The ram as a model for behavioral neuroendocrinology

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Abstract

The sheep offers a unique model to study male sexual behavior and sexual partner preference. Rams are seasonal breeders and show the greatest libido during short days coincident with the resumption of ovarian cyclicity in the ewe. Threshold concentrations of testosterone are required for the acquisition and display of adult sexual behavior. In addition, estrogens produced from circulating testosterone by cytochrome $P450$ aromatase in the preoptic area are critical for the maintenance of sexual behaviors in rams. Sex differences in adult reproductive behaviors and hormone responsiveness are the result of permanent organizational effects exerted by testosterone and its metabolites on brain development. Early exposure to ewes enhances ram sexual performance, but cannot prevent some rams from exhibiting male-oriented sexual partner preferences. Neurochemical and neuroanatomical studies suggest that male-oriented ram behavior may be a consequence of individual variations in brain sexual differentiation.
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Introduction

Scientists have used laboratory animals (primarily rats) for many years to study physiological mechanisms underlying the regulation of behavior. The information acquired from this body of work has been pivotal. The rat has been a convenient model that provides preliminary information that, at least in part, can be applicable to other species, including humans. Therefore, we have a large repository of information about the natural history and physiology of the laboratory rat. The rat, however, may not always be the best model for a particular research project. Recently the domestic sheep has become valuable as a tool for understanding sexual behavior, neural and endocrine systems related to reproduction. Although there is an abundance of information about domestic sheep, most of it is written from an animal husbandry perspective. The purpose of this article is to review information about the natural history, behavior and physiology of the domestic ram for scientists who may be interested in using sheep as a model for their work in behavioral endocrinology and physiology. This paper will review our current understanding of the biological and social aspects of sexual behavior in domestic rams.

Domestication

Sheep were domesticated in southwest Asia around 9000 BC. There are four main breeds: the Argali (*Ovis ammon*) of central Asia, the Bighorn (*Ovis canadensis*) of North America, the Urial (*Ovis vignei*) of southwest Asia, and the Mouflon (*Ovis musimom*). Mouflon are restricted mainly to Mediterranean islands. All wild type sheep can interbreed and are considered a single species. Domestic rams can interbreed with wild type ewes if a wild ram is not present (Ryder, 1983). Scientists speculate that the Mouflon is the progenitor of all European breeds (Ryder, 1983). All domestic sheep, as well as the wild Mouflon, have 54 chromosomes (Vorontsov et al., 1972). Some modern domestic sheep could have arisen by

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hybridization of other wild types such as the wild Argali ($2n=56$) followed by selection for a reduced chromosome number (Nadler et al., 1973).

Domesticating sheep did not alter their new inheritance, but rather allowed for a greater range of variation to survive. The observations of variation led to selective breeding for preferred traits such as a wooly fleece, longer tails and no horns (Ryder, 1983). Sheep breeders have used artificial selection by selective breeding over many generations. These selection criteria differ widely around the world and have resulted in numerous modern breeds.

The biological process involved in domestication probably involved "imprinting" of young lambs on a human rather than its mother. There is a critical period that lasts only for a few hours following the birth of lambs, during which lambs develop a sensory image of their mother (or substitute; for review on this topic see chapter by Nowak et al., in this issue). The ewe learns to identify her own lamb during this same critical period. It is this ability to bond to humans during a critical period along with the inherent flocking behavior of this species that contributed to the early ecological relationships between humans and sheep (Lay et al., 1971; Reed, 1977).

How to study sexual behavior in sheep

Reproductive efficiency is an important selection criterion for sheep. In a modern-day sheep operation, females that fail to become pregnant are eliminated from the flock. Rams are tested for fertility using semen evaluation and a behavioral evaluation called a "serving capacity test". Serving capacity refers to the ability of a ram to successfully inseminate a number of ewes (preferably during the ewe's first estrous cycle following introduction of the ram). Since the recommended stocking ratios for American sheep producers is between 1:30 and 1:50 rams to ewes, sheep producers must be certain that their rams are efficient breeders.

The serving capacity test was first developed by Mattner and colleagues in Australia (Mattner et al., 1971). These scientists defined serving capacity as "the number of matings with estrous ewes a ram achieves in a specific time period when confined to a pen of limited size." In the basic serving capacity test, yearling rams are exposed individually to 3–4 unrestrained hormone-induced estrous ewes in 4 m × 4 m pen enclosures for a 30-min test during which the number of services (ejaculations) are recorded. Rams can be classified as either sexually active or sexually inactive after their first test with females. Sexually active rams are assigned an ejaculation score (total number of ejaculations in 30 min). Rams that are sexually active on their first test rarely become inactive. If they are tested repeatedly with females, they can be assigned a serving capacity score, which is the average number of ejaculations each ram achieves over repeated 30 min. testing periods. Rams classified as high libido show an average of 5–6 ejaculations within 30 min, whereas low libido rams perform less than 4 ejaculations. Among the sexually active rams, serving capacity scores are predictive of fertility success in pasture matings (Price, 1987). At the U.S. Sheep Experiment Station in Dubois, Idaho serving

capacity tests were routinely used to select potential sires and to identify individuals that fail to become sexually active. Hundreds of rams have been tested annually for the past 18 years. Each year approximately 20% of the rams are below optimum for selection as herd sires. There are many different reasons for poor performance during a serving capacity test.

The first major observation made during the use of the serving capacity test is the tremendous variation in sexual behavior of rams. Some rams are immediately stimulated by the ewes and begin courtship and mounting within minutes of being introduced into the testing pen. Other rams fail to even investigate the ewes and never direct courtship behaviors toward them.

Some sexually inactive rams will begin to copulate when provided with additional opportunities. These rams are typically called low sexual performers because they inseminate fewer females (Perkins et al., 1992b). Among the group of rams identified as sexually inactive, are rams that will not mount females but will mount male pen-mates. A ram that fails to become sexually active when exposed individually to at least three estrous females for 20 min on repeated occasions, and that mounts males exclusively in the presence of estrous females is classified as a male-oriented ram (see Mate preferences and sexual attraction).

A brief description of ram copulatory behavior

Sheep are polygamous breeders. Rams use olfactory cues to detect estrous ewes (Lindsay, 1965). If a receptive ewe is introduced into a pen containing a ram with prior copulatory experience, the ram will approach her within several seconds. There are several stereotyped behaviors that the ram may engage in prior to his initial mount. These include sniffing the genital region of the ewe; pawing at her flank repeatedly with his foreleg while standing behind and at a small angle to her (foreleg kick); and nuzzling, licking and nibbling at her flank and ano-genital area. Prior to copulation rams will also elevate the head and retract the upper lip in response to the odor or taste of the ewe's urine, a behavior referred to as flehmen. The flehmen response draws non-volatile odors into the vomerona-sal organ for detection by the accessory olfactory system. Some males additionally emit low-pitched 'gargling' vocalizations before and while pawing the ewe. The sum total of these behaviors is frequently called "courting behaviors".

There is considerable variation among males in the frequency and duration of these precopulatory responses. It is not clear whether they play a functional role in stimulating the ewe or inducing her to stand for copulation. A fully receptive ewe stands quite still after the initial approach by the ram and will often turn her head to one side and appear to watch him. There is also a characteristic wagging of the tail (fanning) that accompanies full receptivity and which may help disperse relevant olfactory cues.

Mounting behavior in rams is accompanied by a series of shallow pelvic thrusts. Rams usually mount several times prior to vaginal penetration and ejaculation, but an experienced ram may ejaculate on the first mount. Rams are capable of multiple

ejaculations with a single ewe, although the intervals between successive ejaculations become progressively longer (Bermant et al., 1969).

Copulatory behavior can be measured in a serving capacity test where a ram is paired with 3–4 estrous ewes as described above, or in tests where an individual ram is paired with an individual estrous ewe. Copulatory behavior tests are usually time-limited and last at least 10 min during which a number of measurements can be taken. These include mount latency, mount frequency, ejaculation latency, ejaculation frequency, and post-ejaculatory interval.

Seasonal reproduction and segregation of the sexes

Sheep in temperate climates are seasonally breeding mammals that are reproductively active after the summer solstice as the day length declines in the late summer and fall. Decreasing day length stimulates the release of gonadotropins, which drive gametogenesis and gonadal steroid hormone secretion in both males and females (Martinet et al., 1993; Lincoln, 2002). Seasonal activation of the reproductive axis initiates cyclic elevations of progesterone and estradiol that triggers the expression of estrous behavior in the ewe, and stimulates increased production of testosterone by the testis, which in turn triggers the expression of libido in the ram. Most domestic rams will mate out of season, but do not exhibit peak performance unless given regular exposure to estrous ewes (Tulley and Burfening, 1983; Tilbrook and Cameron, 1990). Therefore, behavioral studies are best planned during the peak-breeding season in the fall and early winter.

Seasonality of breeding in feral and wild populations of sheep is associated with segregation of the sexes for much of the year. Ewes are gregarious by nature and flock together for grazing, protection, and rearing of young lambs. Young rams up to 2 years old are present with the ewe flock in most wild populations. Feral and wild adult rams tend to be more solitary although some breeds such as Soay and wild Mouflon form male groups. As the breeding season (rut) approaches, males congregate and often engage in fights that are believed to stabilize dominance hierarchies. During the rut, rams disperse and move through the flock in search of estrous ewes. The rut is usually spread over 2 or 3 weeks in mountain sheep, Soay and Mouflon breeds, but rams may stay with the ewes for up to 8 weeks. After the breeding season has finished, rams re-establish a male group and move away from the ewe home-range areas.

In contrast to wild populations of sheep, sexual segregation is enforced in most modern husbandry practices by exclusion of rams from ewe flocks, except during breeding. At the USSES in Dubois, Idaho, single sire breeding takes place in November (35 ewes/ram) after which the ewes are moved to the Fall/Winter rangeland. Lambing begins in April at the Field Station. Ewes and lambs are penned together for 2–6 weeks before being moved to summer rangeland. Male lambs are weaned and separated from ewes in August at 4–5 months of age. Young rams are kept separate from mature rams until 12 to 18 months of age. This cycle of breeding begins again in the fall.

Hormonal control of sexual behavior in adult rams

Testosterone is essential for the development and maintenance of sexual behavior in rams. Sexual activity increases with elevated levels of testosterone during puberty (Thwaites, 1982; Orgeur and Signoret, 1984). The expression of sexual behavior in rams at puberty can be suppressed by treatment with either a GnRH agonist (Tilbrook et al., 1993) or active immunization against GnRH (Brown et al., 1994), both of which reduce gonadotrophin secretion and testicular development.

The importance and relationship to sexual behavior of testosterone has been demonstrated by castration and hormone replacement studies. Rams castrated before puberty show reduced or no sexual interest as adults (Clegg et al., 1969; Parrott, 1978). Sexual behavior declines in sexually experienced adults after castration and may take up to 12 months before rams completely lose interest (Clegg et al., 1969; D'Occhio and Brooks, 1980). On the other hand, treatment with testosterone stimulates sexual behavior in rams castrated either before puberty (Clegg et al., 1969; Mattner et al., 1976; D'Occhio and Brooks, 1980, 1982; Parrott and Baldwin, 1984; D'Occhio et al., 1985) or after puberty (Clegg et al., 1969; Mattner, 1976). Likewise, the restoration of sexual behavior with hormone replacement therapy is not immediate but occurs after a few weeks of treatment. Rams that are sexually experienced before they are castrated have been found to resume sexual behavior more quickly following treatment with testosterone than rams that were castrated prior to puberty (Clegg et al., 1969).

Testosterone is converted to estradiol by cytochrome $P450$ aromatase within the central nervous system of rams and there is evidence that this metabolite of testosterone and not testosterone itself is responsible for maintenance of sexual behavior in rams. Aromatase is enriched within brain regions important for the control of male reproductive behaviors (Roselli et al., 1998, 2000). Treatment of castrated rams with estradiol stimulates sexual behaviors (Mattner, 1976; Parrott, 1978; D'Occhio and Brooks, 1980, 1982; Parrott and Baldwin, 1984; D'Occhio et al., 1985), but the treatment with the non-aromatizable dihydrotestosterone is ineffective (Parrott, 1978; D'Occhio and Brooks, 1982; Parrott and Baldwin, 1984; D'Occhio et al., 1985). In rodents estrogens and androgens synergize to stimulate copulatory behavior (Sachs and Meisel, 1994), however, such synergism has not been consistently reported for rams (Mattner, 1976; Parrott, 1978; D'Occhio and Brooks, 1980; Parrott and Baldwin, 1984).

As was shown originally in rodents (Damassa et al., 1977), sex drive in rams is not directly related to serum levels of testosterone. There is no correlation between circulating levels of testosterone or other androgens and the level of sexual activity (Knight, 1973; Schanbacher and Lunstra, 1976; Howles et al., 1980); nor are there differences in the concentrations of testosterone between high and low libido rams (Perkins et al., 1992a; Stellflug, 2006). Treatments with exogenous androgens neither initiate sexual activity in sexually inactive rams (Knight, 1973) nor enhance behavior in sexually active rams (Lincoln and Davidson, 1977). In fact, circulating concentrations of

testosterone are well above the threshold levels necessary to facilitate sexual behaviors in rams (D'Occhio and Brooks, 1982). Thus, although circulating testosterone is an important physiological regulator of sexual activity in rams, it is apparent that other factors must also be involved.

Sexual differentiation of reproductive behavior in sheep

Sex differences in adult reproductive behaviors and hormone responsiveness are the result of organizational effects that gonadal steroid hormones exert during discrete critical periods in early fetal life (MacLusky and Naftolin, 1981). These early effects of gonadal steroids are permanent, in contrast with the reversible activational actions that steroids exert on behavior after puberty. Sexual differentiation in mammals will follow the female pattern of differentiation unless the fetus is exposed to testicular hormones, which stimulate cellular programs that direct the development of the male pattern of differentiation (MacLusky and Naftolin, 1981). The terms used to describe masculine differentiation are: masculinization, the production of male-typical copulatory behaviors; and defeminization, the suppression of female-typical sexual receptivity. These terms can also be applied to other behaviors such as sexual partner preference and to patterns of gonadotrophin secretion, i.e. male-typical tonic secretion versus female-typical cyclic secretion. Gestation in the sheep lasts approximately 150 days. Gonadal differentiation occurs between gestational day 25 (G25) and G35 and the external genitalia begin to differentiate on G45 (Clarke et al., 1976a). The fetal testes synthesize elevated levels of testosterone starting around G35 (Attal, 1969; Pomerantz and Nalbandov, 1975) and the testicular content of testosterone continues to increase from this time until birth. Fetal males have higher circulating concentrations of testosterone at G65 to G70 than do fetal females (Pomerantz and Nalbandov, 1975). Concentrations of testosterone in males decline between G70 and G90, and are not significantly greater than in female until late in gestation and during postnatal life (Pomerantz and Nalbandov, 1975; Roselli et al., 2006). Thus, it appears, in sheep, that testicular androgen is available to sexually differentiate males as early as the first trimester of pregnancy.

Short (1974) administered testosterone implants to pregnant ewes on G20, G40, G60 and G80 and left the implants in place until parturition. Female lambs exposed to testosterone from G20 or G40 showed complete masculinization of external genitalia. Those implanted with testosterone on G60 or G80 showed normal female external genitalia although the clitoris was enlarged. Female sheep exposed to testosterone from G20 to G60 until birth, did not display estrus behavior during adulthood (defeminization) and showed male-like mounting patterns (masculinization) (Short, 1974). The results suggest that masculinization of the internal and external genitalia in sheep occurs during the early phase of elevated fetal testosterone and behavioral masculinization occurs later.

Clarke and colleagues (Clarke et al., 1976b; Clarke, 1977) assessed the effects of maternal testosterone treatment in sheep over several different gestational periods on estrous cyclicity and the display of male-typical mounting behavior. The greatest degree of genital masculinization was achieved in ewes exposed to testosterone over days G30–G80, whereas the greatest behavioral masculinization and defeminization was seen in ewes exposed to testosterone over either G50–G100 or G70–G120. Ewes exposed to testosterone from G90 to G140 exhibited regular estrous cycles and receptivity, with a slight but statistically nonsignificant enhancement of masculine behavior compared to control ewes. These results confirmed that the critical period for behavioral masculinization/defeminization occurs slightly later than the sensitive period for genital masculinization. Furthermore the period of maximum behavioral sensitivity to testosterone occurs prior to G90. Exposure of ewes to testosterone from G30 to G90 has also been shown to suppress the LH surge mechanism, progesterone negative feedback on gonadotropin secretion, and to masculinize the control of tonic LH secretion resulting in the advancement of puberty. For a more complete discussion of the sexual differentiation of the neuroendocrine control of gonadotrophin secretion in sheep, see Foster et al. (2002).

The role of experience in sexual performance of rams

E.O. Price and his colleagues at the University of California at Davis have conducted a number of experiments that help elucidate the contributions of learning and social experience to subsequent sexual behavior in rams. Data from this laboratory suggests that management practices for sheep might contribute to sexual development and performance in rams (Price, 1987). 20% to 35% of sexually inexperienced yearling rams reared in all male groups are sexually inactive when they are first exposed to estrous females. In a typical domestic sheep operation, young ram lambs are removed from their mothers and sisters by about 3 months of age and raised in all male groups. There is a great deal of male–male interaction that takes place in these groups including mount attempts, mountings and foreleg kicks.

In one experiment over 100 commercial rams born at the Hopland Research Center in California were maintained as a single all-male group after weaning at 3 months of age (Price et al., 1994). They were assigned to one of two groups: sexually experienced or no sexual experience. Rams in the sexually experienced treatment group were given four individual 30-min exposures to estrous ewes when the rams were 4 months old. Control rams were given no early exposure to ewes. Both groups of rams were isolated from females except during periods of testing. All rams were tested with estrous ewes in the fall when the rams were 22 months of age. Three rams in the sexually experienced group failed to show sexual interest in ewes during their early exposure. One of these was still sexually inactive at age 22 months. In the control group (no previous sexual experience), nearly 28% (13 of 47) of the rams were sexually inactive at 22 months of age during their first test with estrous females. By the fourth day of testing, nearly half (6 of 13) of the sexually inactive control rams began to exhibit sexual behaviors while seven individuals remained sexually inactive. This study shows that intermittent exposure of ram lambs to estrous ewes early in life can improve their sexual performance as yearlings. The authors also conclude that there is more than

one explanation for mating failure in sexually inexperienced rams. In follow-up tests, the sexually inactive rams were allowed continuous exposure to females. Some of the inactive rams became sexually active under these conditions. However, two rams were identified to be male-oriented because they were disinterested in ewes and would predominantly mount males when given sexual partner preference tests.

In a similar study, Price et al. (1999) conducted an experiment to determine if direct contact with females was necessary for enhanced sexual performance in rams. 7- to 8-month-old ram lambs were randomly assigned to treatment groups. One group had direct contact plus fence line exposure to ewes; the second group had fence line exposure only with ewes; and the control group had no contact with ewes. All the rams were tested with females during four separate sexual performance tests 1 year later. During their first test, there were clear differences between the treatments. 59% of the rams reared without contact with females failed to become active during their first sexual performance test. In contrast, only 15% of the rams reared with direct contact with females were inactive during their first sexual performance test. 38% of the fence-line contact group was sexually inactive during their first test. All of the rams were re-tested once a week for 4 weeks. By the fourth test, the number of inactive rams in the control group was reduced to 22%, while the number in the direct contract remained the same at 15%. The number in the fence line contact group was reduced to 19%. The authors suggested that the rams in the direct contact group (15%) that were sexually inactive during performance tests were likely to be male-oriented. They also concluded that early fence line contact with females could only partially substitute for early mating experience in enhancing sexual performance in yearling rams. One important observation made was that rams in the fence line contact group that spent a lot of time in close proximity to the estrous ewes tended to be more sexually active.

These important experiments that attempt to piece out the role of experience on sexual performance suggest that for rams, early exposure to females will increase the probability of rams becoming sexually active at an earlier age. As little as four separate 30-min exposures to estrous females (total 120 min) can significantly increase the percentage of rams that will be sexually active during their first exposure to females a year later. Early contact with females does not appear to prevent some rams from being male-oriented, or for some to have low libido. Therefore, it is likely that both sex-typical neuroendocrine development of the brain along with early exposure to females is important for subsequent sexual behavior in this species.

Mate preferences and sexual attraction

As discussed above, most domestic rams develop a sexual preference for females over males, even if they are raised in all male groups from weaning. Most rams also engage in male–male mounting behavior when females are not present, but will exhibit a distinct preference for females when given a choice. In contrast, a small percentage of rams develop a same-sex preference for other rams even when raised with females (Katz et al., 1988;

Price et al., 1994). Male-oriented rams will often mount male pen mates and are sexually inactive when individually exposed to estrous females. When presented with rams and estrous ewes in a sexual partner preference test, male-oriented rams mount and occasionally rectally intromit and ejaculate with rams while ignoring equally available estrous females.

Male-oriented rams exhibit species-typical male copulatory patterns with a male rather than female stimulus partner. Unfamiliar age-matched rams are used as stimulus animals and not chosen or tested for their sexual partner preference. All rams mount opportunistically. If, for example, a ram is eating at a feeder or drinking, other rams will attempt to mount him. When crowded together during moving, rams will mount the animals that are just in front of them. Observations of male–male mounting among a cohort of rams are not predictive of male sexual partner preference as operationally defined by sexual partner preference tests (Price et al., 1988).

Presumably, the development of male-orientation is strongly selected against in nature and in multi-male breeding programs for farmed animals. However, artificial insemination programs could perpetuate the tendency, particularly when male stimulus animals are used as teasers for collection of semen (Price, 1987). The male-oriented rams that have been identified at USSES were not a product of artificial insemination. But, male–male competition for access to females has been nearly eliminated through the standard practice of single sire pen breeding for many generations. There are now several reports documenting the occurrence of same-sex sexual preferences in rams (Zenchak et al., 1981; Price et al., 1988; Perkins et al., 1995; Resko et al., 1996; Perkins and Fitzgerald, 1997; Alexander et al., 1999).

In our research, sexual partner preferences are determined by first administering a series of at least 9 separate serving capacity tests to rams (Roselli et al., 2004a). Rams that fail to mate estrous ewes are then given an overnight test with 3 estrous ewes. After these initial tests, a subset of high libido rams and nonperforming potentially male-oriented rams are given sexual partner preference tests that present them with a choice between two rams and two estrous ewes. The stimulus rams are restrained and the test subject is free to interact with or ignore them. The frequencies of genital sniffs, foreleg kicks, nudges, vocalizations, flehmens, mount attempts, mounts, and ejaculations are recorded, as well as the sex of the animal to which these behaviors are directed. Price et al. (1988) first described the sexual partner preference test and found that restraint of the stimulus animals minimizes bias in their presentation and eliminates individual differences in aggressiveness. Tests are administered initially when the rams are ~16–18 months old and then again when they are ~28–30 months old. Rams that exclusively mount other rams are classified as male-oriented, whereas rams that exclusively mount ewes are classified as female-oriented. The majority of rams are female-oriented, estimated between 60% and 70% (Price et al., 1988; Perkins et al., 1992a; Roselli et al., 2004b). However, a significant proportion, between 6% and 8% meet the criterion for classification as male-oriented. For a more complete discussion of considerations important for partner preference testing in

sheep, see Price (1993) and Resko et al. (1999). Recently, Stellflug et al. (2006) found that 3 out of 5 rams characterized as male-oriented after one breeding season of testing will breed with ewes when placed in a competitive breeding environment with other rams. Rams that breed with females under these conditions would no longer meet the criteria for classification as male-oriented in our research. This study suggests that accurate descriptions of sexual partner preference require at least two to three breeding seasons of testing. These results point to the need for further research into the time course and development of sexual attraction and the significance and predictive value of sexual partner preference tests in rams.

Neurobiology of sexual partner preference in rams

The characterization of rams with distinct and verifiable sexual partner preferences provides a unique opportunity to explore the associations between an operationally defined behavioral phenotype and neurobiological traits. Not surprisingly, studies to date have focused on the hormone-sensitive limbic brain circuitry that controls male sexual behavior and motivation (Newman, 1999). This circuitry is highly sexually dimorphic and is established under the influence of testosterone and its estrogenic metabolites during critical periods in development, i.e. sexually differentiated (Simerly, 1995). Sex steroid receptors and aromatase are expressed in sexually dimorphic patterns across this circuitry (Roselli and Resko, 1993; Simerly, 1995). Recent genetic studies confirm that neural steroid receptor and aromatase concentrations contribute to the expression of sex-specific behaviors and partner preferences (Wersinger et al., 1997; Bakker, 2003).

Experiments in several species of mammals (including rats, mice, hamsters, ferrets, dogs, and pigs) and in Japanese quail support the hypothesis that organizational effects of gonadal steroids, which lead to permanent structural and/or chemical brain traits, determine adult sexual partner preferences (Adkins-Regan, 1988; Baum, 2006). Consistent with this hypothesis, Perkins et al. (1995) found that the estrogen receptor content of the sheep amygdala is sexually dimorphic and that estrogen receptor concentrations in the amygdala are significantly lower in male-oriented rams than in female-oriented rams and not different from concentrations in ewes. Because the amygdala receives sensory inputs from both the main and accessory olfactory systems, the difference in estrogen receptors implies that the amygdala of male-oriented rams may process olfactory information differently than female-oriented rams. Further support for the idea that male-oriented behavior in rams may result, in part, from variations in brain differentiation was the observation by Resko et al. (1996) that aromatase activity is significantly lower in the medial preoptic area of male-oriented than of female-oriented rams. Previous studies in rats demonstrated that the capacity for aromatization in the MPOA is a sexually differentiated characteristic of the brain that is organized by perinatal exposure to gonadal testosterone (Beyer et al., 1993; Roselli and Klosterman, 1998).

In common with other mammals, a sexually dimorphic nucleus that is larger in males than in females was discovered in the preoptic area/anterior hypothalamus of sheep (Roselli et al., 2004a). This nucleus resembles the sexually dimorphic nucleus of the preoptic area (SDN-POA) in rats and was, therefore, named the ovine SDN (oSDN). Like the SDN-POA in rats, the oSDN is significantly larger in males than in females and constitutes the central division of the medial preoptic nucleus. However, in addition to a sex difference in size, the oSDN was two times larger in female-oriented rams than in male-oriented rams. In this respect the oSDN also resembles the third interstitial nucleus of the anterior hypothalamus (INAH3) in humans (LeVay, 1991), which is significantly larger in heterosexual men than in homosexual men and women. The dense cluster of neurons that comprise the oSDN express aromatase mRNA, levels of which are greater in female-oriented rams than in male-oriented rams and ewes. These results indicate that the volume of the oSDN and level of aromatase within this nucleus are associated with the expression of sexual partner preferences. Further study is needed before these brain differences can be ascribed as a cause or consequence of the behavior.

Conclusions

Sheep were the second species to be domesticated by humans, so we have a long history and important relationship with them. Sheep provided our ancestors with many products including food and fibers. Now, it appears that this species can be used as an important biomedical model. To do so, requires that we understand the neuroendocrine mechanisms mediating their behaviors. This paper provides some basic natural history and current information about sheep that may be helpful to future researchers.

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