

Parental Care in Amniotes: Patterns, Neural Mechanisms, and Evolutionary Implications

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Abstract:

Parental behaviour is one of the key strategies animals employ to adapt to their environment and ensure the survival of their offspring. Amniotes (including reptiles, birds, and mammals) exhibit significant differences in their parenting styles: reptiles often compensate for low-investment parenting behaviour by laying many eggs, birds primarily engage in cooperative parenting by both parents, while mammals, due to their viviparous and lactation mechanisms, generally exhibit long-term and high-cost maternal care. In some species, rare instances of paternal or single-parent care have been observed, indicating diverse adaptive evolutionary pathways. Recent studies have revealed the neural mechanisms underlying parental care, including the critical role of brain regions such as the hypothalamus and its medial preoptic area (MPOA) in maternal and paternal behaviour; specific neurotransmitters and hormones such as oxytocin, dopamine, and prolactin have also been shown to play important roles in regulating parental care behaviour. Additionally, genetic regulation of neural circuits and hormone secretion further elucidates the molecular basis of parental care behaviour. Reviewing the parental care patterns and neural mechanisms across different taxonomic groups not only helps us understand the selective pressures faced by animals during evolution but also provides important insights for research on human social behaviour and related neuropsychiatric disorders.

Keywords: Parental behaviour; Amniotes; Neural mechanisms; Evolutionary adaptation.

1. Introduction

Parental behaviour refers to the actions taken by parents to raise their cubs. It includes nesting, feeding,

migration and so on and takes an essential role in ethology. Decision in resource distribution and parental investment in animals can be shown by the pattern of parental care. The amount of parental care can

affect the fitness of the new-born animals. Defence against enemies also depends on parental investment, whether by direct protection or indirect nutrients supply. Various parental cares also indicate the strategies they take to adapt their own environments. With strict environments, mammals usually prefer to invest more on a limited number of infants while reptiles would rather produce larger number of offspring.

Among animals, diverse ways of parenting occur. This article focuses on the parental care in amniotes. Amniotes refer to a range of vertebrates who are developed with an amnion from an embryo or a foetus, including birds, reptiles and mammals [1]. Most reptiles do not show parental care, but most of the parental behaviour occurs in birds and mammals. 97% of birds and all mammals perform basic parental behaviour such as hatchling and breast milk [2]. Reptiles often choose to increase the number of eggs they produce instead of paying a lot of efforts to take care of all their offspring. This method has low energy cost to increase the number of surviving eggs. At the same time, birds and mammals have fewer eggs or infants but provide intensive parental care to all offspring and intend to survive all the offspring. Though it is a highly demanding way, higher quality of offspring is cultivated. Some species show maternal care only, while paternal care also shows up in some other ones. One seldom-occurring phenomenon is that in some species, only the male oversees raising the offspring. This phenomenon is more frequently occurred in external fertilisation, but a few birds also show this pattern of uniparental care [3].

There are specific neural mechanisms working for the practice of parenting. Hormone is a common factor that is related to the patterns of action. It can influence the emotion and intention. Maternal effect in a family can be affected by hormone as well [4]. The offsprings' phenotype is decided partly by the mother's ability to send the correct signals to the family members. Secret about maternal effect is a key to research the advantages of the phenomenon of common maternal care. It can also be applied in matriarchal society. Experiments on mice find out that during pregnancy, hormone can remodel the neural circuits which are responsible for parenting [5]. This change is intended to enhance the parental behaviour of female mouse. Females can be motivated more by hormone to take care of their offspring after they are pregnant and give birth. Then they can get prepared after their cubs are born. Meanwhile, neural plasticity is found to contribute to the paternal care in mice, which is controlled by oxytocin [6]. This helps to reveal why males in most species uncommonly show parental care. Now, different classes of neural receptors are found relative to the parental care [2]. The specific circuits stimulating or inhibiting the action of

parenting depend on the case of various situations such as weather, the acquisition of food and the number of predators.

Research on parental behaviour reveals how instinct in animals can be influenced in neurological level. These receptors which is controlled by the gene expression display the natural selection of diverse pattern of parenting and different parental imprinting preference. Furthermore, it indicates the basic factors to build social behaviours. Parenting can affect the building of the society in animals because most social animals are made in the units of families.

2. Patterns and Diversity of Parental Care in Amniotes

2.1 Reptile

Though parenting is not common in reptiles, some of them provide guarding, nesting and warming to the offspring [7]. Environment factors can decide the level of parenting as well. With strict environment, parents usually pay more efforts to make sure that their next generation can survive. They have specific mechanism of recognition to their offspring. Patterns of parenting can vary because of different mechanisms of recognition of offspring. Types of recognition contains direct and indirect ones [7]. Some reptiles use spatial information to locate their nest and do not need specific recognition to their eggs as foreign ones can hardly enter their brood [7]. Purpose of recognition also differs among reptiles. Recognition can prevent the damage to their own offspring when they try to destroy others' eggs instead of providing parental care [7].

In reptiles, parental care—when present—serves primarily to mitigate high early-life mortality in unpredictable environments, often through nest defense, thermoregulation, and spatial protection. These relatively simple yet energy-efficient strategies illustrate how minimal investment can still enhance reproductive success. Understanding the sensory and cognitive bases for offspring recognition in reptiles provides a foundation for exploring the underlying neural mechanisms that regulate such targeted care.

2.2 Birds

One obvious parental behaviour of most birds is that the parents hatch their eggs and forage in turn. Most bird couples care for their eggs together. Biparental care takes the main role in birds' behaviour because they are commonly monogamy. The two genders share equally responsibility of incubating and foraging. They cooperate and pay the same level of parental investment to make sure both of

their genes can be passed on. Maternal care sometimes shows up alone in birds as well. Uniparental care gives more chances to reach the gene diversity by imposing polygamy. It is relatively female reproductive output is constrained by physiological limits as they can only give birth by themselves while males can reproduce with several females to reach the purpose. On the other hand, when there is only maternal care, only females can ensure all their eggs pass on their genes.

There is also a study showing the maternal behaviour in birds can be related to age [8]. Old birds can be experienced but also show less care sometimes. It has been hypothesized that they may already have a lot of offspring who have passed on their genes in the past, new offspring would be less essential to reach their goal. Moreover, different brood sizes result in different female behaviour [9]. Theoretically, large brood size leads to less maternal care because the energy cost from the mother increases. With more offspring, some of them can survive of talents such as big size or strong running skills even with less parental investment. From another perspective, more parental investment is shown through more nutrients given when they are forming eggs to have a born larger body size.

There are exceptions for birds that only the male ones raise the offspring. For instance, Australian mallee-fowl incubates the eggs all by the male partner alone [10]. They adjust the position of vegetation in their nest to change the temperature on the eggs [10]. This action is usually done by female partners in other birds. This strategy means males choose females of ideal quality and spend more energy and time hatching and feeding their children. In this way, females can lay more eggs for different males and this strategy ensures that large number of next generations pass on their genes. Meanwhile, more males could have their offspring.

In birds, biparental care enables efficient division of labor in incubation and feeding, directly improving chick survival in energetically demanding conditions. The prevalence of cooperative breeding reflects a fine-tuned balance between reproductive success and ecological constraints. These coordinated behaviours offer a valuable model for investigating how neural circuits and hormonal signals synchronize parental roles between partners.

2.3 Mammals

Maternal care exists in all mammals as they give breast milk. All mammals show maternal care for the next generation for lactation. One unique feature for mammals is that they are both viviparous and lactational. The higher similarity in epigenetic between viviparous mothers and their children than in oviparous can be one reason for the

generally higher parental investment in mammals like breast milk [11].

Rarely, paternal caring is also shown in social mammals, only 5% to 10% of mammals to be specific [12]. One distinct example for paternal love is wolf. Male wolves directly take part in looking after cubs by playing and teaching them in a pack even when the infants are not theirs.

Most males can be aggressive to infants to ensure their own resources or status. Kinship theory explains the difference in imprinting genes between females and males. There is a conflict theory that offspring passing on the maternal imprinting genes tends to be detrimental as the gene will inhibit the growth of foetus to guard against the maternal resources, thus the natural selection would not prefer this kind of genes [13]. Differences between the two genders in their roles in reproduction also influence the parental investment. Female mammals can directly provide resources by offering breast milk to the cubs, but males can only help after they are weaning. This brings the problem that the participation of male mammals in parenting can be hardly controlled by gene to judge the right starting moment [13].

In mammals, the combination of viviparity and lactation necessitates prolonged and energetically costly maternal investment, often accompanied by complex social interactions and, in rare cases, paternal care. Such sustained caregiving enhances offspring developmental outcomes and shapes long-term social bonds. This high degree of parental commitment provides a unique context for examining the neuroendocrine and genetic adaptations that sustain long-term caregiving behaviour.

3. Neural Mechanism of Parenting in Amniote

3.1 Brain Structures in Charge of Parenting

Different regions of animals' brain have their own jobs. Some of them are found closely related to parenting behaviours. Hypothalamus, as one vital region for parenting, has specific activation of circuits during lactation and starvation [14]. It also covers the androgen and estrogen receptors which link to sexual behaviour. In hypothalamus, medial preoptic area (MPOA) is the most evident region responsible for parental care [2]. This area contains specific neurones MeA (MeApd) VGat-Cre (GABAergic) that can control the activation of infant aggression in males [2]. Additionally, a small area in MPOA, the cMPOA has stronger relation with male sexual behaviour rather than female [2]. This is still a mysterious fact as maternal caring is much more common than paternal. Medial preoptic

nucleus (MPN) neurones are required for both maternal and paternal caring [6].

MPN neurones build Galanin and Calcitonin receptors which oversee maternal caregiving and now are also found relating to paternal care [6]. Galanin is functioned for finding mates, resting and feeding [2]. For parenting, galanin mainly works for the cleaning of cubs including licking and grooming [2]. Males has extra toxin secreted from the MPOA galanin neurons that inhibit the mating and parenting behaviour of recognition and licking while still stimulate the invasive fighting between males [2]. Meanwhile, cMPOA glutamatergic neurons expressing calcitonin (CALCR+) are also essential for the motivation of maternal care [2]. Silenced CALCR neurons suppressed maternal care seriously and leads to a low survival rate of pups for less than 20% [2]. Estrogen receptor alpha is another receptor responsible for parental care especially for recognition of the offspring [2]. Sex experiences can influence the plasticity of neurons connections in charge of parenting. Sexually naive animals usually show no parental care to infants as it is unnecessary to spend their energy on others, and the caregiving behaviours appear only until their first offspring are born [6]. This fact proves that parenting for some species is a behaviour related to plasticity of neurones and needs to learn and activated [6]. Specially for paternal caring, the circuit for aggressing infants should be suppressed. This can be one reason for the rare paternal precipitation in nursing for infants. Plasticity of neuron connections between lateral hypothalamus and oxytocin neurons is strengthened when male mice have their own offspring [6]. The connection inhibits the expression of infanticide in males [6].

3.2 Hormones Related to Parenting

Hormones that response for parental behaviour are mainly oxytocin, dopamine and prolactin. Various proportion of androgen and estrogen is also one factor of different decisions of parental investment. The main reason for differences between parental investment is the effect of hormones.

Oxytocin plays a significant role in maternal care. It is associated with moods and social behaviours thus the parents' moods can be influenced by the oxytocin level in the body fluid and the various gene expression for oxytocin receptors [15]. During the parturition and lactation, females are exposed to rapidly increased amount of oxytocin thus a bond between mothers and the offspring forms in a moment [16]. Paternal care is affected by oxytocin as well. Oxytocin ligand secretion from paraventricular hypothalamic nucleus (PVH) is found to be vital in the existence of paternal caregiving, without the hormone male

mice tend to ignore or invade the new-born infants [6].

Another hormone related to parenting is dopamine. Dopamine is released in a male mouse after pairing with a female partner for some time along with increasing licking behaviour which indicates potential parental care [17].

Prolactin secretion in birds increases during the breeding and causes the transition from sexual behaviour to parental care [18]. Prolactin is released from hypothalamic neurones, a kind of cell called lactotrophs is specifically in charge of prolactin secretion [18]. The pathway which facilitates the secretion of prolactin is controlled by the pathway containing dopamine [18]. This inspires that environmental factors influence the prolactin level and parental care stimulation. This hormone is seen as a valuable indicator of the parental investment in research since it regulates the parenting in birds and affects the resource allocation [18].

4. Conclusion

This review systemizes the potential evolution patterns and the diverse mechanisms in neurological perspective of parental behaviours among reptile, birds and mammals. The different parenting models such as uniparental and biparental care indicate the adaptation of animals in various environments. Some regions of brain are found especially to be related to parenting. The activation and inhibition of certain circuits are essential in the balance of parenting behaviour. Moreover, secretion of hormones including oxytocin, dopamine, prolactin and sex hormones affect the parental investment on the offspring. Genes can code for special neural circuits and specific gene expressions oversee parental care directly. More research can also be expected in other fields to make the findings more effective and reliable. For instance, research from the mathematical perspective to display the trend of parenting in different species statistically can help. Other methodologies like gene edition and ecological modelling should be encouraged to apply on parenting study to give more exact and specific results as well. More species should be investigated about parental behaviours to build more animal models in ethology. Review on parental care in amniotes including most modes of parenting helps the understanding on selective pressure during the evolution. In neuroscience, the general mechanisms and patterns of neural circuits and hormone which control altruism behaviours can be revealed by researching the neural principle of parental care. Moreover, the research inspires the development of roles and social diseases related to family in human.

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