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Effects of Varying Temporal Exposure to Lead on Behavioral Development in Herring Gull (*Larus argentatus*) Chicks

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BURGER, J. AND M. GOCHFELD. *Effects of varying temporal exposure to lead on behavioral development in herring gull* (Larus argentatus) *chicks*. PHARMACOL BIOCHEM BEHAV 52(3) 601-608, 1995.—In humans and other animals, lead exposure in infants and young animals affects anatomic, physiologic, behavioral, and intellectual development. Yet it is largely unknown whether the effects occur gradually or are more pronounced if exposure occurs at particular stages. In this article we examine the effects of temporal differences in lead exposure on early behavioral development in herring gulls (*Larus argentatus*). We randomly assigned 64 1-2-day-old gull chicks to one of four treatment groups to receive a lead acetate dose at age 6 days (100 μg/g) or 12 days (50 or 100 μg/g), or to receive matched volume saline injections on the same days. Behavioral tests were performed at 2-5-day intervals to examine locomotion, balance, righting response, thermoregulation, and visual cliff. Flight behavior was examined at fledging. Results were compared with previously studied exposures at 2, 4, and 6 days of age. Righting response and balance were disrupted immediately after exposure, regardless of the timing of exposure. Thermoregulatory, visual cliff, and individual recognition behavior were more affected by exposure at 2-6 days, and there was little effect with exposure at 12 days. These results confirm the existence of critical periods for certain behaviors to lead exposure in developing herring gulls.

Lead Postnatal Temporal Critical periods Gulls Behavioral toxicology

LEAD, derived from natural geochemical processes, urban and industrial pollution, and agricultural runoff, enters air, soil, water, and the biota of ecosystems. Significant contributors to current body burdens in humans include inhalation of air and dust, and ingestion of food and water (30,31). Human blood lead levels have decreased in recent years as a result of the decreased use of lead paint and leaded gasoline (3). Nonetheless, lead levels are increasing in some cohorts of children (2). Continued concern has prompted the United States Environmental Protection Agency to propose a zero level for lead in drinking water and to regulate lead as a carcinogen (25).

Lead exposure poses a serious threat to humans and other primates, mammals, birds, and other animals because it causes neurobehavioral, hematologic, nephrotoxic, and reproductive effects (5,32,34). Lead at low doses is still problematic for human infants and children (35) and may lead to retarded psychomotor and intellectual development for other mammals (1,7,23,29,38,39) and birds (4,6,12,14,15,24,28). Animals can serve as useful models to examine critical periods of exposure. Critical periods are characteristic of many aspects of development, and are important to processes such as teratogenesis and learning (36,41).

In this study, we examine the effects of lead exposure at ages 6 and 12 days on young herring gulls (*Larus argentatus*) to test for critical periods in neurobehavioral development. Birds share with humans a reliance on visual and vocal communication, making them useful indicators for the study of neurobehavioral toxicity. Moreover, birds can serve as bioindicators of overall ecosystem health, because many birds are the top trophic level. Birds have a relatively short neonatal development period when they depend on their parents for protection and the provision of food.

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Herring gulls are ideal for experiments because they are large and easy to raise in the laboratory, they adapt readily to handling, they eat a variety of foods, and there is a voluminous literature on their behavior (9–12,15,27,37). At 6 days of age, herring gulls are relatively sedentary, whereas at 12 days, the chicks move about their territory and are exposed to uneven terrain, unfamilliar surroundings, and aggressive neighbors. Behavioral deficits at 12 days of age might reduce survival.

This article complements work that examined effects of exposure from ages 2–6 days (19). We have shown differences in weight, individual recognition, locomotion, balance, righting response, visual cliff, and thermoregulation as a function of exposure from 2–6 days of age. Chicks injected at 6 days were significantly lighter at fledging than controls and 2-day lead-injected chicks. Lead injections for the 2-day-old chicks had a greater negative effect on locomotion, depth perception, and individual recognition than injections at a later stage. However, lead injection on day 6 had a greater effect than injections on day 2 for balance and thermoregulation. These experiments showed that for some behaviors, exposure at 2 days was more critical than that at 6 days; but for other behaviors, exposure at 6 days was more critical (18,19). The present experiments compared behavior at 6 and 12 days.

METHODS

Under appropriate federal and state permits, 64 1–2-day-old herring gull chicks were collected from colonies at Captree, Long Island, New York, and Barnegat Inlet Island, New Jersey, in early June 1993. Only the first hatched chick in any nest was collected, to minimize effects on reproductive success. Chicks were marked with numbered leg bands for identification and randomly assigned to a treatment or control group.

Chicks were housed in groups of two or three in cages until 35 days, when they were housed in a large flight cage. They were initially maintained in groups because in nature they are normally found in broods of two to three. Three to four times daily, they were fed a diet of high protein cat and dog food by only one research assistant to allow for normal imprinting. This caretaker fed each chick individually until the gull no longer wanted to eat, to ensure that no chick was deprived of food by competition with other cagemates.

Exposure

Chicks were given an intraperitoneal injection of lead acetate at 6 days (100 μg/g of lead in sterile water) or 12 days (half receiving 50 μg/g, half receiving 100 μg/g), or a normal saline solution. The initial dose was selected to be comparable to previous experiments; the half-dose was given at 12 days to reduce possible toxic effects of one large dose. Because the chicks grow rapidly between 6 and 12 days, and the same dose at the latter age would involve a much larger total injection, we had a cohort that received only a half-dose at 12 days of age. Control chicks were injected in the same manner as experimental ones.

Lead injection was performed by MG, not otherwise involved in the behavioral experiments, and the exposure regimen was not revealed to the persons performing the behavioral tests. Exposure was by injection rather than feeding, to ensure a standardized dose, as chicks normally eat different amounts of food and often regurgitate food with toxics.

Initially, there were 16 chicks in each of the three lead groups (6 and 12 days full dose, and 12 days half-dose), and 16 chicks in the control group. Over the course of the experiment, some chicks in all exposure groups died (two to five). This mortality was much less than what young gulls normally experience in the wild [30–60%, depending on the year, weather, and predation pressures (11)].

Testing

Some tests were performed every other day until 28 days, and on days 34 and 42 (righting response, balance, incline, and visual cliff). Others were performed every 3–4 days (actual cliff, thermoregulation, and individual recognition). The design was balanced with all groups being tested at the same ages. This combination of tests was used to evaluate balance, locomotion, depth perception, individual recognition, and thermoregulation. The tests that might involve habituation were performed less often. Normally, chicks were fed before tests were performed.

Although several assistants performed the tests, they were all blinded with respect to the lead status of the chicks. Further, the same assistants performed the same tests; that is, the same two people performed the thermoregulation and visual cliff experiments, and the same two people performed the other tests to avoid interobserver variability.

Prior to feeding, righting response was measured by putting the chick on its back and recording the time it required to right itself to a standing position. Chicks were weighed and fed. The chick was then placed on a balance beam, a narrow level board (6 cm wide and 35 cm long), and allowed to walk to test balance and distance walked. We timed the length of time (up to 30 s) that they could remain on the board without falling, and recorded the distance they moved.

We also tested balance by the maximum angle tolerated on an incline, by placing chicks on a level board and slowly elevating it (10–12 s), recording the angle they first slipped or began to move, and the angle at which they fell off. The board was covered with sandpaper to provide traction. If they walked, we recorded whether they walked up or down.

Thermoregulation was examined by placing a chick in the center of an apparatus that offered choices between full sun, a raised object that provided no shade, or a shaded area without a raised object. The chicks were maintained in visual and vocal isolation until they were tested. The test ran for 2 min, and the substrate temperature was 27–29°C in the shade and 38–44°C in full sun. Data were divided into low temperatures (38–39°C in full sun) and high temperatures (41–43°C) for analysis. These temperatures were chosen because temperatures below 39°C seem to pose no problem for chicks in the wild, whereas temperatures over 40°C generally result in shade-seeking. We recorded the time for the chick to reach cover (a solid object that provided no shade), time to reach the shade (provided no cover), the total time out of 2 min that the chick remained in the shade, and the total number of calls given by the test chick during the entire 2-min test.

Depth perception was tested on a visual cliff, where the chicks could move about on a solid opaque surface, cross onto a transparent surface, or jump or fall off the sides. The apparatus was 40 cm high. Chicks were placed in the center, facing the side where they could see both the opaque and transparent surfaces. They remained on the test apparatus for 3 min. We recorded the total number of visual peerings given at the cliff edge. Peering was when the chick stopped abruptly at the cliff edge with its feet at the edge and its body well back from the edge, and extended its head to peer over the edge.

We also tested them on an actual cliff every 3rd day, when they had been deprived of food for at least 2 h. They were

placed 1 m high on a small, flat table, and then the caretaker placed a spoon with food about 10 cm from the edge of the table (over the cliff). We recorded the number of peers and calls chicks made at the cliff, and whether they fell (into a pillow at the bottom).

Individual recognition was tested only in the morning, when the chicks had been deprived of food for 2 h. Chicks were tested by having a caretaker and another person who looked similar sit on each side of a 100-cm-wide table. Each person held a spoon with food at the same height above the table, did not speak, and wore the same clothing. The chick was placed in a small box in the center between the two people and allowed to acclimate for 30 s, when the box was removed. We recorded the first direction in which the chick moved, its final choice, time to make that choice, distance moved after 5 s, and time to reach the food.

At about 34-36 days of age, chicks begin to practice for flight by flapping their wings and jumping up and down. From 42-54 days, each chick was taken outside in the sun and allowed to practice for 1 min. We recorded the number of wing flaps and jumps per minute, and the height of the highest jump. We used the average value for each chick in our comparison.

Because the chicks were acclimated to people from day 1, they showed no signs of fear or escape behavior during any of the tests. Visual cliff, thermoregulation, and incline were performed following feeding so that the chicks were satiated and did not run to the technician. During all tests chicks were in visual and vocal isolation from the other chicks. Whenever possible, the technicians were also hidden from view.

We present the results from 1992 (19) and 1993 together on some graphs to allow a comparison of the effects of exposure at different ages. The methods employed in 1992 and 1993 were the same with respect to capture and handling, dosing, caging, holding and maintenance room, foods, feeding schedule, test apparati, test protocols, and primary personnel. The only test that differed was the thermoregulatory test, in that ambient air temperatures in the sun in 1992 were not as hot as they were in 1993.

Statistical Tests

We used analysis of variance (ANOVA) to examine differences among groups (39,43), and Duncan's multiple range test to determine which group means differed significantly. Before running the ANOVAs, we used general linear model regression procedures [PROC GLM (39)] to determine that Day did not contribute significantly to variations in behavior (except for recognition of individuals, which is presented by age). We used Kruskal-Wallis χ^2 tests for the flight measures because we had two groups (lead and control), and the data were not normally or log-normally distributed. In some figures we also

TABLE 1

BEHAVIORAL RESPONSES OF HERRING GULL CHICKS (AGED 14-24 DAYS) AS A FUNCTION OF TREATMENT, AND ANOVA COMPARISONS OF BEHAVIOR 1-10 DAYS POSTINJECTION

	Behavior at 14-24 Days				ANOVA Comparing at 14-24 Days	ANOVA Comparing 1-10 Days Following Exposure
	Control	Lead at 6 Days	Lead at 12 Days, Half Dose	Lead at 12 Days, Full Dose		
No. of birds	12	11	14	13		
Righting response (s)	2.4 ± 0.1 (A)	2.5 ± 0.1 (A)	2.5 ± 0.1 (A)	2.9 ± 0.1 (B)	0.005	0.0001
Balance beam						
Distance moved in 5 s (cm)	1.5 ± 0.5 (A)	0.3 ± 0.3 (B)	0.9 ± 0.4 (C)	0.4 ± 0.2 (B)	0.06	0.003
Distance moved in 30 s (cm)	4.1 ± 0.9	2.7 ± 0.8	3.0 ± 0.7	2.1 ± 0.6	NS	NS
Incline: maximum angle*						
Angle first move (degree)	46 ± 0.7 (A)	46 ± 0.7 (A)	47 ± 0.5 (A)	49 ± 0.7 (B)	0.002	0.0001
Distance (cm) moved in 15 s	11 ± 1.2 (A)	11 ± 1.9 (A)	10 ± 2.7 (A)	6 ± 1.1 (B)	0.001	0.0001
Actual cliff						
No. of calls	22 ± 1.6 (A)	30 ± 1.8 (B)	23 ± 1.3 (A)	31 ± 1.9 (B)	0.0001	0.0006
No. of peers	4 ± 0.3 (A)	6 ± 0.7 (B)	4 ± 0.2 (A)	5 ± 0.4 (C)	0.04	0.0001
Visual cliff†						
No. of calls	20 ± 1.1 (A)	27 ± 1.3 (B)	23 ± 1.0 (A)	18 ± 0.9 (A)	0.0001	0.001
No. of peers	5 ± 0.2	5 ± 0.2	4 ± 0.2	4 ± 0.1	NS	0.0007
Thermoregulation‡						
Time to reach shade	17 ± 2.7 (A)	32 ± 3.1 (B)	22 ± 3.1 (A)	23 ± 2.9 (A)	0.05	0.01
Time in shade	80 ± 2.9 (A)	62 ± 2.8 (B)	82 ± 2.9 (A)	78 ± 2.9 (A)	0.01	NS
Visual recognition§						
Time to first respond	8 ± 1.6	11 ± 2.1	6 ± 1.3	13 ± 2.2	NS	0.0007
Time to choose (s)	16 ± 2.2	19 ± 2.7	19 ± 2.4	18 ± 1.7	NS	0.0001
Time to reach food	28 ± 3.1	27 ± 3.0	24 ± 2.9	36 ± 2.9	0.03	0.0001

Means that are identified with the same letter (in parentheses) do not differ significantly from each other (Duncan's multiple range test). Similar letters do not differ from each other.

*Significant difference in angle to fall off or final distance moved.

†No significant difference in initial responses or final score.

‡No significant differences in total time in shade or final score.

§No significant differences in initial distance moved in 5 s.

present the data for exposure at 2, 2-4-6, and 6 days to facilitate comparisons (19).

We examined data in two ways, given the design of exposure on different days: a) We compared behavior of all groups at ages 14-24 days (same age comparison); and b) we compared behavior for the 10 days following exposure (same exposure period). In the latter comparison, behavior for control chicks was for 7-23 days; for chicks exposed at 6 days, it was 7-17 days; and for chicks exposed at 12 days, it was 13-23 days. This allowed us to compare the magnitude of effect immediately following exposure. However, in most cases the differences were consistent with the two methods. Data are therefore largely presented for the first method. When the results of the two methods differed, we also present the data from the 10 days following exposure.

RESULTS

The righting response differed significantly among groups for the same-age comparison at 14-24 days of age, with the full-dose, lead-12 group requiring significantly longer to right themselves (Table 1). However, when we examined behavior in the 10 days following injection, all lead-exposed chicks required an average of 2.5-2.9 s to right themselves, whereas control chicks required an average of only 2.0 s. Righting seems to be disrupted immediately following exposure.

On the balance beam, the full-dose lead-12 and lead-6 groups moved less than did the controls and the half-dose, lead-12 gulls in the same age comparison (Table 1). Similarly, on the maximum angle incline the full-dose, lead-12 gulls performed significantly less well than the controls or lead-6 gulls at 14-24 days of age.

The ability to locate and remain in the shade when exposed to high temperatures is critical for survival of birds in the wild. In this experiment, there were no differences in the time for controls and gulls exposed at 12 days (regardless of dose) to reach shade, compared to controls; but birds exposed at 6 days took significantly longer to reach shade (Table 1 and Fig. 1). Similarly, time in the shade was significantly greater for controls and lead-12 compared to lead-6 chicks (Table 1 and Fig. 1).

Gulls were tested on a visual cliff and on an actual cliff (Table 1). On the actual cliff, the lead-6 and full-dose, lead-12 gave significantly more calls, but only the lead-6 gulls gave significantly more calls on the visual cliff than did the other groups. Similarly, the lead-6 gulls and full-dose, lead-12 chicks gave significantly more peers on the actual cliff than did the other exposure groups (Table 1).

There were no significant differences as a function of exposure (or age of exposure) for individual recognition for percent correct response to caretaker, initial time to respond, or time to choose the caretaker when gulls were tested at 14-24 days of age. However, the lead-12, full-dose group took significantly longer to reach the food (Table 1). Figure 2 shows the pattern for time to choose for gulls exposed at 12 days and for controls, as well as for exposure at 2 and 6 days [after Burger and Gochfeld (19)]. This figure shows that time to choose is more severely affected in the days immediately following exposure (note the significance in Table 1 for a comparison of 1-10 days postinjection).

Flight practice behavior was examined for the lead-exposed and control birds at 42-54 days of age. There were no differences among the lead exposure groups. However, there were significant differences between the control and lead groups in

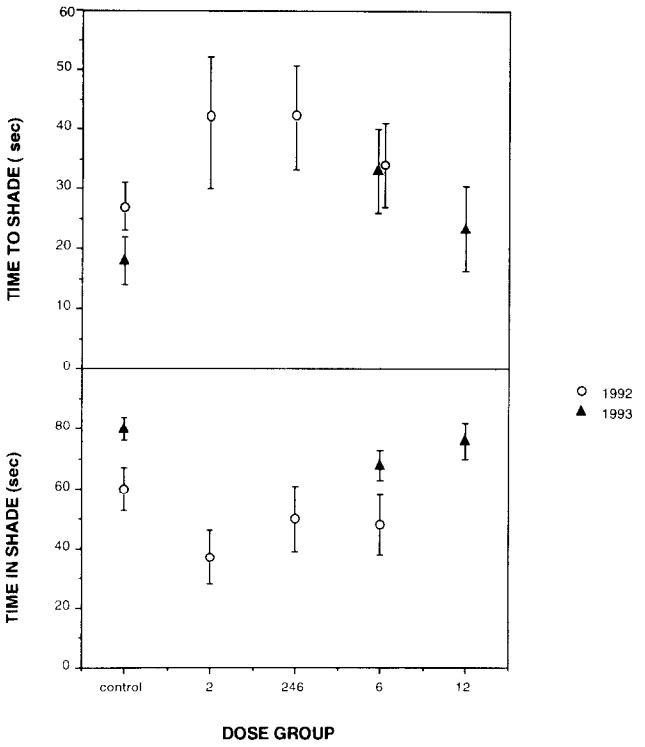

FIG. 1. Time to reach shade for herring gull chicks exposed at 2, 2-4-6, 6, or 12 days of age and for controls (top), and total time spent in the shade once they reached it (bottom). The test was 2 min in duration. The 2-4-6 group received a divided dose on each of the 3 days.

number of jumps per minute ($\chi^2 = 10.8, df = 1, p < 0.001$), number of flaps per minute ($\chi^2 = 13.2, df = 1, p < 0.0004$), and height of the jumps ($\chi^2 = 14.0, df = 1, p < 0.0002$). The lead-exposed gulls flapped and jumped less often and jumped to a lesser height than did controls (Fig. 3). Thus, behavioral impairment was still evident 30-44 days after injection.

There were no overall differences in weight at fledgling as a function of treatment.

DISCUSSION

Methodologic Consideration

One objective of this study was to determine critical periods when a similar dose results in more severe effects than at other ages or stages in development. However, there are two key problems in reaching this objective: a) The dose (as determined per body weight) may not have the same effect for different ages given the weight change between 6- and 12-day-old chicks; and b) there are developmental changes that normally occur between 6 and 12 days of age in the herring gull that might make interpretation difficult.

Herring gulls normally weigh just under 100 g at 6 days of age, and average 180-200 g by 12 days (14). Thus, an equivalent dose results in nearly twice the total amount of lead at 12 days. Because the larger amount of lead administered acutely might have produced a more severe effect, we also injected

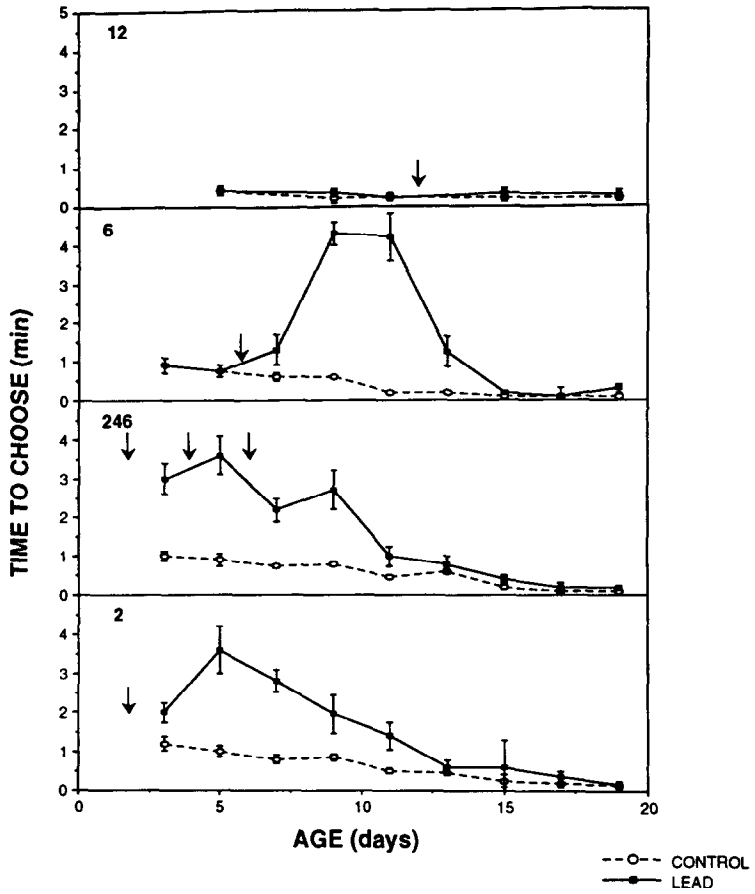

FIG. 2. Temporal response of herring gull chicks to the primary caretaker. Shown is the mean time (±SE) required to choose between the caretaker and the noncaretaker as a function of the age at which the test was administered. Arrow, time of injection; dashed line, control; solid line, lead-exposed gulls. [Data for 2, 2-4-6, and 6 days of exposure from (17)].

12-day-old chicks with a half-dose (equal in absolute amount of lead to that received by the 6-day-old chicks).

Second, as chicks age they normally become more agile and more coordinated, and improve in their ability to recognize their parents (11). It is difficult directly to compare the behavior of 6- and 12-day-old chicks. To partially understand these effects, we examined behavior at the same age (14-24 days of age), as well as for the 10 days following exposure. Some behaviors (i.e., righting and balance) that change only slightly during development showed similar effects by either analysis. However, behaviors that change markedly during development might show a significant effect only when examined immediately after exposure. This happened only with some behaviors associated with individual recognition (Fig. 2).

Third, one might question whether herring gull chicks collected from the wild already had significant exposure to lead or some other toxicant, which makes interpretation difficult. Lead levels of wild herring gull chicks from these colonies have been examined (17,21). Two-day-old herring gull chicks collected from these same colonies have average lead levels of 0.8 ppm in the liver; by 15 days lead levels are 0.3 ppm (21); at fledgling lead levels are 1-2 ppm in feathers of wild young gulls (17). Lead levels in dosed fledglings average 5 ppm compared to 0.2 ppm in controls for feathers, and 7 ppm in exposed vs. 0.05 ppm in controls for liver (15). These data suggest that control gulls have lower lead levels than wild birds.

Levels of other heavy metals that might compromise these results, such as mercury (0.23 ppm), cadmium (0.01 ppm), and selenium (2.9 ppm), are also low in herring gull eggs from these colonies (13,17). If levels in eggs are low, resultant levels in chicks are also low. Although other toxicants could be problematic, we believe the levels of other toxics to be below a problematic threshold, because behavioral impairments are not obvious in gulls observed in nature (20).

Finally, it could be argued that herring gull chicks in the wild normally do not receive these levels of lead from their food. The levels of lead we used resulted in feather levels in fledglings in the laboratory that were equivalent to those that can occur in fledglings in the wild from uncontaminated sites (22). Herring gull young in the wild normally receive lead through their food, and their exposure is presumably chronic, although it could be acute, given that gulls feed extensively at landfills and other disposal sites. Because young gulls can eat different amounts of food, resulting in different exposures,

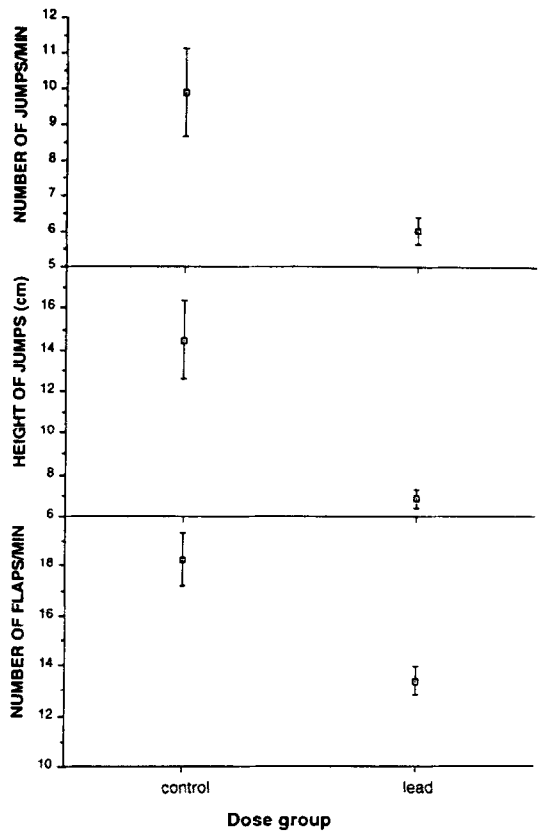

FIG. 3. Practice flight behavior of herring gull young from 42–54 days of age, when they normally fledge in the wild. Shown are the mean (±SE) number of jump or flaps per minute and the mean height of jump per minute for control and chicks exposed at 12 days.

we decided to use injection in the laboratory experiments to ensure equal exposure.

Relevance of Measures to Behavioral Development

The behaviors examined in the laboratory have a direct relationship to survival in the wild for young herring gulls, as well as for other birds. Moreover, they relate to important developmental stages in young herring gulls. These gulls nest in a variety of habitats that vary in their heterogeneity (10,11). Thus, young gulls encounter hills or uneven terrain and can fall down embankments, requiring the ability to right themselves and maintain balance on uneven substrates. Gulls that fail to right themselves quickly are exposed to territorial clashes, cannibalism, and predation (9).

In some places, herring gulls nest on cliffs or in trees (8), making it adaptive for gulls to perceive a cliff edge and respond accordingly. Moreover, this ability is required until fledging, because chicks raised either on cliff ledges or in tree nests can fall from their nests and die in the fall or be ignored by their parents (and subsequently starve or be eaten by predators).

Righting, balance, and depth perception become critical abilities when young chicks begin to move out of the nest and wander about the territory. In herring gulls, this movement begins at 3–4 days of age, and by 12 days of age, the chicks move freely (if haltingly) about their territory. Thus, disruption at 12 days of age could have greater consequences than at 6 days of age.

The ability to regulate their temperature behaviorally by seeking shade when exposed to extreme heat or cold is also important for the survival of herring gulls (26,33). Particularly on sandy beach habitats, chicks may be exposed to extreme heat stress, as sand temperatures in the sun far exceed ambient air temperatures. Thermoregulation is also more critical at 12 days of age, because chicks may wander from their nest site (away from cover and protection from the sun) and parents brood the chicks less (26). Chicks are required to seek shade under extreme conditions. Thus, disruption of thermoregulation at 2–6 days of age is less problematic than disruption at 12 days of age.

Individual recognition normally develops in herring gulls at 6–8 days of age; young chicks begin to wander away from the nest and can get lost or starve if they do not recognize and respond to their parents. Chicks that wander into neighboring territories can be killed by neighbors during territorial clashes (9,11). Thus, the disruption of individual recognition can cause immediate death or starvation. Similar critical periods for the development of individual recognition have been reported for other gulls (25).

Critical Periods

The main objective of this article was to determine the critical period for effects of lead exposure for herring gulls. We exposed chicks to lead at 6 and 12 days of age and compared the results to a previous experiment in which chicks were exposed at 2, 4, and 6 days of age (19). Overall conclusions from the two studies are that: a) Righting response and balance was disrupted immediately after injection for all exposure ages, and recovered within 2 weeks to control levels. b) Thermoregulation behavior was most severely affected at 2, 4, and 6 days of exposure, and showed little effect when exposure occurred at 12 days of age. c) Ability to perceive and respond to a visual cliff was most severely affected when exposure occurred at 6 days, particularly with respect to number of calls and peers, and latency to respond. However, on an actual cliff behavior was affected by exposure at both 6 and 12 days. d) Aspects of individual recognition were most severely affected at different ages: Accuracy of response was most severely affected when lead exposure occurred at 2 days of age, latency of response was most severely affected when exposure occurred at 6 days of age, and there was no effect of lead on individual recognition when exposure occurred at 12 days of age. e) Flight practice behavior that occurs at 40–45 days of age was affected equally regardless of age of exposure.

Righting response, balance, and location were disrupted immediately after exposure, but recovered within 2 weeks. Thus, these changes were not permanent. However, they could affect survival if they led to increased predation or aggressive encounters with neighbors during this period.

Thermoregulatory behavior was most affected when lead exposure occurred from 2–6 days, when chicks are most vulnerable to thermal stress. During this period they are covered with down rather than feathers, and are thus less able to withstand excessive heat or cold (26,33). If they fail to seek shade quickly when not brooded by parents, they are vulnerable to excessive heat.

Similarly, individual recognition was most severely affected by lead exposure at 2–6 days of age. Thereafter, lead

had very little effect. By 12 days of age, chicks learned to recognize their parents, and recognition was not disrupted by lead. This suggests that lead affects their learning ability with respect to individual recognition, and does not disrupt recognition once it is learned.

To some extent, both visual recognition and behavioral thermoregulation are cognitive processes. Thus, the results of these experiments indicate disruption of cognitive processes and parallel results with a variety of mammals that show lead-induced cognitive deficits with high lead exposure [reviewed in (2-7)].

Overall, these experiments indicate that critical periods for lead exposure for most behaviors in young herring gulls occur between 2 and 6 days posthatching. Thereafter, lead disrupts balance and locomotion for a short time, but has a lesser affect on visual cliff, thermoregulation, and individual recognition behavior.

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