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Social odor as a source of learning in human infants

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Maternal odor has recently emerged as an important but ill-understood factor in sociocognitive learning in early human development. We propose that social odor plays its unique role in the first year of life through dissociable affective and perceptual mechanisms. These mechanisms yield distinct predictions for future studies of social odor.

Social odor in early development

Human beings are born utterly helpless, relying entirely on their social environment for survival. To ensure survival, infants are sensitive to a wide range of social signals, crucial for establishing bonding with caregivers. While the role of visual and auditory processing in early social learning has been extensively studied, we know surprisingly little about one of the most basic and fundamental means of social communication: olfaction.

In the past, research on odor as a social signal in human infancy has mostly focused on the facilitation of breastfeeding and stress reduction in neonates [1]. However, recent studies suggest a much broader influence. Maternal odor (Box 1) enhances infants' attention to their mother's face [2]; improves categorization of faces [3] but not objects [4]; leads to greater brain synchrony with unfamiliar adults [5]; and reduces responses to fearful faces [6]. Thus, maternal odor affects a wide range of affective and cognitive processes.

We argue that social odor plays a fundamental role in early sociocognitive development that is qualitatively different from its role later in life, and outline how at least two distinct, yet complementary mechanisms enable this role in early development.

Affective mechanism

The affective mechanism capitalizes on the finding that fear learning in early life differs fundamentally from fear learning later in life (Figure 1A). The underlying theory, which has been extensively studied in rats [7], proposes that offspring of altricial species show reduced fear conditioning early in life to facilitate attachment to a caregiver. During a subsequent transitional period, when offspring become more mobile and begin to leave the nest temporarily, fear conditioning is modulated by maternal presence. In the mother's absence, offspring show typical amygdala-dependent fear conditioning also observed in adults. In the mother's presence, offspring show reduced fear conditioning as before.

Neurobiologically, this maternal buffering effect in rats is explained by a reduced glucocorticoid (i.e., corticosterone) release, which reduces amygdala reactivity. Crucially, this phenomenon is not only observed during the actual presence of the mother, it is also elicited by maternal odor [7]. After this transitional period, offspring show amygdala-dependent fear conditioning similar to that in adults, regardless of maternal presence.

Although direct evidence in humans is lacking, indirect evidence suggests comparable mechanisms in our species. For example, children show reduced avoidance learning in maternal presence, which is modulated by the child's cortisol level [8].

We suggest that not only is the overall mechanism similar, but that maternal odor has a similar modulatory influence. Initial evidence for this hypothesis comes from studies showing that infants who smell their mother show a reduced attentional response to fearful faces [6] and increased approach behavior and brain-to-brain synchrony with strangers [5].

Perceptual mechanism

The perceptual mechanism focuses on crossmodal facilitation, emphasizing the inherent link between odor and other social signals such as faces and voices. In general, crossmodal facilitation is observable from birth and involves different senses [9]. However, olfaction may be particularly important. First, while an odor can linger in the absence of a person, a person who is present is always accompanied by their odor. By contrast, for example, voices are present only when a person is speaking. Therefore, odor has a particularly high co-occurrence rate with other social signals. Second, olfaction is an early-developing modality, being largely functional even prenatally [1]. By contrast, the visual system in

Box 1. What is social odor?

For the present purpose, we use the term social odor to refer to the odor typically associated with a person. On the one hand, this includes body odors, which can originate from different parts of the body, and are idiosyncratic but also influenced by different factors such as diet or health status [1]. On the other hand, it also includes artificial odors commonly used by the individual, such as deodorant or scented soap. The mélange of these odors is considered a person's social odor, in the case of the maternal odor, the odor of the mother. Previous studies on the role of social odor in early sociocognitive development have focused almost exclusively on maternal odor (contrasting maternal odor with no odor, or, less commonly, with the odor of an unfamiliar mother [2,6]). Thus, while we suggest that many of the processes discussed here should also occur for the odor of other caregivers or even for the odor of other, less familiar individuals, this suggestion awaits empirical confirmation.

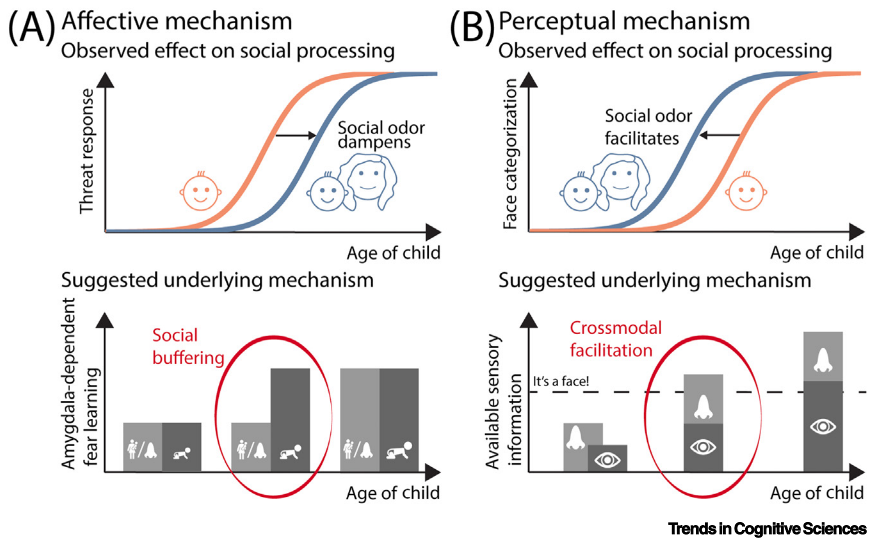

Figure 1. Overview of the suggested affective versus perceptual mechanisms of social odor. (A) Affective mechanism: during a transitional period, maternal odor reduces the infant fear response (blue = maternal odor present; orange = maternal odor absent). This can be explained by maternal buffering, where maternal odor impacts stress hormone release and thereby amygdala responsivity, as suggested for rats (bottom panel: light gray = mother or maternal odor present, dark gray = mother and maternal odor absent) [7]. (B) Perceptual mechanism: during a transitional period, maternal odor facilitates infant face categorization. In neonates, visual acuity is poor, and face and odor have not yet been associated. As visual acuity increases, face and odor information become linked, resulting in crossmodal facilitation, which loses importance again as visual acuity improves further (bottom panel: light gray = maternal odor, dark gray = visual information, dashed line = face classification threshold) [10].

particular is not fully developed at birth, increasing the importance of other sensory systems to disambiguate sensory input (following the general principle of inverse effectiveness [10]).

Supporting the notion of a crossmodal influence of odor on visual processing, recent studies show that maternal odor facilitates face processing. Infants as young as 4 months show an increased interest in their mother's face [2] and improved face categorization [3] when exposed to maternal odor. This effect is strongest in early infancy and gradually decreases between 4 and 12 months [11]. Moreover, maternal odor specifically affects the processing of social signals [4], and infants exposed to maternal odor tend to process even face-like objects as faces [10].

Together, these results paint a picture of crossmodal facilitation by social odor across infancy [10] (Figure 1B). At birth, infants are only starting to learn face categorization, but this ability develops rapidly. In the first months, however, face categorization is still challenging, and – like any processing under low signal-to-noise conditions – benefits from additional sensory information, favoring crossmodal facilitation [3,10]. As visual perception becomes more sophisticated, the influence of maternal odor on face categorization likely decreases [11].

How do both mechanisms of social odor relate?

Both mechanisms suggest a unique importance of odor for sociocognitive processing in infancy, but focus on different realms and lead to partially different predictions.

Development

Both mechanisms predict a quadratic change with infant age, with a peak effect of odor during a transitional period, but they do so for different reasons.

According to the affective mechanism, in the first months of life infants show a reduced fear response, regardless of odor. In the second half of the first year of life, odor should have the largest impact (possibly coinciding with the onset of locomotion [12], which bears similarity to rat pups leaving the nest). The effect of odor decreases as the fear response generalizes across settings.

For the perceptual mechanism, infants must first associate faces and odor; once this association is established, odor can play its role to full capacity, before decreasing in importance as vision improves. Here, the peak influence is likely to be earlier; the largest influence reported is at 4 months [11], but as younger infants were not tested, we do not currently know whether this reflects the strongest influence or whether an even stronger influence could be observed earlier.

Since longitudinal studies for either mechanism are missing, these hypothesized timelines, as well as their potential development beyond infancy, await further investigation.

Specificity

The two mechanisms make different predictions about which types of signals are affected by odor. For both mechanisms, while previous studies have focused on the impact of odor on face processing (except [5], in which natural interactions are used), other perceptual domains provide valuable test cases. According to the affective mechanism, odor should similarly affect auditory or nonsocial threat signals, as it is based on the affective content rather than the conveying modality. By contrast, the perceptual mechanism predicts a stronger effect for faces than for voices, as voice–odor pairing only occurs when a person is speaking, while face–odor pairing occurs as soon as a person is present. For nonsocial signals, the effect should be minimal. Furthermore, the perceptual mechanism predicts a general impact on face processing, whereas the affective mechanism predicts a selective impact on threat signals (though there is likely also an impact on other affective processes via different mechanisms).

Another facet of specificity is the distinction between maternal odor and that of another person. As discussed in Box 1, we currently lack empirical data on the effects of non-maternal but social odors. While the affective mechanism indeed predicts a specificity for maternal (or highly familiar) odor, the perceptual mechanism should not depend specifically on maternal odor [2]; as any face is accompanied by social odor, any odor should suffice to facilitate face categorization. An open question is whether subcategories of social odor are learned; does, for instance, female odor specifically facilitate the processing of female rather than male faces?

Neurobiological mechanisms

Direct evidence for the neural processes underlying each mechanism is limited. However, most studies indicate the involvement of sensory areas in paradigms primarily tapping perceptual mechanisms [3,4,10,11], while initial evidence suggests the involvement of attention-related areas for the affective mechanism [6]. Additionally, the affective mechanism should influence general stress responses, predicting changes in peripheral measures (such as heart rate or skin conductance) and hormonal levels (such as cortisol release). By contrast, the perceptual mechanism should affect only cortical activation without broader physiological effects.

In addition to distinguishing between the two mechanisms, future studies should explore the potential interplay between the two, as, for example, affective content is likely to influence perceptual processes.

Concluding remarks

We argue that social odor plays a fundamental, yet often overlooked, role in early sociocognitive development through at least two distinct mechanisms. Future studies mapping effects over the course of early development, as well as the specificity to maternal odor, will provide valuable insights into the origins, contributions, and interplay between the two for a better understanding of early social learning.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used DeepL in order to proofread. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Declaration of interests

The authors declare no competing interests.

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