

催产素在抚育行为启动中的调控机制

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摘 要

抚育行为(Parenting Behaviors)是亲代或异亲抚育者为无法自理的年幼个体提供帮助和支持的一系列活动。个体在接收到婴儿发出的脆弱信号(如哭声、面孔、气味等)后,其大脑中由催产素系统主导的“抚育神经网络”被快速激活,从而驱动个体产生抚育动机并降低行为反应阈值,这就是抚育行为的启动,对生物进化有着至关重要的意义。研究表明过度激活HPA轴会抑制催产素系统的活动水平并削弱个体对幼崽信号的响应,从而干扰抚育行为的启动,然而催产素能够通过影响大脑中的奖赏系统,增加个体对社会线索的敏感性,从而促进抚育行为的启动。理解催产素在抚育行为启动中的调控作用,有助于深入认识社会行为的生物学基础,为相关心理障碍的干预提供新的视角。

关键词

催产素, 抚育行为启动, 奖赏系统, 神经机制

The Regulation Mechanisms of Oxytocin in the Initiation of Parenting Behaviors

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Abstract

Parenting Behaviors refer to a series of activities through which parents or alloparents provide support to dependent offspring. The initiation of such behavior is critically important. Upon perceiving vulnerable infant cues (e.g., crying, facial features, or odor), the caregiver's brain rapidly recruits the oxytocin-centered "parental-care network", which potentiates affiliative motivation and lowers the behavioral response threshold—constituting the neuroendocrine initiation of parenting behavior. Studies show that overactivation of the HPA axis suppresses oxytocin activity, impairing responses to

offspring cues and hindering parenting initiation. In contrast, oxytocin facilitates this process by enhancing sensitivity to social signals via the brain's reward system. Understanding oxytocin's role in parenting initiation helps reveal the biological basis of social behavior and offers new insights for treating related psychological disorders.

Keywords

Oxytocin, Initiation of Parenting Behavior, Reward System, Neural Mechanism

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1. 引言

抚育行为(Parenting Behaviors)包含一系列旨在保护并确保年幼个体生存的行为(Bernard & Dozier, 2008), 当年幼个体处于痛苦或需要抚育与保护的状态时, 亲代或异亲抚育者的照料系统将被激活, 这一系统会促使个体对他人发出的痛苦信号作出响应, 并主动提供帮助、安抚与支持(Canterberry & Gillath, 2012; Gillath et al., 2016; Gillath et al., 2005), 这就是抚育行为的启动, 会直接影响后代的存活率、生长发育及心理社会化进程(Rogers & Bales, 2019)。抚育行为启动受阻, 可能会导致降低亲子互动质量、抑制幼儿情绪表达与探索行为, 损害其认知能力与情绪调控发展, 对抚育者产生持久压力与身心健康损害, 甚至降低后代存活率(Preiß et al., 2025; Sadik et al., 2022; 韩成全等, 2024; 李珊珊等, 2018)。当前社会抚育支持体系面临双重挑战: 一方面, 三孩政策实施后, 多子女家庭的照护负荷显著增加(祝哲等, 2025), 父母慢性应激水平上升已成为公共健康关切; 另一方面, 部分父母在婴儿出生后 2 个月内完全回避日常照护任务, 出现抚育行为启动失败(Seyed et al., 2021), 这种环境压力的生物学本质是 HPA 轴的过度激活直接抑制了核心亲社会神经肽——催产素系统的功能活性。因此, 揭示催产素系统在抚育行为启动的动态调控机制, 不仅深化了对社会行为神经可塑性的理论认识, 也为高抚育负荷群体的心理适应障碍提供了精准的转化医学靶点。

慢性应激、早期逆境和妊娠期情绪障碍等过度激活下丘脑 - 垂体 - 肾上腺轴(HPA Axis), 这种激活模式并非简单的线性抑制关系, 其效应具有显著的强度依赖性与情境特异性(Juruena et al., 2020; McEwen & Akil, 2020; O'Donnell et al., 2013), 适度应激可经由糖皮质激素的快速非基因组效应暂时增强催产素神经元兴奋性, 形成“应激 - 抚育动机”的短期适应性联动; 然而, 长期或高强度的 HPA 轴过度激活则通过糖皮质激素受体的基因组途径下调催产素受体(OXTR)表达, 从而抑制个体对抚育线索的适应性响应能力, 导致抚育行为启动障碍(Jianhua et al., 2017; Liu et al., 2025; Nazarloo et al., 2025)。催产素(Oxytocin, OXT)作为下丘脑释放的神经肽, 可反向调控 HPA 轴应激反应(Liu et al., 2025), 并通过中脑边缘多巴胺系统增强对社会线索的响应能力, 促进对幼崽的敏感性及照护动机(Carcea et al., 2021; Marlin et al., 2015; Valtcheva et al., 2023)。尽管 OXT 干预已证实可有效改善应激诱导的抚育动机低下及社交回避(Lyu et al., 2025), 但 OXT 的调控作用是贯穿于整个抚育行为过程还是作用于其中一个阶段仍是亟待探索的问题。

抚育行为一般包括启动(Initiation)、维持(Maintenance)和衰退(Decline)三阶段, 以往研究多聚焦后者, 探讨长期抚育中的情绪调控与角色维持(Cafiero & Justich Zabala, 2024; Li, 2020), 而启动环节才是“无即全盘空”的关键起点, 在多数物种中抚育行为的启动受到激素状态、神经环路活性、环境刺激以及早期社会经验等因素的精细调控(Blumenthal & Young, 2023; 韩成全等, 2024)。综上, 本文旨在系统梳理抚育

行为启动背后的认知神经机制,关注 OXT 在“感知 - 动机 - 决策”三阶段中的调控作用,并探讨药理学、神经操控与感觉经验三类催产素的干预策略来挽救抚育行为启动障碍的可能性,并展望未来在该领域的研究方向与临床转化潜力。

2. 从感知到行动：催产素在抚育行为启动三阶段的调控机制

抚育行为启动过程是由外周信号经中枢整合到运动指令的过程,可拆解为“感知、动机、决策”三个阶段:1) 感知(Detection)——对幼崽哭声、面孔等脆弱线索进行快速感觉登记;2) 动机(Motivation)——情绪共鸣与奖赏预期被唤醒,形成他人导向的注意偏向;3) 决策(Decision)——在成本 - 收益计算中抑制竞争需求,锁定“照护”为优势目标,并将意图转化为具体的动作。啮齿类动物中行为指标有衔回幼崽、舔舐、哺乳、筑巢等,人类则是抱婴、注视、回应哭声等。在真实的神经加工过程中,感知、动机与决策并非严格线性序列,而是高度动态、并行且相互嵌套的认知过程。

抚育行为启动受内源性和外源性因素的综合影响,催产素(Oxytocin, OXT)在其中发挥关键作用,OXT 是下丘脑合成,神经垂体释放的神经肽激素,通过中枢与外周途径调控母婴依恋、社会认知、焦虑及应激反应等社会行为,促进亲密关系建立(Matsushita & Nishiki, 2025; Menon & Neumann, 2023; Wang et al., 2022),在抚育行为的启动与维持过程中,OXT 至关重要(Keverne & Kendrick, 1992; Rilling & Young, 2014; Ross & Young, 2009; Valtcheva et al., 2023)。小鼠实验表明,OXT 与催产素受体(OXTR)双重缺失致哺乳障碍;仅 OXTR 缺陷即引发母性行为异常,表现为幼崽衔回延迟和舔舐减少(Yuan et al., 2025),甚至出现“完全母性启动失败”,不筑巢、不舔舐、不衔回,导致 72 小时内幼崽死亡率 > 90% (Mota-Rojas et al., 2025)。但也有研究发现只有高压环境下才可以激发和维持抚育动机(Tsuneoka et al., 2022)。综上,催产在抚育行为启动的感知、动机、决策这三个阶段中可能发挥着重要的调控作用。

2.1. 抚育行为启动的感知阶段

与未生育女性相比,产后母亲对婴儿线索(婴儿哭声、面孔、气味等)表现出更高的注意力投入、生理唤醒和更积极的情绪反应,并在主观评价上对婴儿情绪(尤其是哭声)表现出更高的容忍度和积极偏向,在面对自己婴儿时,其大脑中“母性神经网络”(如岛叶、杏仁核、额下回、背外侧前额叶皮层等)表现出更强的激活(Bjertrup et al., 2021; Pearson et al., 2010),给予非父母被试催产素,在响应婴儿笑声时其杏仁核和海马的功能连接以及楔前叶(镜像网络)和眶额皮层(情绪调节网络)的功能连接增强(张火垠等, 2019)。

动物研究中有类似发现,幼崽接近可激活母鼠内侧视前区(Medial Preoptic Area, MPOA),说明该脑区对幼崽感觉输入具高敏感性(Zelmanoff et al., 2025)。幼崽哭声作为“声学开关”可以快速启动接近 - 衔回行为,该过程依赖听觉皮层(Auditory Cortex, AC),并且通过基底杏仁核(Basal Amygdala, BA)到听觉皮层的投射通路(BA-AC),实现了对哭声的多感官整合调控,光遗传激活 BA-AC 通路可诱导 AC 神经元对叫声产生显著兴奋性反应,从而增强幼崽信号感知能力。此外,幼崽哭声也可以通过丘脑后侧内核到室旁核(PIL→PVN)催产素神经元通路强化母性动机,确保衔回行为的启动与维持(Nowlan et al., 2025; Valtcheva et al., 2023)。当未生育母鼠观察母鼠衔回幼崽时,视觉信号经视网膜 - 上丘(Superior Colliculus, sSC)浅层神经元传递,随后 sSC 向 PVN 发出单突触谷氨酸能兴奋性投射,直接激活 PVN 催产素神经元,从而把“看到他人育幼”这一外部感官事件转化为内部动机信号,为后续听觉皮层可塑性与衔回行为的启动做准备(Carcea et al., 2021)。

2.2. 抚育行为启动的动机阶段

婴儿线索不仅被“注意”,还被赋予奖赏价值。产后早期,母亲对婴儿哭声表现出更强的边缘 - 奖赏系统激活,该神经反应强度可预测后续母性敏感性水平,提示母乳喂养可能通过神经内分泌机制促进

母性大脑的敏感性(Kim et al., 2011)。伏隔核(Nucleus Accumbens, NAc)在调控幼崽“奖赏显著性”中起关键作用:母鼠 NAc 中 D2 受体被过度激活会降低其对幼崽的兴趣,而激活腹侧被盖区-伏隔核-内侧前额叶(VTA-NAc-mPFC)奖赏通路,则增强抚育动机,表现为母鼠更愿意接近幼崽,表明该通路是抚育动机的神经基础(Teng et al., 2025),NAc 中催产素受体(OXTR)密度与雌性草原田鼠的异亲抚育行为呈正相关,在 NAc 中注射 OXTR 拮抗剂会阻断这种抚育行为的启动(Kenkel et al., 2017)。在草原田鼠中,NAc 中的 OXT 促进对特定个体的主动接近和偏好行为,这属于从动机转化为行动的关键一步,NAc 通过整合奖赏信息,推动从动机到主动抚育行为的转化(Dumais & Veenema, 2016)。

奖赏系统在抚育行为启动中的关键作用已得到多项神经影像学研究的支撑:母亲观看自己婴儿笑脸时,NAc 与眶额皮层(Orbitofrontal Cortex, OFC)显著激活,而且这种激活强度与母亲自评的抚育动机以及亲子亲密感呈正相关(Strathearn & Kim, 2013),为“婴儿笑脸作为高奖赏价值刺激,驱动母性投入”的假说提供了直接证据。进一步研究发现,患有创伤后应激障碍(PTSD)的母亲在观看婴儿表情时,NAc 激活显著降低,而且其功能抑制程度与母性回避行为显著相关(Pointet Perizzolo et al., 2022),这从病理学角度反向佐证了 NAc 正常功能对于维持积极抚育动机的必要性。

此外,OFC 通过增强 VTA 的多巴胺(DA)系统向腹侧纹状体释放多巴胺(DA),为雌性未生育小鼠习得抚育行为提供动机基础,说明奖赏系统参与抚育行为的启动(Tasaka et al., 2025)。OXT 系统通过其受体(OXTR)在 MPOA 区域的表达,将外部幼崽线索转化为内在“需要照顾”的驱动状态,提供抚育行为的“动机燃料”,决定个体是否进入“抚育就绪”模式(Dumais & Veenema, 2016);向内侧视前区(MPOA)和腹侧被盖区(VTA)注射催产素拮抗剂(OTA)可抑制抚育行为的诱导(Okabe et al., 2017)。前扣带回皮层(ACC)通过其与丘脑(CL)的兴奋性反馈环路,在未生育母鼠首次接触幼崽时提供一种“行为启动的动机推力”,将外部幼崽刺激转化为内在照顾驱动力,从而促使异亲抚育行为的快速启动(Glat et al., 2022)。以上这些研究共同揭示了奖赏系统与催产素通路在抚育动机中的协同作用。

2.3. 抚育行为启动的决策阶段

内侧前额叶皮层(mPFC)的边缘下皮层亚区(IL)在产后早期阶段通过整合感官与动机信息,在多个竞争性刺激中“选择”启动母性反应,从而发挥“决策门控”作用(Pereira & Morrell, 2011)。内侧前额叶(MPOA)在抚育行为启动的决策阶段中起到整合内外信号并调控行为优先级的关键作用,激活 MPOABRS3 神经元可以实现在饥饿与抚育需求冲突时的行为优先级转换(Alcantara et al., 2025)。最近梁妃学团队通过“威胁下取回幼崽(PRUT)”范式揭示了 mPFC 第六层(L6)中表达 D1 多巴胺受体的神经元及其向 MPOA 的投射在介导母性防御过度自卫的决策中起着关键作用,其在“自我保护”和“抚育幼崽”的冲突中充当经验可调的“决策门控”:威胁信号增强该通路活性并抑制逃跑回路,从而提高母性动机,启动抚育行为,该结论对于理解妊娠期和产后母性行为障碍具有潜在意义(Wu et al., 2025)。

越来越多研究表明催产素在抚育行为启动的决策阶段扮演核心角色,中央杏仁核内侧部(CeL)神经元接收来自大细胞催产素神经元的轴突输入,通过抑制 CeM (中央杏仁核内侧部)来“关闭”恐惧反应,从而让母鼠在风险情境下选择照顾幼崽(Yoshihara et al., 2021)。催产素在决策阶段可以将幼崽感官输入转化为抚育动机信号,驱动从“攻击抑制”到“主动育幼”的动机转换,其配体通过整合外侧下丘脑(LHA)增强的兴奋性输入,激活内侧视前区(MPOA)抚育相关神经元并抑制杀婴相关的神经元(Inada et al., 2022)。人类研究中发现尽管异亲抚育者最初对婴儿线索的神经反应较弱,但随着抚育经验的积累,其 mPFC 对婴儿刺激的特异性反应逐渐增强,表现出“经验依赖的决策权重调控”,即越带越准、越带越快的抚育响应模式(Glasper et al., 2019)。综上,催产素系统通过“感知-动机-决策”三个阶段将外部幼崽信号最终转化为抚育行为,其活动水平与受体密度直接决定了个体是否可以启动抚育的“阀门”。第三部分将

聚焦“催产素的干预策略”，旨在为从实验室发现走向临床与公共健康实践搭建一座可操作的桥梁。

3. 催产素干预：从实验室到产房的抚育启动“助推”策略

为了更清晰地梳理催产素系统在抚育行为启动中的可调控性，本文将其干预策略划分为三类：药理学干预、感觉-经验性干预、神经操控性干预。前两者多来自“外部输入”，但作用路径不同；后者则聚焦于“内部系统”的激活。如此分类既体现干预手段的多样性，也便于后续从机制层面评估其生态有效性及临床转化潜力。

3.1. OXT 在抚育行为中的药理学干预

人类研究中发现外源性催产素可增强非父母成人的“养育脑”相关网络(如镜像、情绪调控、共情网络)的激活与功能连接，使其对婴儿刺激产生更强的情绪共鸣与接近动机，从而模拟出类似父母的神经与情感状态(张火垠等, 2019)。啮齿类动物研究发现鼻内 OXT 给药能够逆转母婴分离(MS)引起的亲社会选择行为损伤(Joushi et al., 2022)，鼻喷催产素显著改善了由幼崽剥夺引发的母性抑郁行为(如衔回延迟、舔舐减少)与短期哺乳功能，显著缩短了母鼠衔回幼崽的时间，增加了舔舐次数(Li et al., 2021a; Li et al., 2021b; Liu et al., 2019)，鼻喷催产素还可以通过激活父亲尾状核、背侧前扣带回等奖赏脑区和共情脑区，把孩子视觉刺激标记为高奖赏、高显著性，从而增强接近与抚育动机(Li et al., 2017)。

侧脑室注射 OXT 可以显著诱导未生育雌性大鼠表现出衔回、舔舐以及依偎幼崽等行为，而且在该区域注射 OXT 可以激活与哺乳激活区域高度重叠的脑区，包括嗅觉皮层、杏仁核、前额叶皮层、伏隔核等，表明 OXT 可能通过这些区域促进抚育行为的启动(Ferris, 2008; Pedersen & Prange, 1979)。腹腔注射催产素还可以显著缩短未生育母鼠在幼崽衔回的潜伏期(Marlin et al., 2015)。以上研究说明外源性催产素摄入有利于提高抚育者对幼崽的关注度和抚育动机。

3.2. OXT 在抚育行为中的神经操控性干预

尽管外源性摄入 OXT 能够调控抚育行为，但这种调控方式终究需落脚于脑内——即催产素神经元自身的兴奋性、受体表达与突触可塑性等内部状态的响应与整合；换言之，外部调控本质上依赖于催产素系统内部固有的神经-分子机制，后者才是决定抚育行为能否被启动、维持与优化的终极“执行者”。通过化学遗传手段恢复 OXT 神经元活性，提高母亲对幼崽的接触意愿，并增加抚育行为，改善应激诱导的抚育行为启动障碍(Chui et al., 2025; Marlin et al., 2015; 赵荣, 2024)。光遗传激活 PVN 的 OXT 神经元可通过内源性释放催产素，快速、有效地启动未生育母鼠的异亲抚育行为，其效果与外源性注射 OXT 相当(Marlin et al., 2015)，光遗传学激活未生育母鼠上丘内侧浅层到室旁核环路(sSC→PVN)可以显著提高幼崽衔回的概率，使用化学遗传学技术(DREADD)抑制未生育母鼠 PVN 中的催产素神经元，延迟了衔回幼崽的时间(Carcea et al., 2021)。Olazábal 团队早期研究发现抚育行为与伏隔核(NAc)中的催产素受体(OXTR)表达呈正相关关系，将催产素受体拮抗剂注入 NAc 后，可完全阻断雌性成年草原田鼠抚育行为的表达(Olazábal & Young, 2006a; Olazábal & Young, 2006b)。最近也有研究者用化学遗传学手段激活下丘脑室旁核(PVN)中的 OXT 神经元，发现可以诱导未生育母鼠的幼崽衔回行为(Tasaka et al., 2025)。

3.3. OXT 在抚育行为中的感觉-经验性干预

尽管光遗传/化学遗传学对催产素环路的“自上而下”驱动足以降低抚育行为的启动阈值，但在生态情境中，该环路的初始激活仍高度依赖“自下而上”的感官触发。在持续的幼崽暴露实验中，9 只幼年大鼠中有 5 只(含 3 只雄性)经平均 1 天暴露即达到母性行为标准(连续 3 日成功衔回幼崽)(Mayer & Rosenblatt, 1979)。视觉输入也对抚育行为的启动起着关键作用，未生育母鼠观察母鼠育儿时 OXT 神经元激活，阻断

视觉线索则抑制抚育行为；纤维光度记录显示，未生育母鼠左听觉皮层对幼崽叫声的响应在行为出现前渐增(Carcea et al., 2021)，早年研究也证明幼鼠的叫声确实可以通过激活母鼠听觉皮层和催产素系统来促进抚育行为(Marlin et al., 2015)。这些结果表明触觉、视觉以及听觉线索是抚育行为启动的关键。

行为神经生态学证据指出，环境丰富化(Environmental Enrichment, EE)通过提供多模态感觉刺激，系统性强化触觉、视觉、听觉等基础感觉通路的发育与可塑性，从而调控个体对幼崽线索的感知阈值与行为启动速度。啮齿类研究发现，EE 提升草原田鼠前额叶皮层(PFC)、岛叶皮层(ICa)、伏隔核(NAc)、尾状核(CP)、基底外侧杏仁核(BLA)及中央杏仁核(CeA)的催产素受体(OXTR)密度，增强催产素信号传导与亲社会行为敏感性(Prounis et al., 2018)。母婴分离(Maternal Separation, MS)致大鼠亲社会行为受损及 HPA 轴功能紊乱，EE 可逆转上述损伤并增强抚育行为(Francis et al., 2002; Joushi et al., 2022; 韩成全等, 2024)。这些非药物干预策略尤其适合作为三孩政策配套支持体系的初级预防手段，可在社区层面推广以降低家庭抚育门槛。

4. 总结与展望

本文系统梳理了抚育行为启动三阶段(感知 - 动机 - 决策)背后的认知神经机制，探讨了催产素对抚育行为启动的影响及调控机制，发现个体通过增强对婴儿线索的感知，激活奖赏通路，推动从动机到主动抚育行为的转化，催产素在整个过程中发挥着重要作用。本文整合了神经内分泌、神经环路机制与行为调控，为理解抚育行为的“启动阈值”提供了新视角。

OXT 在毫秒级别的释放动态与抚育行为启动的因果时点仍然未知，未来研究需构建具有高时序分辨率的在体记录技术，实时捕捉催产素神经元的放电活动与具体社会行为，如“接近 - 衔回 - 舔舐”等微行为之间的动态关系。这类研究将有助于确定“最佳干预时机”。可整合行为学范式、光纤光度法、电生理记录及荧光探针技术，在动物模型中解析 OXT 信号的精确时序特征(Lu et al., 2023; Qian et al., 2023; Qu et al., 2024)。

其次，OXT 系统并非孤立作用，而是与 HPA 轴、多巴胺、加压素、内源性阿片肽等神经内分泌系统形成多层级、非线性的交互网络。机制上，OXT 不仅通过抑制 HPA 轴降低皮质醇水平，其释放本身也受应激状态的“倒 U 型”调节——中等应激促进 OXT 脉冲式分泌，而极端应激则抑制其合成(Cox et al., 2015; Smith & Wang, 2014)，这种双向调节的生理意义在于：在不同威胁情境下，个体需要灵活权衡自我防御与亲代投入，这要求 OXT 与应激系统形成动态对抗而非简单的单向抑制。未来研究需采用微透析、荧光探针等技术，在体解析不同应激强度下 OXT、糖皮质激素与多巴胺的实时共变模式，尤其需关注其在不同性别、生育状态及抚育经验个体中的差异化调节规则，以揭示情境依赖性的分子基础(Rappeneau & Castillo Díaz, 2024; Thurston et al., 2025)。

最后，为了让研究从实验室走向产房，未来应该多关注高抚育负荷家庭(如多子女父母)的催产素系统表观遗传变化，为政策制定者提供精准的生物学标记物支持，并通过非药理学手段来提升 OXT 水平、降低皮质醇并增强情绪韧性与应激调控能力(Cárdenas et al., 2020; Grahm et al., 2021; Qian et al., 2025)，探索药理学 - 非药理学整合干预的协同效应，以更有效地逆转应激等因素所致的社会功能损伤，为抚育启动障碍提供全面干预策略。综上，需从神经环路机制、神经内分泌互作及内 - 外源性调控等多维度深化应激与 OXT 系统关系的研究，推动临床转化。

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