

Neurobiological bases of social bonding and pair-bond formation in animals

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Introduction

The formation of strong social bonds among individuals, let them be animals or humans, is essential for individual well-being as well as for survival at both individual and species levels. It is widely accepted that in humans, social bonding and pair-bond formation are a critical component of mental health. An inability to do so is used as a diagnostic component of various psychological dispositions and disorders, including autism, Asperger's syndrome, social anxiety and schizophrenia. Study of the neurobiology underlying social bonding may shed light on the causes and treatment of such disorders. A detailed study of it should, necessarily, also include the exploration of the neurobiological bases of social bonding in animals as it can provide us with an insight into the origins of these disorders.

But the study of social bonding and pair-bond formation in animals on its own is also an important scientific endeavor as it can help us understand numerous behavioral phenomena, including monogamy, mate recognition and parent-infant recognition as well as the social advantage of monogamous pair relationships in certain mammalian species, including humans.

How do mammals develop pair-bond formation? Are there behavioral cues or physiological-biochemical mechanisms behind it? Is it a sensory cue, a look, between two animals, or a scent, a pheromone-system based attraction between them, or is it a bit more complicated than that? And in that case, which are the hormones and neurotransmitters that may play a distinguished role in the neurobiology of the monogamous animals?

Here we review some recent findings on the neuropeptidergic regulation of monogamous bonding in prairie voles and examine how conserved mechanisms also underpin mate recognition and mother-infant recognition in the promiscuous species. These mechanisms help us understand the neurobiological bases of pair-bond formation in both monogamous animals and humans.

Monogamy in the animal world

In the animal kingdom most species are polygamous, however the amount of social monogamy in animals varies across taxa. For instance, with over 90% of birds engaging in social monogamy but only ~5% of mammals are monogamous. Socially monogamous species are scattered throughout the animal kingdom: A few insects, a few fishes, a large number of birds, and a few mammals are socially monogamous. The diversity of these species with social monogamy suggests that it is not inherited from a common ancestor but instead evolved independently in many different species.

The definition of monogamy is when a male and female form a strong social bond and reproduce exclusively with each other. They also take care of their offspring together (bi-parental care) and they usually show “selective aggression”, which means that they guard their mate, offspring and nest from other individuals, no matter if male or female.

Recently, research has been done with species from the *Microtus* genus both in laboratories and in the field, to study the neurobiological mechanisms of this rare social behavior. The *Microtus* genus is uniquely applicable for the present investigation, as the various species of the *Microtus* genus display different pair-bonding behaviours: whereas certain species of them are promiscuous, others are strictly monogamous.

The case of the Prairie vole (*Microtus ochrogaster*)

They are found in grasslands in North America where they live in burrows under the ground. This greyish-brown rodent is mainly nocturnal and feed on fruits, seeds, grass and sometimes insects. They form pairs after mating; travel together and share a nest. If they lose their mate, they usually never find another partner again. They are bi-parental and the offspring are born without hair but develop quickly and are fully grown after two months. The male participates in the care-taking by collecting material for the nest, gather food and even groom and retrieves the pups.

The different species in the family Cricetidae, genus *Microtus*, differ markedly and for this reason they are excellent targets for comparative behaviours studies, with special regard to investigation of pair bonding and social behaviour. The montane (*M. montanus*) and meadow (*M. pennsylvanicus*) vole is promiscuous, solitary, do not share a nest and only the female takes care of the pups, whereas the prairie vole (*M. ochrogaster*) is a highly affiliative, monogamous species.

Oxytocin (OT) and arginine vasopressin (AVP) two neuropeptidergic candidates for regulating social bonding

2 neuropeptides mediators of partner-preference formation in animals and humans

Oxytocin (OT)

Arginine vasopressin (AVP).

They contribute to the processing of social cues necessary for individual recognition.

Activation of these 2 neuropeptide receptors together with dopamine receptors, in ventral striatum, the “reward center” of brain, during mating result in conditioned partner preference, called pair bond.

In the behavior of male prairie vole both OT and AVP has a major role

Oxytocin is found in mammals as a neuropeptide hormone acting as neuromodulator in the brain. Oxytocin, is a nine amino acid, called cyclic neuropeptide. It is produced in the hypothalamus and then released into the blood circulation to reach different organ on which it affects. It has a role in uterine contractions, pain suppression at spinal level, nursing, milking and also producing nutrients to the offspring after birth.

New investigations have begun of oxytocin's role in different behaviors such as orgasm, social recognition, pair bonding, anxiety and maternal behavior.

Arginine vasopressin, known as vasopressin, or antidiuretic hormone, is a neurohypophyseal hormone found in most mammals and also in humans. It controls the reabsorption of molecules in the kidney tubules by affecting the tissue's permeability, increases peripheral vascular resistance, resulting in increased arterial blood pressure. Has a main role in homeostasis, regulation of water, glucose, and salts in the blood.

It derives from a precursor that is synthesized in the hypothalamus and most of it is stored in posterior pituitary. It is released from pituitary and is released into the blood stream, some is released into the brain and has an important role in social behavior and bonding

Research has proven that both OT and AVP is of great importance when it comes to forming memories and also for learning. Memory and learning is essential for individual recognition & for the pair bonding in both sexes of prairie voles

They also have a role in sexual behaviour, mating and the mother-offspring bond

The role of oxytocin (OT) in social behavior

Studies with female prairie voles has given us that OT is an important hormone before, during & after delivery of offspring.

In an experiment where OT was injected into the cerebral ventricles of virgin female rats showed that they could produce nurturing behavior towards pups within 2 hours after the injection.

Other studies have shown us that an OT antagonist injected into the brain will block the maternal behavior of rats that has just given birth, but when onset of maternal behavior has started, OT also maintain the behavior which means that OT antagonist fails to inhibit maternal behavior once the nurturing has been established.

Studies on mice without any OT, "OT-knock-out", that they give birth on time and has no incidents, but they where unable to lactate which in turn confirm to us that OT has an essential role in lactation. The pups died within 24 hours of birth.

The pregnancy hormones in female mammals, progesterone and estrogen, induce increased synthesis of OT receptors in central olfactory projections and also OT and dopamine receptors in nucleus accumbens, area of the brain dealing with social reward.

To increase social contact in both sexes, they must overcome anxieties & inhibit aggression, this will enable the social bonds. In small rodents, ventricular infusions of OT has lead to a nonselective increase in social contact and affiliation (need of belonging to a group)

The role of arginine vasopressin (AVP) in social behavior

Studies with AVP have shown us that it also have a role in social bond formation. In mice studies, where they are lacking the AVP receptors it ahs been shown that they have reduced anxiety behavior and impaired social recognition. Melaes treated with AVP antagonist prevent the development of partner preference and parental care after mating.

lv. injection of AVP in rodents demonstrated its importance for male territorial marking, aggression, social recognition & anxiety.

The role of OT and AVP in social behavior of the prairie vole

The prairie vole is the best example of a strictly monogamous animal. The male and female is bonded for life after mating. They spend time with each other, grooming for hours and nest together. The male aggressively guards the female. They are affectionate parents for their pups. Although there is another close relative, montane vole, that has no interest in partnership after mating.

Studies have showed that the prairie vole has receptors in the brain for both OT and AVP associated with reward and reinforcement, whereas the montane vole does not. Meadow vole also shows different pair bonding behavior than prairie voles.

The variation of OT and AVP receptors in the different vole species, gives them their differences in social behavior. According to observations, OT seem more important to females and AVP is more critical for males.

AVP release in male prairie vole leads to development of pair-bond, aggressive guarding of female and also the paternal care of the pups.

During mating, AVP is released into the ventral palladium in the male prairie vole and there is increased central release of OT during vaginocervical stimulation.

On the other hand, infusion of OT into the cerebral ventricles of female prairie voles accelerates pair bonding, as these females require only a brief cohabitation with a male, without mating, to form a partner preference^[1].

The monogamous species have lower densities of AVP receptors in the septum, central grey matter, ventral forebrain and the lateral habenulae, indicating the importance of these brain structures in the social bonding process.

Prairie vole has the highest density of OT receptors in prelimbic cortex, stria terminalis, nucleus accumbens and the midline nucleus of thalamus. The promiscuous montane vole showed low or no OT receptor density in these areas.

Both OT and AVP receptor antagonists prevents pair-bonding in female/male prairie voles. Increased AVP receptor expression in males enhanced the affiliation and partner preference behavior, this was also enhanced in an experiment with meadow voles that originally is a promiscuous vole.

Recent studies have shown that the receptor coding regions for AVP in the microtine species are very different between monogamous and promiscuous voles. Specifically, monogamous prairie and pine voles have a sequence of repetitive microsatellite DNA in the promoter region of the gene responsible for AVP receptors that is not present in promiscuous meadow and montane voles ^[2].

Summary and conclusions

Taken together all these evidences it has become evident by now that AVP and OT play a key role in social bonding behavior in animals. These neuropeptide systems, including the

neuropeptides OT and AVP and their central receptors, form the neurobiological basis of social bonding, pair-bonding, mate-mate and parent-infant relationships as well as that of monogamy versus promiscuity.

Selected literature

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