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Genetic Mediation of Infanticide and Parental Behavior in Male and Female Domestic and Wild Stock House Mice

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Infanticide is a reproductive strategy found in many mammals, especially rodents. The proportion of male and female house mice (*Mus domesticus*) that are either infanticidal or noninfanticidal is strain specific and varies widely from stock to stock. Male house mice also show strain-specific variation in the behavioral mechanisms that inhibit infanticidal individuals from killing their own offspring. The adult offspring generated from reciprocally crossed CF-1 and Wild stock house mice were tested for their behavior toward newborn pups. In male CF-1 × Wild hybrids, the proportion of infanticidal and noninfanticidal males matched with their maternal phenotype, whereas female CF-1 × Wild hybrids exhibited a proportion of behaviors typical of the CF-1 phenotype, regardless of their mother's genotype. Our results suggest three conclusions: first, that infanticide is a highly labile and heritable behavior in both sexes; second, that there is a sex difference in the genetic substrate that regulates the inheritance of infanticidal behavior; and third, that selection pressures in male mice may operate independently on the mechanisms that promote spontaneous infanticidal behavior versus the mechanisms that inhibit infanticide.

KEY WORDS: Infanticide; parental; house mouse; *Mus*.

INTRODUCTION

Infanticide—defined as the killing of conspecific young—is no longer considered a maladaptive or sociopathological behavior. In fact, it is a widespread reproductive strategy found in many organisms, including mammals (e.g., Hausfater and Hrdy, 1984; Hrdy, 1979). Rodents, especially the house mouse species *Mus domesticus* and *M. musculus* have become widely studied models for understanding the evolution, socioecology and physiology of infanticide (e.g., Huck *et al.*, 1982; Perrigo and vom Saal, 1989). Both sexes will kill preweanling young. During reproduction, however, sex-specific behavioral and hormonal mechanisms act to prevent infanticidal male and female mice from harming their own offspring. The hormonal changes associated with pregnancy (19 ± 1 days) and parturition are responsible for inhibiting pup-killing behavior and promoting parental care in female mice (e.g., McCarthy and vom Saal, 1985). In contrast, infanticide is more complex in male house mice, where, depending on the strain, a variety of multiple and apparently redundant inhibitory mechanisms can act to prevent males from killing their own sired young (Palanza and Parmigiani, 1991; Perrigo and Belvin, 1992). These inhibitory mechanisms include female cohabitation, exposure to chemosensory and tactile cues, and a unique neural ejaculatory "trigger" that inhibits infanticide within 2 to 3 weeks after mating (vom Saal, 1985; Kennedy and Elwood, 1988; Soroker and Terkel, 1988).

Strain-specific differences in infanticidal and

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parental behavior are well established among the myriad of inbred laboratory and wild stocks of *Mus domesticus*. Wild-trapped stocks routinely show a high proportion of infanticidal phenotypes in both sexes, but in laboratory inbred stocks, some strains show high to intermediate levels of spontaneous infanticide, whereas other strains may exhibit little, if any, tendency to kill preweaning young. The enormous range in stock-to-stock variation suggests that genetic factors regulate the expression of infanticidal behavior (e.g., Svare *et al.*, 1984). Relatively little research, however, has examined infanticide in male and female hybrid crosses from different mouse strains (see Svare and Broida, 1982), nor has there been any research on the potential genetic differences underlying the multiple inhibitory mechanisms found in male mice.

We have studied infanticide extensively in both CF-1 laboratory stocks and wild-trapped stocks of *Mus domesticus*. As background to the present experiments, about 50% of virgin CF-1-stock male mice exhibit infanticide, whereas 80–90% of virgin Wild-stock male mice from Alberta, Canada, exhibit infanticide. Among virgin females, the frequency of infanticide in CF-1 and Albertan Wild females is 10–20% and 60–80%, respectively. Our experimental hypothesis was simple and straightforward: given the broad phenotypic differences in infanticidal behavior between CF-1 and Albertan Wild mice, an F_1 hybrid cross could reveal specific details about the genetics of both sex- and strain-based differences in infanticidal behavior.

METHODS

Animal Stocks and Routine Husbandry

Two *M. domesticus* stocks were used here: a CF-1 laboratory stock and a Wild stock whose progenitors were originally trapped in granaries near Alberta, Canada, in 1979 (Perrigo and Bronson, 1982). Both stocks have existed as "closed" colonies for several years, and although technically inbred, we maintain sufficiently large numbers of randomly paired breeders to minimize brother–sister matings. Recent taxonomic revisions have also established that domestic laboratory stocks and New World commensal and feral wild stocks are ancestors of *M. domesticus*, the feral house mouse of Western Europe, whereas *M. musculus*, although very similar, occurs in Eastern Europe and Western Asia (see Marshal and Sage, 1981).

All animals were maintained at L:D 12:12 from birth. Males and females of both stocks were grouped five per cage at weaning (23 days of age). When 3 months of age, all animals were separated and individually housed in 28 × 18 × 12-cm cages with corncob bedding and cotton nesting material (Nestlets) and given Purina Mouse Chow and water ad libitum. Room temperatures were maintained at 22 ± 2°C. Specific methodology is described for each experiment.

Assessment of Infanticidal, Parental, and Pup-Ignoring Behavior

When a male or female house mice encounters a neonate he or she either attempts to kill it or does not harm it. These are clear-cut, unambiguous responses. We assess an animal's behavior toward pups by quietly placing a 1- to 3-day-old neonate at one end of the mouse's home cage farthest from its nest. An infanticidal animal will typically approach a pup and suddenly lunge at and kill it with rapid bites to the head and back. This is an acute and dramatic response, so we cannot always intervene on behalf of the pup. Whenever possible, though, pups are quickly rescued by banging on the cage top and, if necessary, immediately euthanized.

If an animal does not attempt to kill the newborn, the pup is left in the mouse's cage for 30 min. This is because most animals that are not infanticidal will exhibit parental behavior instead. By definition, parental males and females groom the pup about its head and genitals and retrieve it to their nest, where they incubate the pup and keep it warm. There is also a small subset of males and females that simply "ignore" pups, neither harming them nor exhibiting typical parental behavior. These individuals appear to straddle a neutral behavioral state between infanticide and true parental behavior (Perrigo *et al.*, 1991).

It should also be emphasized here that, whenever possible, we use a modification of the above test procedure to protect the pup from injury. Specifically, the pup is placed within a tube made of 1.5-mm^2-wire mesh screen, just large enough to slide a neonate comfortably inside. The pup is quiescent, secure, and completely buffered from attack. Thus, when an infanticidal animal encounters a screen-protected pup, it often attacks and repeatedly bites at the screen, but without injuring the neonate (Perrigo *et al.*, 1989a). While this humane test procedure is a reliable assessment of infanti-

cidal tendencies in most CF-1-stock males, a screen-protected pup has not been an efficient testing paradigm in either CF-1 females or Wild-stock house mice (see also Elwood *et al.*, 1990). Thus, if a screen-protected pup does not elicit an attack, an unprotected pup is then placed in the cage for 30 min, which yields the same information as the procedure noted above, including infanticide among those individuals that simply do not respond aggressively to a screen-protected pup but will attack an unprotected pup. In any case, all testing procedures have been approved by the University of Missouri Institutional Animal Care Review Board (Animal Protocol Reference No. 208) and NIH Grant NS20075.

In addition, an animal's reaction toward a pup seems to be a nonspecific response, with no evidence of kin or sex recognition. Previous studies have shown that neither sex, age (1–10 days), relatedness, nor strain type of the pup has any discernible influence on a male's or female's propensity to exhibit either infanticide or parental behavior (Svare *et al.*, 1984; vom Saal, 1985). CF-1 pups were thus used for all behavioral tests.

EXPERIMENT I. THE PHENOTYPIC FREQUENCY OF INFANTICIDAL AND PARENTAL BEHAVIOR IN VIRGIN MALE AND FEMALE CF-1- × WILD-STOCK HYBRIDS

Methodology

As noted in the Introduction, virgin male and female house mice from CF-1 and Albertan Wild stocks show reliable and characteristic differences in their proportions of infanticidal and parental phenotypes. Thus, in the following experiment, we generated male and female offspring from all possible mating combinations of male and female CF-1-stock and Albertan Wild-stock parents, then tested these offspring when adult (4 months of age) for their behavior toward newborn pups. A control situation was also established; specifically, CF-1 and Wild-type offspring were cross-fostered to opposite-type mothers.

Thirty pairs of breeding animals were established for each of six different mating groups: (1) Wild♀ × Wild♂; (2) Wild♀ × CF-1♂; (3) CF-1♀ × CF-1♂; (4) CF-1♀ × Wild♂; (5) CF-1♀ × CF-1♂, whose pups were cross-fostered to Wild mothers; and (6) Wild♀ × Wild♂, whose pups were cross-fostered to CF-1 mothers. Mating pairs were created by individually housing a 5-month-old proven stud male with a 4-month-old virgin female chosen at random from our colonies. When a female became visibly pregnant, the stud male was removed so that each female could deliver and raise her pups in isolation. No differences in pregnancy rates were noted between same- and opposite-stock crosses (85–95% success in all groups); likewise, most females were inseminated within several days of being paired with a male, regardless of the combination.

For cross-fostered animals, individuals from litters born on the same day were randomly switched to the opposite-type female within several hours after birth. Wild- and CF-1-stock mice have dramatically different litter sizes; thus, each Wild mother received 6–8 newborn CF-1 pups randomly chosen from several litters, whereas each CF-1 mother received 10–12 newborn Wild pups randomly chosen from several litters. Whenever possible, foster litters were constituted with an equal number of males and females.

Pups from all groups were weaned at 23 days of age and randomly grouped in same-sex cages consisting of either 5 females or 5 males per cage until 3 months of age, when 45–55 animals from each sex and cross (out of a total of 100–150 animals in each group) were randomly chosen and isolated for behavioral testing 4 weeks later, at 4 months of age. All animals were tested with a 1- to 3-day-old pup at 2 h after lights-on.

Results

Figure 1 shows the proportion of infanticidal, ignore, and parental phenotypes within each of the 12 experimental groups tested here (2 Mother Types × 2 Sexes × 3 Mating Groups). All pairings are listed at the bottom of the histogram bars in Fig. 1 by Mother Type first. A loglinear analysis—which is analogous to a multiway chi-square test—was performed on the entire data set; however, significant main effects and interactions were the same as those obtained by using simpler chi-square statistics comparing behavioral frequencies within each Sex × Mother Type grouping. Thus, for the sake of clarity and brevity, the chi-square results are reported as follows:

Male Offspring of Wild Mothers. All virgin males derived from Wild mothers showed a high proportion of spontaneous infanticidal behavior (80%

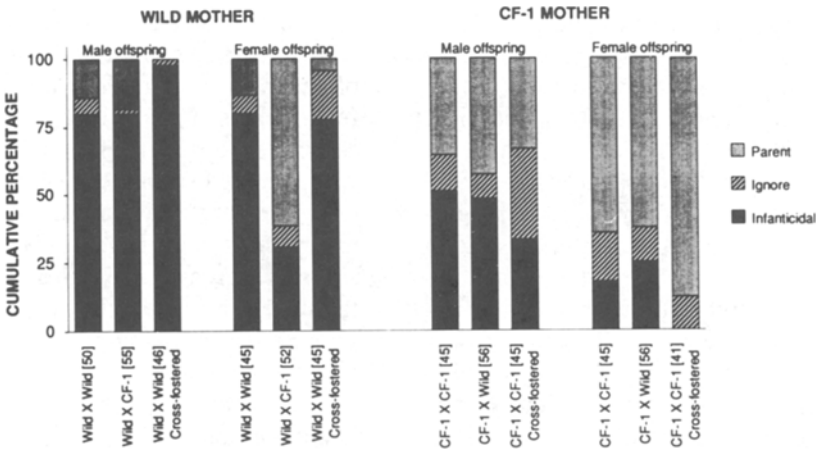

Fig. 1. The proportion of infanticidal, parental, or pup-ignoring individuals in each experimental group. All pairings are listed by mother type first. [*N*] = number of individuals tested.

or greater in all three groups). However, infanticidal behavior was significantly increased in Wild-type males fostered to CF-1 mothers ($\chi^2_{df\ 4} = 10.7$, $p < .05$); in fact, none of the fostered Wild males displayed parental behavior.

Female Offspring of Wild Mothers. Eighty percent of the Wild-type females raised by either their own or a CF-1 foster mother exhibited spontaneous infanticidal behavior. However, those female offspring who were fathered by CF-1 males showed a significant reduction in infanticidal behavior (31%, $\chi^2_{df\ 4} = 48.8$, $p < .0001$). Furthermore, the proportion of behaviors in female offspring sired by a CF-1 male was no different from the proportion of behaviors noted in female offspring raised by their CF-1 mothers, regardless of whether their father was a CF-1 or a Wild male (31% infanticidal versus 18 and 25% infanticidal, respectively; $\chi^2_{df\ 4} = 3.65$, $p > .45$).

Male Offspring of CF-1 Mothers. Regardless of father type or cross-fostering, there were no significant differences in the proportion of infanticidal versus noninfanticidal (parental and ignore categories combined) male offspring derived from CF-1 mothers (33–51% infanticidal; $\chi^2_{df\ 2} = 3.4$, $p > .15$). However, cross-fostering CF-1-type males to Wild mothers did have a significant effect on reducing the frequency of parental behavior while elevating the percentage of males that ignored pups ($\chi^2_{df\ 4} = 11.6$, $p < .05$).

Female Offspring of CF-1 Mothers. Regardless of father type, female offspring generated from CF-1 mothers showed similar frequencies of spontaneous infanticide (18 vs. 25%). Nevertheless, cross-fostering a CF-1-type female to a Wild-type mother resulted in a complete inhibition of spontaneous infanticide ($\chi^2_{df\ 4} = 12.9$, $p < .05$).

EXPERIMENT II: THE TIMING OF INFANTICIDE INHIBITION IN THE EJACULATION-TRIGGERED RESPONSE OF WILD-STOCK MALE HOUSE MICE

Background

Ejaculation triggers a unique neural timing phenomenon in male house mice (vom Saal, 1985; Perrigo *et al.*, 1990, 1991). In sexually naive male CF-1 mice, about 50% of individuals exhibit spontaneous infanticide when they encounter a pup. The stimulus of ejaculation, however, promotes infanticide such that immediately following mating, 90% of CF-1 males will now exhibit infanticide. But, by the time a male's own sired offspring would be born about 3 weeks after mating, infanticide is inhibited in virtually all males. When infanticide ceases, most males express parental behavior similar to that of a newly lactating female. They remain parental throughout the entire period of their mate's lactation, but many males spontaneously begin killing pups again between 50 and 60 days after mating. The reemergence of infanticidal behavior thus coincides with the weaning of pups.

Remarkably, these behavioral changes occur in CF-1 males in the total absence of any female cues whatsoever following mating; thus, these ti-

med behavioral changes toward pups result specifically from the stimulus of intravaginal ejaculation and have also been noted among other laboratory stocks of *Mus domesticus*, as well as wild *Mus musculus* from Israel (Soroker and Terkel, 1988) and the Norway rat, *Rattus norvegicus* (Mennella and Moltz, 1988). As described in the Introduction, it is now widely accepted that multiple inhibitory mechanisms can act either independently or in unison, depending on the particular mouse stock; likewise, the efficacy of ejaculation also depends on the particular stock used. It should be emphasized, however, that in the CF-1 males used in our experiments, ejaculation appears to be the primary mechanism that inhibits infanticide (Perrigo *et al.*, 1991).

As the aim of the current experiment was to examine what effect reciprocal crosses of CF-1 × Albertan Wild mice would have on the ejaculation-mediated timing of infanticide inhibition in male hybrids, our first step was to examine this phenomenon in Albertan Wild stock males. To our knowledge, no such test had ever been done on a Wild *Mus domesticus* stock; thus, we had no a priori knowledge of how Albertan Wild males would respond to ejaculation.

Methodology

Twenty Wild-stock males, 6 months of age, were allowed to mate by placing two estrus-primed Wild-stock females in the male's home cage at 1 h before lights-on. Three hours later, females were examined for the presence of either a copulatory plug or sperm in the vagina to confirm that the male had ejaculated. Upon confirmation of ejaculation (Day 0), each Wild male was immediately tested with a newborn pup to determine whether he was infanticidal or parental. Males were then retested for their behavior toward a pup at 2 h after lights-on at Days 7, 14, 21, 60, and 90 after mating.

Results

Figure 2 compares the results of the above experiment with a nearly identical experiment performed on CF-1-stock males (N = 28) of the same age and under the same conditions (Perrigo *et al.*, 1991). As determined by Fisher exact tests comparing the frequency of infanticidal versus noninfanticidal behavior in both stocks at each test day, there were no differences in the time course of the inhibition of infanticide following mating between either our Albertan Wild or our CF-1 stock (Fisher exact: p = .20, .56, 1.0, 1.0, .15, and .56 for Days 0, 7, 14, 21, 60, and 90, respectively). Two points should be stressed here. First, mating inhibited infanticide in the same proportion of males (~75%) in both stocks by 2 weeks after mating (pups are born at day 18 in Wild stocks and day 19 in CF-1 stocks); and second, although not shown in Fig. 2, virtually all males that transitioned from infanticidal to noninfanticidal behavior after mating behaved parentally toward pups.

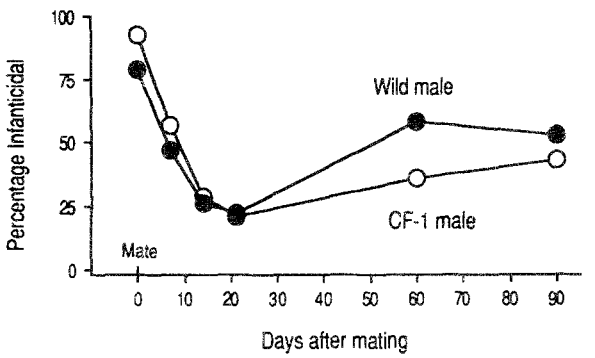

Fig. 2. The time course of infanticidal inhibition from coital ejaculation (day 0) until 90 days later in Wild-stock males (N = 20) versus CF-1-stock males (N = 28). The CF-1 data are redrawn from Perrigo *et al.* (1991).

As we observed no differences whatsoever in the timing curves between Albertan Wild males and CF-1 males, we decided for purely ethical reasons not to test the postmating inhibition of infanticide in the F_1 hybrid males generated in the previous experiment. This would have entailed the use and potential injury of many more pups, all at the expense of gaining little, if any, useful information toward the original objective of this experiment.

DISCUSSION

The results in Fig. 1 confirm a genetic substrate for the inheritance of infanticidal and parental behavior. The most parsimonious explanation suggests that maternal genotype in both the CF-1 and the Albertan Wild stock exerts dominance over the infanticidal and parental characteristics of male offspring, as hybrid males exhibited the strain-specific phenotype of their mother's stock. In female offspring, however, hybrid females exhibited the behavioral phenotype of CF-1 females, regardless of whether derived from an Albertan Wild mother or

Albertan Wild father. These results suggest a sex difference in the inheritance of infanticide and that a genetic substrate for infanticide appears to be sex-specific in house mice, at least in the two stocks tested here. This sex difference is not surprising, however, because infanticide in house mice is known to be a sexually dimorphic and steroid-sensitive behavior, subject to regulation by gonadal hormones during fetal, postnatal, and adult life. Although no genetic model has explained a specific hormonal mechanism to account for strain-based differences in infanticide, the current physiological evidence suggests that various mouse stocks have undergone genetic changes in their sensitivity to steroids at the neural tissue levels responsible for governing behavior toward pups (Svare *et al.*, 1984; Perrigo and vom Saal, 1989).

Svare and co-workers have extensively examined sex- and strain-based hormonal differences in infanticide between C57BL and DBA stock laboratory mice (Svare and Mann, 1981; Svare and Broida, 1982; Mann *et al.*, 1983; Svare *et al.*, 1984). C57BL mice are an androgen-deficient stock in which about 70–80% of adult males (>70 days of age) exhibit infanticide, while only 20–30% of adult DBA males kill young. In contrast, adult females of the C57BL and DBA stock rarely kill young. In the only other hybrid study of infanticide that we know of, male offspring generated from reciprocal C57BL × DBA crosses all showed phenotypic behaviors identical to the pure DBA genotype, regardless of the maternal genotype (Svare and Broida, 1982). This contrasts markedly with our present results, which suggest a maternal dominance in the phenotype of male offspring from reciprocal CF-1- × Albertan Wild-stock crosses.

With regard to postnatal maternal effects, Svare and Broida (1982) found no behavioral differences when newborn male C57BL and DBA mice were reciprocally cross-fostered. Male offspring retained their original phenotype regardless of being fostered with their own- or an opposite-type mother. On the other hand, our results show that cross-fostering did indeed have a significant, but *opposite* effect upon the behavior of Wild-type males and CF-1-type males and females. Specifically, being raised by CF-1 mothers—which routinely show *low* levels of infanticide—resulted in significantly elevated infanticidal behavior in Wild-type males, whereas being raised by Wild mothers—which routinely show *high* levels of infanticide—completely eliminated infanticide in CF-1 females.

One potential speculation as to why cross-fostering seemed to amplify phenotypic differences between offspring and their foster mothers may stem from the fact that inbred domestic stocks, such as the CF-1, have undergone intense artificial selection for large litter size (mean of 13.7 pups/litter in this experiment) and rapid postnatal weight gain, whereas Wild stocks routinely produce much smaller litters (mean of 5.7 pups/litter in this experiment), obtain a much smaller adult body size, and show relatively slow postnatal growth. Perhaps some sort of nutritional and developmental interaction may have occurred during lactation that simply cannot be explained within the context of this experiment. It must be stressed, however, that regardless of the peculiar and contradictory maternal effects noted in both sexes, this result in no way diminishes our primary conclusion of inherited differences in infanticide.

Our present results—plus the fact that laboratory and wild stocks vary so dramatically in their proportion of infanticidal phenotypes—suggest that infanticide is a highly labile and heritable behavior. Because infanticide was once thought to represent an aberrant and pathological behavior, it is easy to suggest an explanation of how such enormous stock-to-stock variation could arise via artificial selection; pup-killing males and females were probably culled frequently enough to influence the gene pools and behavioral evolution of various inbred lab stocks. Our results also demonstrate that there is no obvious genetic correlation between strain-specific levels of spontaneous infanticide in males and the neural ejaculatory mechanism that inhibits infanticide following mating. Figure 1 shows that artificial selection has reduced the level of spontaneous infanticide in CF-1 males, while Fig. 2 shows no significant difference in the time-course of post-mating infanticidal inhibition between CF-1 and Albertan Wild males. In addition, in other inbred mouse stocks some males may exhibit relatively high levels of infanticide, while ejaculation per se does not inhibit infanticide (e.g., Kennedy and Elwood, 1988). Interestingly, previous studies have shown that individual variation in both of these behavioral components is correlated with *in utero* variation in exposure to sex steroids during late fetal development (vom Saal, 1983, 1984, Perrigo *et al.*, 1989b, 1991). But despite these known hormonal influences, the present evidence suggests that selection can operate independently on these two traits. The obvious follow-up experiment would be to examine

the behavior of F_1 hybrids from a stock that exhibits copulatory inhibition versus one that does not.

When viewed *in toto*, infanticidal behavior probably results from an amalgam of polygenic and sex-specific traits influencing a wide range of neural and developmental responses to the organizational and sensitizing effects of sex steroids. This also suggests that the neural and hormonal mechanisms that regulate the expression and inhibition of infanticide and parental behavior within each sex have, to a large degree, evolved independently of each other (see Perrigo *et al.*, 1990). The genetic lability of infanticide should not be so surprising given that house mice are well-known for their enormous behavioral, reproductive, and social flexibility (Bronson, 1979; Berry, 1981; Perrigo, 1990). Genetic studies of infanticide in house mice could thus yield a wealth of unique information concerning the evolution and physiology of a violent, but effective reproductive strategy found in a variety of mammals.

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REFERENCES

Berry, R. J. (1981). Town mouse, country mouse: Adaptation and adaptability in Mus domesticus (M. musculus domesticus). *Mammal Rev.* **11**:91–136.

Bronson, F. H. (1979). The reproductive ecology of the house mouse. *Q. Rev. Biol.* **54**:265–299.

Elwood, R., Masterson D., and O'Neill, C. (1990). Protecting pups in tests for infanticidal responsiveness in mice, *Mus domesticus. Anim. Behav.* **40**:778–780.

Hausfater, G., and Hrdy, S. (eds.) (1984). *Infanticide: Comparative and Evolutionary Perspectives*, Aldine, Chicago.

Hrdy, S. B. (1979). Infanticide among animals: A review, classification, and examination of the implications for the reproductive strategies of females. *Ethol. Sociobiol.* **1**:13–40.

Huck, U., Soltis, R., and Coopersmith, C. (1982). Infanticide in male laboratory mice: effects of social status, prior sexual experience, and basis for social discrimination between related and unrelated young. *Anim. Behav.* **30**:1158–116.

Kennedy, H., and Elwood, R. (1988). Strain differences in the inhibition of infanticide in male mice *(Mus musculus). Behav. Neur. Biol.* **50**:349–353.

Mann, M., Kinsley, C., Broida, J., and Svare, B. (1983). Infanticide exhibited by female mice: Genetic, developmental and hormonal influences. *Physiol. Behav.* **30**:697–702.

Marshal, J., and Sage, R. (1981). Taxonomy of the house mouse. *Symp. Zool. Soc. Lond.* **47**:15–25.

McCarthy, M., and vom Saal, F. S. (1985). The influence of reproductive state on infanticide by wild female house mice (Mus musculus). *Physiol. Behav.* **35**:843–849.

Mennella, J., and Moltz, H. (1988). Infanticide in rats: Male strategy and female counter-strategy. *Physiol. Behav.* **42**:19–31.

Palanza, P., and Parmigiani, S. (1991). Inhibition of infanticide in Swiss male mice: Behavioral polymorphism in response to multiple mediating factors. *Physiol. Behav.* **49**:797–802.

Perrigo, G. (1990). Food, sex, time and effort in a small mammal: Energy allocation strategies for survival and reproduction. *Behaviour* **114**:191–205.

Perrigo, G., and Belvin, L. (1992). Time and sex in the male mouse: Temporal regulation of infanticide and parental behavior. *Chronobiol. Int.* **9**:421–433.

Perrigo, G., and Bronson, F. H. (1982). Signaling and priming communication: Independent roles in the reproductive isolation of spatially-separated populations of rodents. *Behav. Ecol. Sociobiol.* **10**:181–184.

Perrigo, G., and vom Saal, F. S. (1989). Mating-induced regulation of infanticide in male mice: Fetal programming of a unique stimulus-response. In Blanchard, R., Brain, P., Blanchard, D., and Parmigiani, S. (eds.), *Ethoexperimental Approaches to the Study of Behaviour.* Kluwer, Dordrecht, The Netherlands. pp. 320–336.

Perrigo, G., Belvin, L., Bryant, W. C., and vom Saal, F. S. (1989a). The use of live pups in a humane, injury-free test for infanticidal behavior in male mice. *Anim. Behav.* **38**:897–898.

Perrigo, G., Bryant, W. C., and vom Saal, F. S. (1989b). Fetal, hormonal and experiential factors influencing the mating-induced regulation of intanticide in male house mice. *Physiol. Behav.* **46**:121–128.

Perrigo, G., Bryant, W. C., and vom Saal, F. S. (1990). A unique neural timing mechanism prevents male mice from harming their own offspring. *Anim. Behav.* **39**:535–539.

Perrigo, G., Belvin, L., and vom Saal, F. S. (1991). Individual variation in the neural timing of infanticide and parental behavior in male house mice. *Physiol. Behav.* **50**:287–296.

Soroker, V., and Terkel, J. (1988). Changes in incidence of infanticidal and parental responses during the reproductive cycle in male and female wild mice *Mus musculus. Anim. Behav.* **36**:1275–1281.

Svare, B., and Broida, J. (1982). Genotypic influences on infanticide in mice: Environmental, situational and experiential determinants. *Physiol. Behav.* **28**:171–175.

Svare, B., and Mann, M. (1981). Infanticide: Genetic, developmental and hormonal influences in mice. *Physiol. Behav.* **27**:921–927.

Svare, B., Kinsley, C., Mann, M., and Broida, J. (1984). Infanticide: Accounting for genetic variation. *Physiol. Behav.* **33**:137–152.

vom Saal, F. S. (1983). Variation in infanticide and parental behavior in male mice due to prior intrauterine proximity to female fetuses: Elimination by prenatal stress. *Physiol. Behav.* **30**:675–671.

vom Saal, F. S. (1984). The intrauterine position phenomenon: Effects on physiology, aggressive behavior and population dynamics in house mice. In Flannelly, K., Blanchard, R., and Blanchard, D. (eds.), *Biological Perspectives on Aggression.* A. R. Liss, New York, pp. 135–179.

vom Saal, F. S. (1985). Time-contingent change in infanticide and parental behavior induced by ejaculation in male mice. *Physiol. Behav.* **34**:7–15.

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