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Maternal modulation of infant glucocorticoid stress responses: Role of age and maternal deprivation

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We recently showed that maternal contact (passive contact with an anesthetized lactating dam) eliminates the corticosteroid response to novelty stress in 12-, 16-, and 20-day-old rat pups that have been deprived of food and maternal care for 24 h. Here we report two experiments in which we examined the role of deprivation in the stress-modulatory effect of maternal contact. Blood levels of plasma corticosterone were determined in three groups of infant rats: a basal not-tested (NT) group, a group placed alone in warm novel test arenas (pup alone, or PA), and a group exposed to novelty in the presence of an anesthetized lactating dam (DAM). These three treatment conditions were combined factorially with a deprivation variable; that is, prior to testing, half the pups were deprived of food and maternal care for 24 h, and half the pups remained with their mothers in the home nest. Experiment 1 employed this 2 (deprived vs. nondeprived) × 3 (NT vs. DAM vs. PA) factorial design at each of three ages: 12, 16, and 20 days postnatal. In Experiment 2 this design was employed at 20, 24, and 28 postnatal days of age. At 12, 16, 20, and 24 days of age, deprived pups displayed a robust glucocorticoid response to novelty stress, and this response was inhibited by maternal contact. Nondeprived animals, on the other hand, displayed a dramatically attenuated glucocorticoid response to novelty that was less effectively inhibited by maternal contact. At 28 days, maternal contact was relatively ineffective in inhibiting the stress response, particularly in the absence of deprivation. These findings replicate and extend our previous ones concerning the psychological control of the pituitary-adrenal system during development and are consistent with the notion of maternal regulation of this physiological system in the infant.

A growing body of evidence indicates that physiological processes in the developing infant are regulated in subtle ways by the mother. Animal studies have shown that the mother regulates processes in the infant as diverse as heart rate, sleep-wake cycles, and secretion of growth hormone (for review, see Hofer, 1983, 1984). We recently discovered a maternal effect on the infant rat's secretion of the adrenal hormone corticosterone. After a period of maternal and food deprivation, contact with an anesthetized lactating female prevents the infant rat pup's corticosterone response to the psychological stress of exposure to a novel environment (Stanton, Wallstrom, & Levine, 1987). This inhibitory effect on the glucocorticoid response was traced specifically to maternal contact. Milk consumption, suckling, and odors associated with lactation were no more effective in inhibiting the glucocorticoid response than was maternal contact alone.

The finding that milk consumption and suckling are unimportant for this inhibitory effect on stress responsiveness in infant rats is striking when one considers that consummatory behaviors, such as feeding and drinking, have a very robust suppressive effect on glucocorticoid stress responses in adult rats (Levine, Weinberg, & Brett, 1979), and that the motivational and neural substrates of consummatory behavior are present in the rat from birth (Epstein, 1984; Hall & Williams, 1983). This raises the possibility that consummatory drives and rewards fail to modulate glucocorticoid stress responses in the infant during early development. One feature of this earlier study (Stanton et al., 1987) was that all pups were deprived of food and maternal care before testing. Thus, although no evidence was found for a role of specific consummatory behaviors, such as suckling and feeding, in the inhibition of adrenocortical activation, the role of consummatory drives (i.e., deprivation of food, suckling, and maternal stimulation) remains unexplored. The present study investigated this issue by examining the stress-reducing effect of maternal contact either in pups that were deprived of food and maternal care or in pups that were nondeprived prior to novelty exposure. Maternal inhibition of the stress response in nondeprived pups would argue against the importance of consummatory behaviors and drives.

EXPERIMENT 1

In Experiment 1 we sought to determine whether the ability of maternal contact to inhibit the corticosteroid

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stress response depended on the period of deprivation preceding the test. We assessed the effect of maternal contact on the stress response by comparing three groups: a basal group that was not tested (NT), and two groups which were exposed to novelty, one with an anesthetized dam present (DAM) and one with no dam present (pup alone, or PA). The pups in these three groups either were subjected to 24 h of maternal deprivation (deprived) or were taken directly from the home nest (nondeprived). Experiment 1 was thus a 2 (deprived vs. nondeprived) × 3 (NT vs. DAM vs. PA) factorial design. This design was employed at each of three ages: 12, 16, and 20 days postnatal. We reasoned that if inhibition of the stress response by maternal contact occurs because pups associate the stimulus dam with consummatory behaviors that are activated by prior deprivation, such inhibition would be attenuated or absent in the nondeprived DAM condition; that is, corticosterone levels in this condition would be elevated, as are those in the PA condition, rather than reduced to basal levels, as they typically are in the deprived DAM condition (Stanton et al., 1987).

Method

Subjects. The subjects were 62 12-day-old, 59 16-day-old, and 75 20-day-old rat pups taken from 30 litters. These ages correspond to those used in our previous research and were chosen because adrenocortical stress responses are small and unreliable prior to 12 days of age, and because 20 days of age represents the end of the preweaning period of development. Litters were housed with their mothers in transparent plastic cages (48.5×25.6×19 cm) supplied with sawdust bedding and ad-lib rat chow and tap water. The laboratory was illuminated on a 12:12-h light:dark cycle. Newborn pups found during an illuminated phase of the light:dark cycle were designated as being born on that day (Day 0). On the first day postpartum, all litters were culled to 8 animals, usually 4 males and 4 females. Litters were left undisturbed until experimentation began. The subjects were tested 4–8 h after light onset.

Apparatus. The apparatus was the same as that described in a previous report (Stanton et al., 1987). Briefly, it consisted of a 37×29×13 cm Plexiglas incubator (subdivided into eight individual 8×9×13 cm compartments) and a number of test chambers that consisted of 28×17×13 cm polyethylene small rodent cages. The incubator was placed over 30°–33° C electric heating pads (General Electric) on a shelf in the main colony room. The test chambers were placed over electric heating pads adjacent to one another on a table in a room adjoining the colony room. Wire mesh lids were placed over the test chambers during testing. Clean paper towels were placed on the floor of each test chamber prior to testing and were discarded or replaced at the end of each test.

Deprivation. Different litters were assigned to the deprived and nondeprived conditions. In the deprived condition, pups were separated from their mothers 24 h before testing and placed individually without food or water into separate compartments of the heated Plexiglas incubator. At this point, each pup was weighed and randomly assigned to an experimental group. Within each litter of pups, 1 male and 1 female was assigned to each of the three groups. Each of the remaining 2 pups was assigned to one of the two groups in a manner that was counterbalanced across successive litters. In this way, a maximum of two same-sex littermates were assigned to a given group. Groups were drawn from a minimum of four different litters.

Procedure. On the day of testing, the three experimental groups (n=9–16/group) and their corresponding treatments were as follows: (1) Not tested (NT)—pups were taken from the incubator (deprived) or from the home nest (nondeprived) and were blood sampled immediately without being exposed to the novel test situation; (2) DAM—pups were placed in a novel test situation with an anesthetized lactating dam; and (3) pup alone (PA)—pups were placed in the test chambers alone, with no dam present (this was the novelty-stress condition).

For each of these conditions, trunk blood was collected from each individual by decapitation. For the tested conditions (DAM and PA) the blood was collected within 1 min after testing was completed. For the NT animals, blood was sampled at the time the testing of the experimental pups began. Blood samples were then individually centrifuged at 2,000 rpm for 20 min, and plasma was extracted and frozen for subsequent corticosterone radioimmunoassay. This assay was a modification of the cortisol radioimmunoassay of Klemm and Gupta (1975) in that we employed a specific antibody for corticosterone (Endocrine Sciences) rather than cortisol. The experiment was planned so that all groups within each age were counterbalanced as closely as possible for sex, litter, day of running, order of running, and weight.

Experimental sessions began approximately 24 h after pups had been deprived. Approximately 20–40 min prior to the experimental session, 2–3 lactating dams having pups the same age (±4 days) as the experimental subjects were injected i.p. with Nembutal (32.5 mg/kg, Abbott Laboratories). This produced a surgical level of anesthesia that was maintained throughout the experiment by administering supplementary doses as necessary. Following injection, the dams were returned to their young so that their nipples would have been recently suckled at the beginning of the experiment. Just before the experiment began, the dams were put into the appropriate test chambers.

During an experimental session, the experimenter removed each rat pup from its deprivation compartment (deprived conditions) or from its home nest (nondeprived conditions), voided its bladder by anogenital stroking with a soft artist's brush, weighed it, and then placed it individually in one of the test chambers. Pups in Groups PA and DAM were placed individually in test chambers either alone or with an anesthetized dam. One litter of animals was tested during a given session. Thus, 2–3 pups were exposed to each experimental condition at a time. On a given test day, one to three sessions (i.e., litters) were run successively. When two or more litters were run, one was deprived and one was nondeprived.

Test sessions lasted 30 min. At the end of this period, the first pup was removed from its experimental chamber, weighed, and then blood sampled by decapitation in a separate room. The other pups were removed and weighed in the same order in which they were placed into the chambers. The test chambers were cleaned between each replication.

Results

The results of Experiment 1 are shown in Figure 1. Each panel corresponds to a different age. Data were analyzed separately for each age by means of a 2 (deprived vs. nondeprived) × 3 (NT vs. DAM vs. PA) factorial analysis of variance (ANOVA).

12 days. Comparisons among the three treatment groups of 12-day-old rats were dramatically influenced by deprivation. The deprived groups (dark bars) showed the same pattern of results that we reported previously (Stanton et al., 1987). Corticosterone levels of PA pups were elevated over those of NT pups, whereas those of DAM pups were not. The nondeprived groups (white bars) showed a different and unexpected pattern of results. Corticosterone levels were not elevated over base in either the DAM or PA pups.

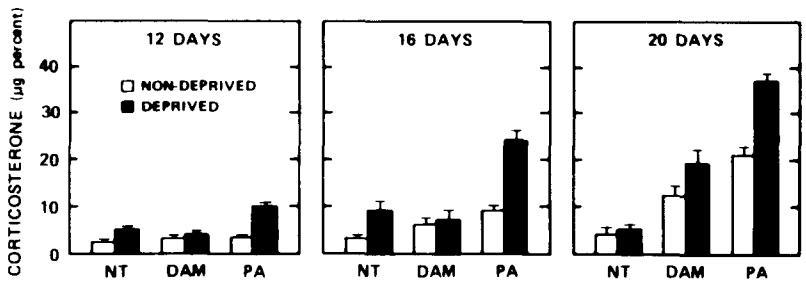

Figure 1. Mean (± standard error of the mean) plasma corticosterone levels for rat pups aged 12, 16, and 20 days under the six sampling conditions of Experiment 1. Different ages are represented in different panels. NT = nontested basal condition; DAM (pup with dam) = maternal contact plus novelty stress; PA (pup alone) = novelty stress only; Nondeprived = taken directly from the home nest prior to the experiment; and Deprived = deprived of food and maternal care for 24 h prior to the experiment.

An ANOVA revealed a main effect of deprivation [$F(1,56) = 119.6$, $p < .001$], a main effect of groups [$F(2,56) = 32.65$, $p < .001$], and an interaction of deprivation and groups [$F(2,56) = 20.46$, $p < .001$]. A Newman-Keuls analysis of this latter interaction indicated that there were no differences among the three nondeprived treatment groups ($p > .05$). On the other hand, differences between deprived treatment groups were apparent. Corticoid levels of Group PA were elevated over those of Groups DAM and NT ($p < .01$), and those of Group DAM were slightly, but reliably ($p < .05$), lower than those of Group NT. All three of the deprived groups displayed elevated glucocorticoid levels relative to their nondeprived counterparts ($p < .05$). The largest effect of deprivation was on the response to novelty in the PA animals. Nondeprived animals failed to show a stress response to novelty. This complicates assessment of the inhibitory effect of maternal contact on the stress response in nondeprived animals because there was no stress response to inhibit.

16 days. The pattern of results at 16 days of age was similar to that obtained at 12 days of age. Deprived animals showed a glucocorticoid response to novelty (compare PA with NT) that was blocked by maternal contact (compare DAM with NT). Nondeprived animals showed lower hormone levels and a greatly attenuated response to novelty (compare PA with NT across deprivation conditions). An ANOVA revealed a main effect of deprivation [$F(1,53) = 54.13$, $p < .001$], a main effect of groups [$F(2,53) = 44.50$, $p < .001$], and an interaction of deprivation and groups [$F(2,53) = 15.02$, $p < .001$]. A Newman-Keuls analysis indicated that for nondeprived animals, corticoid levels of Group PA were reliably ($p < .01$) elevated over those of Group NT but not over those of Group DAM. Corticoid levels of Groups NT and DAM also did not differ. Following deprivation, Group PA showed corticoid levels that were reliably elevated ($p < .01$) over those of Groups NT and DAM, which did not differ between themselves. Deprivation elevated corticoid levels in the NT and PA conditions ($p < .05$), but not in the DAM condition. Thus, as was the case at 12 days, deprivation had more of an effect on the magnitude of the stress response to novelty (PA condition) than on the (inhibitory) response to maternal contact. However, the small size of the stress response in the nondeprived animals complicates the interpretation of this latter effect.

20 days. A somewhat different pattern of results emerged at 20 days of age. Deprivation no longer elevated basal levels. Regardless of deprivation, hormone levels of pups in the PA condition were elevated over base, but this elevation was greater in deprived animals. Also, regardless of deprivation, corticoid levels of pups exposed to novelty in the presence of an anesthetized dam were intermediate between basal and stress levels. An ANOVA revealed a main effect of deprivation [$F(1,69) = 37.03$, $p < .001$], a main effect of groups [$F(2,69) = 131.09$, $p < .001$], and an interaction of deprivation and groups [$F(2,69) = 12.4$, $p < .001$]. A Newman-Keuls analysis of this latter interaction indicated that there were no differences in hormone levels associated with deprivation in the NT condition, but nondeprived animals were reliably ($p < .01$) below their deprived counterparts in the DAM and PA conditions. At each level of the deprivation factor, all pairwise comparisons between the three treatment groups were reliable ($p < .01$). Again, the main effect of deprivation was on the magnitude of the stress response to novelty. Maternal contact reduced this stress response regardless of prior deprivation.

The main question investigated here was whether the stress-reducing effect of maternal contact depended on prior maternal deprivation. Were this the case, contact with an anesthetized dam would have reduced corticoid levels in deprived pups but not in nondeprived pups. There was no clear evidence of this outcome in the present experiment. Indeed, at 20 days of age, maternal contact reduced the stress response regardless of deprivation. At the younger ages, maternal contact produced corticosterone levels in nondeprived pups that were either equal to or less than those of deprived pups. A clear answer to this question is complicated, however, by another, perhaps more remarkable, finding of the present study, that is, that 24 h of separation from the mother markedly potentiates the adrenocortical stress response to novelty. At all

ages, corticoid levels in the PA condition were very much higher in deprived pups than they were in nondeprived pups. This was true both in absolute terms as well as in relation to basal levels. Because the ability of novelty to drive the adrenal gland was reduced in nondeprived pups, it is difficult to determine whether the suppressed corticoid levels of pups in the nondeprived DAM condition reflects a suppressive effect of maternal contact or simply a lack of adrenocortical activation by novelty.

EXPERIMENT 2

The purpose of Experiment 2 was to reexamine, at a later stage of rat development, the question asked in Experiment 1. The same experimental design was employed in weanling-aged animals, that is, pups aged 20, 24, and 28 days. Our purpose in extending the analysis of this phenomenon to the weaning period was twofold. First, the study would provide additional empirical information about how the phenomenon changes with age. Second, since the capacity of nondeprived pups to respond to stress is more evident at these later ages, we thought that a clearer picture might emerge concerning the effects of deprivation on the ability of maternal contact to inhibit these glucocorticoid responses.

Method

Subjects. The subjects were 60 20-day-old, 74 24-day-old, and 86 28-day-old rat pups taken from 32 litters. Age was determined, pups were culled, and the pups' early lives were spent in the same manner as those in Experiment 1. Pups remained with their mothers either until the time of testing (nondeprived) or until they were separated from their mothers 24 h prior to testing (deprived). On the 21st day postpartum, litters were provided with clean cages containing fresh bedding.

Apparatus and Procedure. The apparatus, design, and procedure were identical to those of Experiment 1, with the following exception: deprived pups spent the deprivation period in individual 28×17×13 cm polyethylene cages rather than in the 8×9×13 cm compartments of the Plexiglas incubator. The deprivation cages used in the current experiment were not warmed with electric heating pads. This change in housing during the deprivation period was made because the compartments of the incubator used in Experiment 1 were inappropriately small for 24- and 28-day-old pups, and because the capacity of animals this age to thermoregulate seemed to obviate the need for an external source of heat. The inclusion of 20-day-old animals in Experiment 2 served both as a check on the effects of this procedural change (by comparison with the 20-day-old deprived animals of Experiment 1) and as a means of a broader, "overlapping" set of age comparisons under a constant set of experimental conditions.

Results

The results of Experiment 2 are shown in Figure 2. Each panel corresponds to a different age. Separate 2 (deprived vs. nondeprived) × 3 (NT vs. DAM vs. PA) analyses of variance were performed at each age.

20 days. In general, contact by 20-day-old rats with a dam reduced the corticoid response to novelty. However, this effect was greater in deprived pups than in nondeprived pups. Corticoid levels in the DAM condition were lower in deprived pups than in nondeprived pups, despite the fact that deprivation increased both basal (NT) and stress (PA) levels of corticosterone. An ANOVA revealed a main effect of groups [$F(2,54) = 48.22$, $p < .001$], and an interaction of deprivation and groups [$F(2,54) = 9.26, p < .001$]. A Newman-Keuls analysis of this interaction indicated that all pairwise comparisons among the three nondeprived groups were reliable ($p < .01$ for PA vs. DAM and PA vs. NT; $p < .05$ for DAM vs. NT). In the deprived condition, on the other hand, the corticoid levels of Group PA were again elevated over Groups DAM and NT ($p < .01$), but these latter two groups did not differ. An analysis of the effect of deprivation at each level of the group factor revealed no effect of deprivation in the NT pups, and opposite effects of deprivation in the DAM ($p < .05$) and PA ($p < .01$) animals.

This pattern of results indicates that inhibition of the glucocorticoid response to novelty by maternal contact is indeed diminished in pups that are not maternally deprived. This occurs despite the fact that the magnitude of the stress response was reduced in the nondeprived PA

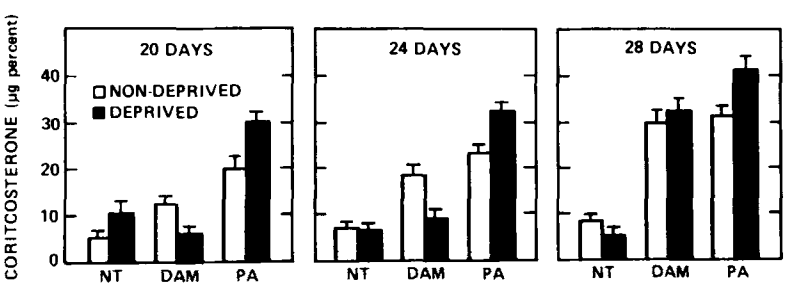

Figure 2. Mean (± standard error of the mean) plasma corticosterone levels for rat pups aged 20, 24, and 28 days under the six sampling conditions of Experiment 2. Different ages are represented in different panels. NT = nontested basal condition; DAM (pup with dam) = maternal contact plus novelty stress; PA (pup alone) = novelty stress only; Nondeprived = taken directly from the home nest prior to the experiment; and Deprived = deprived of food and maternal care for 24 h prior to the experiment.

condition. These results can be contrasted with those obtained in 20-day-old rats in Experiment 1. In the nondeprived animals, for which the present experiment was procedurally an identical replication of Experiment 1, hormone values associated with the three treatment conditions agreed closely across experiments. The deprived animals, on the other hand, showed an effect of treatment conditions that was different from that obtained in Experiment 1. This probably reflects procedural differences between these two experiments in the manner in which the animals were housed during the deprivation period (see General Discussion below).

24 days. The pattern of results at 24 days of age was similar to that obtained at 20 days of age. Maternal contact attenuated the corticoid response to novelty to a greater degree in deprived animals than in nondeprived animals, despite the fact that deprivation potentiated the stress response itself. An ANOVA revealed a main effect of groups [$F(2,68) = 75.97$, $p < .001$], and an interaction of deprivation and groups [$F(2,68) = 14.32$, $p < .001$]. A Newman-Keuls analysis of this interaction revealed precisely the same pattern of results that was obtained at 20 days of age. In nondeprived pups, all pairwise comparisons between the three treatment groups were reliable ($p < .05$ for PA vs. DAM; $p < .01$ for PA vs. NT and DAM vs. NT). In deprived pups, corticoid levels of Group PA were elevated over those of Groups DAM and NT ($p < .01$), which did not differ. Deprivation did not affect hormone levels in the NT condition, it significantly lowered hormone levels in the DAM condition ($p < .01$), and it significantly elevated hormone levels in the PA condition ($p < .01$). This pattern of results indicates that at 24 days of age, prior separation from the mother has a very important influence on the ability of maternal contact to inhibit the corticosteroid response to novelty. Nondeprived animals show much less inhibition than do deprived animals. This is true despite the fact that nondeprived animals show less of a stress response to novelty than do deprived animals.

28 days. The pattern of results at 28 days of age differed from that obtained at 20 and 24 days, primarily in that maternal contact was a much less effective inhibitor of the glucocorticoid stress response. Nevertheless, there was still some indication that deprivation enhanced the inhibitory effect of maternal contact. An ANOVA revealed a main effect of groups [$F(2,80) = 79.3$, $p < .001$], and an interaction of deprivation and groups [$F(2,80) = 3.42$, $p = .038$]. A Newman-Keuls analysis of this interaction revealed that the effect of treatment conditions again depended on the level of the deprivation factor. In nondeprived animals, the hormone level of Group NT was reliably ($p < .01$) below that of Group DAM and Group PA, which did not differ from each other. In the deprived animals, hormone levels of Group NT were again lower ($p < .01$) than those of Groups DAM and PA; however, hormone levels of Group DAM were also lower than those of Group PA ($p < .05$). This pattern of results suggests two conclusions. First, the ability of maternal contact to inhibit corticoid stress responses begins to disappear by 28 days of age (see Stanton & Levine, 1988). Second, maternal deprivation slightly retards the disappearance of this effect; that is, the effect was entirely absent in nondeprived animals but remained present to a limited degree in deprived animals.

Taken as a whole, the results of the present experiment indicate that the ability of maternal contact to inhibit the glucocorticoid response to novelty is influenced by prior maternal deprivation during the weaning period of development. This occurs despite the fact that deprivation increases adrenocortical responsiveness to novelty and was most evident at 20 and 24 days of age. By 28 days of age, maternal contact begins to lose its potency as an inhibitor of the adrenocortical response to novelty stress, even in deprived pups.

GENERAL DISCUSSION

The present study was designed to determine whether maternal modulation of infant stress responses is influenced by prior separation from the mother, and whether this effect changes with age. It is not possible to answer this question directly over the entire range of ages examined because of an unexpected finding of this study. To our surprise, we found that, at all ages studied, failure to maternally deprive pups attenuated the stress response to novelty. Elevations in corticosterone following novelty exposure were much lower in nondeprived pups than in deprived pups. At 12 and 16 days of age, the magnitude of the stress response was so attenuated in nondeprived animals that it obscured evaluation of how deprivation influences the inhibitory effect of maternal contact. Essentially, there was no stress response to inhibit in nondeprived animals. This effect of deprivation on the stress response points to another manner in which the developing pituitary-adrenal system is regulated by the mother. Not only does maternal presence suppress stress responsiveness, but maternal absence (deprivation) potentiates it. This stress-potentiation phenomenon has been analyzed more extensively elsewhere (Stanton, Gutierrez, & Levine, 1988).

At 20, 24, and 28 days of age, stress responses in nondeprived animals were of sufficient magnitude to permit evaluation of our original hypothesis. At these ages, deprivation enhanced the inhibitory effect of maternal contact; that is, there was less inhibition of the stress response with maternal contact in the nondeprived pups (i.e., their hormone levels were higher) than in the deprived pups. Nevertheless, maternal contact did have an inhibitory effect in nondeprived pups, at least at 20 and 24 days of age.

Another possible finding of this study was that ambient temperature during the deprivation period may influence glucocorticoid secretion during the novelty test. At 20 days of age, the pattern of results during testing seemed to depend on whether pups spent the deprivation period in a warm incubator (Experiment 1) or in cages at room temperature (Experiment 2). Although some caution may

seem warranted here, because this effect of temperature is inferred from comparison of data from different experiments, we feel confident in this finding because it has been replicated in an independent study (Stanton & Levine, 1988). Deprived pups kept in an incubator showed a potentiated stress response and an attenuated inhibitory effect of maternal contact relative to nondeprived pups (Experiment 1). Deprived pups kept in individual cages at room temperature showed somewhat less of a stress response than those kept in an incubator and an inhibitory effect of maternal contact that was significantly greater than that of nondeprived pups (Experiment 2). This pattern of results is reminiscent of a previous report that ambient temperature during periods of prolonged maternal separation can have dramatic effects on the acute physiological and behavioral responses of rat pups to novelty exposure. Hofer (1973) reported that preweanling rat pups that are maternally deprived for 18 h at nest temperature respond to novelty exposure with increases in activity relative to those of nondeprived pups. Pups that are deprived at room temperature, in contrast, show decreases in activity relative to nondeprived pups. Ambient temperature in the deprivation period also influenced the cardiac response to novelty exposure in Hofer's study. Pups deprived at nest temperature showed cardiac acceleration that was sustained throughout the test period, whereas pups deprived at room temperature showed cardiac acceleration that was transient rather than sustained. Hofer's results and the present findings point to the importance of temperature as a modulator of the effects of maternal separation on the infant's response(s) to novelty.

The central question of this study was whether inhibition of the glucocorticoid response to novelty by maternal contact is a result of the motivational properties of the mother which result from prolonged maternal separation. The answer appears to be that maternal deprivation does play a limited role, but to an extent that is age dependent. At 20 and 24 days of age, maternal contact inhibited the glucocorticoid response to novelty to a greater degree in deprived pups, but inhibition was nonetheless evident in nondeprived pups. At these ages, then, deprivation enhanced the inhibitory effect of maternal contact but was not a necessary condition for its occurence. At 28 days of age, maternal contact inhibited stress responsiveness only in deprived pups, but at this age the inhibitory effect was becoming rather weak, possibly as a result of the process of weaning (see Stanton & Levine, 1988). This increasing role of deprivation as a function of age is consistent with other known changes in the motivational control of behavior that occur during postnatal development in the rat (Hall & Williams, 1983). Moreover, the ages at which it was possible to assess the effect of deprivation in this study are also those at which nutritive factors take on increasing significance in the mother-infant interaction (Williams, Hall, & Rosenblatt, 1980). The present findings suggest a limited role for these motivational factors in the maternal modulation of stress physiology in the developing rat.

REFERENCES

Epstein, A. (1984). The ontogeny of neurochemical systems for control of feeding and drinking. *Proceedings of the Society of Experimental Biology & Medicine*, **175**, 127-134.

Hall, W. G., & Williams, C. L. (1983). Suckling isn't feeding, or is it? A search for developmental continuities. In J. S. Rosenblatt, R. A. Hinde, C. Beer, & M. C. Busnel (Eds.), *Advances in the study of behavior* (Vol. 13, pp. 219-254). New York: Academic Press.

Hofer, M. A. (1973). The role of nutrition in the physiological and behavioral effects of early maternal separation on infant rats. *Psychosomatic Medicine*, **35**, 350-359.

Hofer, M. A. (1983). On the relation between attachment and separation processes in infancy. In R. Plutnik (Ed.), *Emotion: Theory, research and experience: Vol. 2. Early development* (pp. 199-219). New York: Academic Press.

Hofer, M. A. (1984). Relationships as regulators: A psychobiologic perspective on bereavement. *Psychosomatic Medicine*, **46**, 183-197.

Klemm, W., & Gupta, D. (1975). A routine method for the radioimmunoassay of plasma cortisol without chromatography. In D. Gupta (Ed.), *Radioimmunoassay of steroid hormones* (pp. 143-151). Weinheim, West Germany: Verlag Chemie.

Levine, S., Weinberg, J., & Brett, L. P. (1979). Inhibition of pituitary-adrenal activity as a consequence of consummatory behavior. *Psychoneuroendocrinology*, **4**, 275-286.

Stanton, M. E., Gutierrez, Y. R., & Levine, S. (1988). Maternal deprivation potentiates pituitary-adrenal stress responses in infant rats. *Behavioral Neuroscience*, **102**, 692-700.

Stanton, M. E., & Levine, S. (1988). *Inhibition of infant glucocorticoid stress responses: Specific role of maternal cues*. Manuscript submitted for publication.

Stanton, M. E., Wallstrom, J., & Levine, S. (1987). Maternal contact inhibits pituitary-adrenal stress responses in preweanling rats. *Developmental Psychobiology*, **20**, 131-145.

Williams, C. L., Hall, W. G., & Rosenblatt, J. S. (1980). Changing oral cues in suckling of weaning-age rats: Possible contributions to weaning. *Journal of Comparative & Physiological Psychology*, **94**, 472-483.

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