two weeks[1]	442.5[a]	390.4[a]	274.2[b]	16.72***
Third two weeks[1]	482.7[a]	450.1[b]	380.9[c]	8.63**
Total (six weeks)	1460.0[a]	1379.5[b]	1336.6[b]	1.49**
Gram of feed per gram bird weight				
Total (six weeks)[1]	2.5[a]	2.2[b]	2.2[b]	17.81**

[1]Means not followed by the same letter were judged different at the .05 probability level using Duncan's New Multiple Range.

,*Denote significance at the .01 and .001 probability levels, respectively.

material. Birds grown in 24-hr. light also excreted a yellowish-white liquid fecal material. It appeared, however, that the water content in the feces of the birds in 24-hr. light was not as high as it was in the feces of the birds in 24-hr. darkness birds. Birds grown in the 12:12 regime excreted a solid brownish-white fecal material which appeared to have the lowest moisture content.

The weights of the birds grown in 24-hr. darkness were significantly less than the weights of the birds in either of the other two treatments.

II. DISCUSSION

The data represented by water consumption supports the concept of induction of diabetes insipidus by controlling the ADH circadian rhythm by means of a light regime. Birds in 24-hr. darkness appeared to consume water not only significantly greater, but also in the typically diabetic pattern (i.e., (1) an immediate diuresis reaching maximum within approximately four days, (2) an interphase of approximately 12 days with a normal urine flow, and (3) a permanent poluria).

Contrasting the water consumption pattern of birds in the 24-hr. light regime to those in the normal (12:12) light regime reveals significantly greater water consumption during the first two weeks. This would be expected if diabetes insipidus were induced shortly after exposure to continuous light and would represent the immediate diuresis. If this occurred early enough for the typical four day maximum to be reached prior to the end of the first two weeks of growth, the 12 day interphase of normal urine flow would prevent the appearance of a significant difference during the second two weeks. There was no

significant difference during the second two weeks. There was greater water consumption during the third two weeks in both the 24-hr. light and 24-hr. darkness regimes which differed significantly from the 12:12 group. This would correspond to the permanent polyuria phase of the disease. Since light received by the hypothalamus is the stimulating factor for the production and release of ADH, exposure to continuous light is believed to lead to an exhaustion of ADH. The timing of the phenomenon is not known, but exhaustion of ADH after four to 10 days of continuous light exposure seems realistic. This would permit the inception of diabetes insipidus and the completion of its initial cycle (which may take as long as four days) by the end of the first two weeks. The permanent polyuria phase would then commence approximately at the beginning of the third two weeks. This would account for the lack of water consumption difference during the second two weeks and the reappearance of the difference during the third two weeks.

Since the light stimulatory effect would be lacking in the 24-hr. darkness regime, ADH would not be produced in these birds. This should also result in diabetes insipidus; however, the disease should be induced very quickly after exposure to total darkness. Therefore, the disease would occur earlier in total darkness than in total light because the time period for exhaustion of ADH would not be a factor.

Since the birds in continuous darkness would incur the disease, pass through intermediate diuresis, and enter the interphase prior to the completion of the first two weeks, the permanent polyuria would

begin before the third two week period. This would explain the greater water consumption by birds in total darkness during both the second and third two week periods.

The postulation of the induction of diabetes insipidus is also supported by the production of copious urine-like fecal material of the birds raised under 24-hr. darkness and 24-hr. light regimes.

While there were significant differences within the feed consumption means, feed was not considered to be involved as a causative or secondary agent in inducing diabetes insipidus.

It was concluded that birds grown in either total illumination or total darkness developed diabetes insipidus.

CHAPTER V

SUMMARY

1. Rhode Island Red cockerels were grown under three different light regimes for six weeks in electrically heated battery brooders. Water consumption was measured to determine the possible induction of diabetes insipidus.

2. Water consumption was evaluated for each two week period of growing time. Both the 24-hr. light and the 24-hr. dark groups consumed more water than the 12:12 group during the first and third two week increments. A similar trend was observed during the second two weeks; however, it was not significant.

3. Total water consumption by birds in the 24-hr. light and 24-hr. darkness regimes was significantly greater than from birds in 12:12 on both a per bird and per gram bird weight basis.

4. Water consumption data collected supports the pattern of diabetes insipidus as observed in other experimental animals.

5. It was concluded that diabetes insipidus was induced in chicks by regulation of the light regimes. Diabetes insipidus was induced in both 24-hr. light and 24-hr. darkness.

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