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ORIGINAL ARTICLE

The Concept of Innate Sexual Priors in the Brain: A Theory on Why We Are Attracted to What We Are Attracted to

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Abstract

Sexuality is an integral part of human nature, yet we know little about its origins and underlying mechanisms. Understanding how the brain processes sexual stimuli is crucial for advancing our knowledge of the origins of sexuality and its variations. Only if a stimulus was internally evaluated as 'attractive' the information can progress to evoke sexual desire or arousal. Importantly, such evaluation processes require an internal reference against which external information is compared. These processes, however, remain largely unexplored, and hence we still do not understand why we are attracted to what we are attracted to. By synthesizing the existing literature and integrating existing models, this narrative review proposes a novel neuroscientific framework on sexuality, addressing key theoretical gaps. As a result, the concept of sexual priors in the brain is introduced. Within this framework, sexual priors refer to mental 'images' representing a collection of internally stored information of what we regard as sexually attractive. Such mental representations act as reference in early internal evaluation processes of sexual stimuli. It is suggested that sexual priors are (partly) innate and sex-specific, contributing to heterosexuality. Evolutionary aspects that could explain the development of these priors are discussed. Furthermore, the framework provides possible explanations for variations in sexual orientation through potential cross-sex shifts in sexual prior content. The refinement of sexual prior content over time may explain the diversity of sexual interests and attraction patterns among humans. Moreover, the concept can be applied to a variety of psychiatric conditions related to atypical and maladaptive sexual behaviors. A proposition is put forward regarding brain areas and networks that may be involved in the formation of sexual priors, serving as potential targets for future research. In summary, by integrating sexual priors into models of sexual stimuli processing, this article fills theoretical gaps while inspiring further research. This work aims to enhance understanding of sexuality, which ultimately could increase social awareness, foster tolerance, and promote psychological well-being.

Keywords Sexual attraction · Sexual orientation · Sexual behavior · Sexual arousal · Neuroscience · Sexual priors

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Introduction

Sexuality is an important part of nature as it is essential for replication and survival of species. Sexual motivation and the feelings of desire, attraction, and arousal are important aspects that can lead to goal directed and sexual behavior, e.g., to achieve a feeling of sexual pleasure. Neuroscientific research has focused on elucidating the neural correlates of these processes. In human research, the most investigated factors are sexual arousal processes, often tested by measuring brain activity during functional magnetic resonance imaging (fMRI) experiments where participants are exposed to visual sexual stimuli. Today, we have a good understanding of which brain regions and networks are active when being sexually aroused or even when experiencing an orgasm (Georgiadis & Kringelbach, 2012; Georgiadis et al., 2012). While it is still difficult to distinguish between brain activity related to desire/arousal processes and those attributed to the processing of sexual stimuli, researchers have suggested which brain regions and networks are involved in each of these phases (Georgiadis & Kringelbach, 2012).

Apart from basic early sensory processing, such as the registration of visual, auditory, and other external information that the brain receives through our senses to comprehend our surroundings, numerous stimuli undergo further internal evaluations. For example, visual sexual stimuli not only need to be evaluated for their sexual or erotic content, but also in terms of desirability and attractiveness, which, as we know, can be very subjective. Only if a stimulus was internally evaluated as 'attractive' the information can progress to further engage brain networks that ultimately evoke the feeling of desire and arousal. While it is plausible to assume the existence of such evaluation processes, they still remain largely unexplored, and we do not understand the mechanisms through which a stimulus gains the quality of being perceived as attractive. In other words, we still do not understand why we are attracted to what we are attracted to.

In this theory and hypothesis article, a conceptual framework is presented that proposes the existence of innate sexual priors in the brain. Within this framework, sexual priors refer to mental 'images' representing a collection of internally stored information of what we regard as sexually desirable and attractive. These mental representations, proposed to encompass more than just visual information, act as reference in early evaluation processes of sexual stimuli, subsequently leading to sexual desire, motivation, and arousal. The idea of the existence of priors representing internally stored information is generally not novel and has found application across various neuroscientific domains (Adams et al., 2015; Angeletos Chrysaitis & Seriès, 2023; Corlett et al., 2019; Fletcher & Frith, 2009; Friston, 2005, 2010; Knill & Pouget, 2004; Kording, 2014; Moutoussis et al., 2014; Smith et al., 2021). Below, the role of priors in other neuroscientific fields is discussed, and a suggestion is provided on how the existence of sexual priors may explain sexual attraction, orientation, and its diversity. The article also discusses evolutionary aspects that could explain the development of sex- and species-specific sexual priors over time. Finally, although it is not the aim of this article to propose a functional brain model, using insights from previous scientific literature,

a proposition is put forward concerning which brain areas and networks may potentially be involved in the formation of sexual priors that can serve as potential targets for future research.

Relevant Neuroscientific Background

Evaluation Processes in the Brain

The brain constantly performs evaluation processes, a fact which is well established, especially in the fields of reward processing, learning, problem-solving, and decision-making (Bentivegna et al., 2024; Cuthbertson & Penney, 2023; Hélie et al., 2017; Herd et al., 2021; Jacobs & Kruschke, 2011; Kruschke, 2008; Morelli et al., 2022; Oldham et al., 2018; Osorio-Gómez et al., 2023; Schultz, 2015; Sharda, 2018; Weinstein, 2023). The evaluation of specific situations is part of every-day life and can be crucial for survival. For example, events or actions that previously led to painful experiences are usually avoided in the future, and we cross a street only when the internal evaluation resulted in "safe to cross!" Hence, we also evaluate ourselves, e.g., in terms of our own self-image and skill-set and put it into the context of our surroundings.

Importantly, evaluations demand a comparison against a reference. Evaluating a reward requires the assignment of a value to a specific gain (Bentivegna et al., 2024; Hélie et al., 2017; Oldham et al., 2018; Schultz, 2015; Weinstein, 2023), which is not possible without referencing against a state with less or without gain, or even loss. Decision-making often involves comparing the perceived attributes of different options upon which a certain course of action is taken (Bentivegna et al., 2024; Cuthbertson & Penney, 2023; Herd et al., 2021; Morelli et al., 2022; Schultz, 2015; Sharda, 2018). In problem-solving tasks, individuals may compare different solutions or strategies in their minds to determine the most effective or efficient way to solve a particular problem (Robertson, 2016; Sarathy, 2018). In learning processes, newly presented evidence or a new experience is compared against existing knowledge or past experiences, e.g., memories, after which knowledge can be updated or new information accommodated (Jacobs & Kruschke, 2011; Kruschke, 2008; Osorio-Gómez et al., 2023; Schultz, 2015).

These instances offer only a glimpse into the plethora of cognitive processes that encompass internal evaluations and comparisons. Nonetheless, the requirement of internal referencing for evaluation processes is important for understanding the concept proposed below.

Priors and Their Role in Neuroscience

The Theoretical Framework

In recent years, neuroscience has increasingly focused on the concept that the brain functions as a 'prediction machine'. It has made use of Bayesian statistical inference models, often used in combination with the predictive coding theory, to describe

various phenomena ranging from basic perception to symptoms of mental disorders (Adams et al., 2015; Angeletos Chrysaitis & Seriès, 2023; Barrett & Simmons, 2015; Corlett et al., 2019; Fletcher & Frith, 2009; Friston, 2005, 2010; Knill & Pouget, 2004; Kording, 2014; Lernia et al., 2023; Liddle & Liddle, 2022; Moutoussis et al., 2014; Paulus et al., 2019; Raber et al., 2024; Seth & Friston, 2016; Smith et al., 2021, 2020, 2019a, 2019b; Sterzer et al., 2018). The theory suggests that the brain generates an internal model of the external world and the self. These internal models contribute to the perception of the world and to the formation of a coherent sense of identity, which is crucial for adaptive behavior as they enable individuals to perceive, predict, interpret, and navigate their environment. According to these theories, the brain continually evaluates sensory input against such internal models and updates them to ensure the inner model agrees with 'reality'—at least to the extent possible. This minimizes prediction errors and improves an individual's ability to interact with the external world.

In the corresponding mathematical framework, a prior (or prior distribution) is used to describe the inner model and determines the probability of an event or outcome before new data is assessed. Such priors may reflect one's past knowledge, expectation, or belief about a specific quantity before new information about the new quantity or new evidence is taken into account. Evidence can have many forms but is generally produced through new experiences made through our senses, i.e., perception. The model further suggests that new evidence is evaluated against the prior, and priors (usually) update after the processing of new evidence. The resulting posterior or updated belief depends on both the prior belief and the new evidence. More specifically, it depends on the magnitude of the disagreement between the previous belief/knowledge and the new evidence/information, as well as their individual precisions. The stronger the prior, or the weaker the evidence, the less likely it is for the prior to change, e.g., knowledge or belief to be updated. For example, if we are exposed to information we already know, there is nothing new to learn and our knowledge does not need to be updated. On the other hand, in case new evidence contradicts our previous beliefs, meaning the discrepancy between prior and new evidence is large, the resulting posterior belief may be a compromise between the new evidence and our prior belief. Figure 1 shows the idea behind this concept. Hence, priors are dynamic and constantly change over time as we are making new experiences or accumulating new evidence over lifetime.

While a detailed discussion on Bayesian statistics, predictive coding, prior types, and the theory behind such processes goes beyond the scope of this article, an excellent overview on these topics can be found elsewhere (Adams et al., 2015; Friston, 2005, 2010; Gelman et al., 2013; Knill & Pouget, 2004; Spratling, 2017). An important note, however, is that Bayesian models utilizing prior concepts successfully describe many neuroscientific observations. How these priors manifest or are represented in the brain is still unclear, and the brain regions and networks that form them may be as diverse and complex as the quantities they represent. However, in this context, priors in themselves are believed to be internally integrated knowledge representing our 'image' of the world, including the self, and serve as reference where required. Acknowledging the following

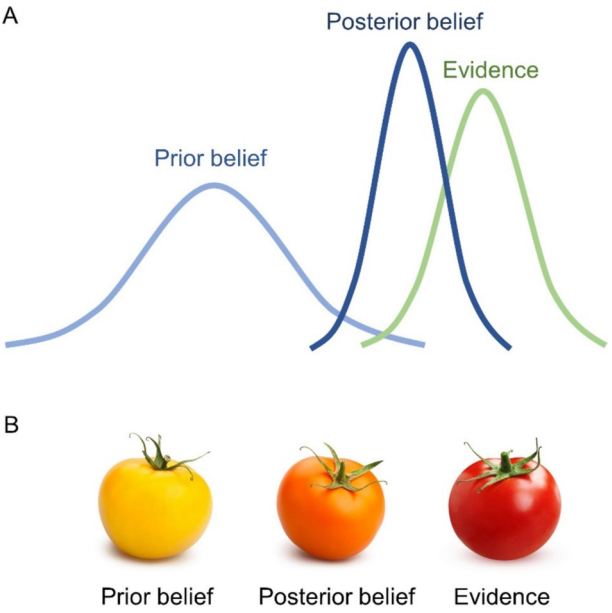

Fig. 1 A: Concept of a Bayesian inference model. **A** Prior probability estimate reflecting the uncertainty or variability in prior knowledge (or belief) undergoes an update to a posterior probability estimate (e.g., posterior belief) by incorporating information from a likelihood distribution that quantifies the probability of observing new information (or new evidence and its precision). The posterior probability (or posterior belief) is proportional to the product of the prior probability and the probability of new evidence. **B** Simplified and fictitious example in the context of beliefs: Consider an individual who had the prior belief that tomatoes are yellow, e.g., because that individual has thus far only seen yellow (e.g., unripe) tomatoes. Later in life, this individual is presented with a ripe (red) tomato (new evidence). This may result in the posterior belief that tomatoes are orange (a compromise between prior and new evidence). Throughout lifetime and more tomato encounters, the prior belief that tomatoes are red may manifest. Note that this is an oversimplified example to illustrate the general concept of updated prior beliefs in the context of Bayesian inference. Most individuals may not conclude that tomatoes are orange based on presented evidence of solely yellow and red tomatoes

characteristics of priors is fundamental for the understanding of the concept presented below:

- Priors can comprise stored information, such as past experiences, knowledge, and beliefs.
- Priors act as reference against which perceived information is evaluated.
- Priors can be updated; thus, they are dynamic.

Internal Priors in Disease Models

Before elaborating on the potential existence of sexual priors, some examples will be provided where the concept of internal priors has been used to successfully describe neurocognitive processes. For example, Bayesian models have frequently

been applied in the fields of self-perception (Barrett & Simmons, 2015; Moutoussis et al., 2014; Smith et al., 2019a, 2019b), pain (Borg et al., 2021; Drusko et al., 2023; Eckert et al., 2022), and mental disorders (Angeletos Chrysaitis & Seriès, 2023; Corlett et al., 2019; Fletcher & Frith, 2009; Harding et al., 2024; Lernia et al., 2023; Liddle & Liddle, 2022; Paulus et al., 2019; Smith et al., 2020, 2021; Sterzer et al., 2018). There are several psychiatric disorders and conditions that are characterized by a disturbance in how an individual experiences the world and the self. The most profound example is psychotic symptoms in schizophrenia, including delusions or hallucinations. Within the predictive coding framework, these psychotic symptoms have been described by a sustained discrepancy between incoming external signals, e.g., a visual stimulus, and priors established through past experiences and expectations (Adams et al., 2013; Fletcher & Frith, 2009; Harding et al., 2024; Liddle & Liddle, 2022; Sterzer et al., 2018). In simpler terms, if the brain fails to update the internal 'image' of the world or a belief even after strong evidence against it is provided, the resulting world-image or belief will still be far from 'reality', which under certain circumstances may result in the manifestation of psychotic symptoms simply as a result of the brain providing (often implausible) explanations for the discrepancy (Adams et al., 2013; Fletcher & Frith, 2009; Liddle & Liddle, 2022; Sterzer et al., 2018). This may result in delusional beliefs which serve as a mechanism to bridge the cognitive gap between prior belief and the new evidence provided.

Another example of internal 'images' is body image. While the term has different definitions and has been employed to convey differing meanings (Fikir & Melaku, 2017; Kling et al., 2019), it is associated with a subjective internal image an individual has of their own body, including perception, feelings, and attitudes towards its appearance (Arzy & Schacter, 2019; Burke et al., 2012; Fikir & Melaku, 2017; Longo et al., 2009). A healthy body image aligns largely with the physical reality. However, in eating disorders or body dysmorphic disorder, an individual´s body image may be distinct from how their physical body appears to others (Glashouwer et al., 2019; Hosseini & Padhy, 2024; McLean & Paxton, 2019; Mufaddel et al., 2013). Body image is also believed to play a role in gender incongruence (Heiden-Rootes et al., 2023; McGuire et al., 2016; Verveen et al., 2021, 2023), where the internal image influenced by one´s own gender identity can be distinct from that corresponding to the sex assigned at birth, generating an internal conflict.

While there exists an extensive body of literature on these subjects, including numerous examples unrelated to mental disorders, a detailed summary exceeds the scope of this article. However, scientific research provides substantial evidence supporting the existence of internal priors serving as internal representations or 'images' of both the outer world and the inner self.

The Human Sexual Response Cycle and Motivation

The Human Sexual Response Cycle and Associated Brain Areas

This section provides a brief overview of what neuroscience has uncovered about sexual desire and arousal processes in the human brain.

Over the last decades, neuroscientific research has shed light on the neural correlates of human sexual desire and arousal both in males and females. Most information has been derived from neuroimaging studies measuring brain activity during fMRI experiments where participants were exposed to, mostly visual, sexual stimuli (Georgiadis & Kringelbach, 2012). Through a comprehensive review of the brain imaging literature, Georgiadis and Kringelbach mapped out findings from previous studies and provided an informative overview of brain regions and networks involved in the different phases of the *human sexual response cycle* (Georgiadis & Kringelbach, 2012). This cycle, among the first explored by Masters and Johnson (1966), refers to physical but also emotional states that occur as an individual becomes sexually aroused and participates in sexual activities, including sexual intercourse or masturbation. Since research is constantly evolving, a variety of *human sexual response cycle* models have been introduced and expanded on over the past decades (Bancroft & Janssen, 2000; Basson, 2001; Georgiadis & Kringelbach, 2012; Georgiadis et al., 2012; Toates, 2009). However, they largely align with the basic phases they entail. Given the provided link to fMRI-related brain activity, here, the example of Georgiadis et al. was chosen as an illustrative case. Once entered, the *human sexual response cycle* has been described to entail the following phases (Fig. 2):

- Sexual desire
- Arousal/excitement
- Consummatory plateau (e.g., physical stimulation)
- Orgasm/climax
- Refractory period of sexual quiescence (or resolution)

These phases are assumed to be similar and highly linked to wanting (desire), liking (excitement/arousal), and satiety (refraction) in other pleasure cycles, e.g., related to food consumption (Georgiadis & Kringelbach, 2012). Different, but partly

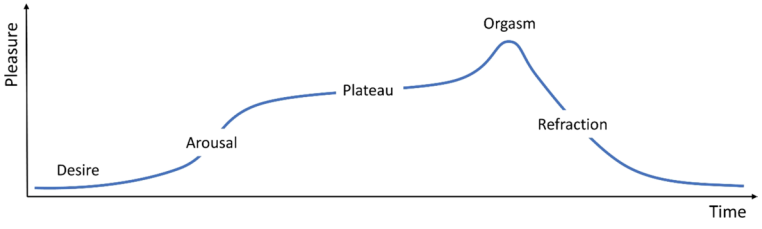

Fig. 2 The different phases of the human sexual response cycle

overlapping, brain areas are assumed to be functionally active during each phase, and their engagement varies across the cycle giving rise to different brain networks involved.

The focus of this article is on mechanisms that may start the cycle. It is well known that different sexual stimuli can elicit sufficient interest for an individual to enter the cycle (Georgiadis & Kringelbach, 2012). Thus, it is reasonable to assume that the corresponding key mechanism underlying the start of the cycle is a sexual stimulus evaluation process. Therefore, processes and brain regions involved in the early phases of the *sexual response cycle* are of particular interest. In this context, Georgiadis and Kringelbach propose a 'sexual interest network', primarily derived from neuroimaging experiments using briefly presented simple erotic stimuli. The associated brain network is assumed to be partly distinct from the arousal network and restricted to recognizing sexual opportunity and directing motivated behavior (Georgiadis & Kringelbach, 2012). The key brain regions thought to be involved comprise subcortical areas, including the hypothalamus, ventral striatum, and amygdala, and cortical areas, such as the anterior insula, pregenual anterior cingulate cortex, orbito-frontal cortex (OFC), superior parietal lobule, and the ventrolateral occipitotemporal cortex, part of the ventral visual stream (Georgiadis & Kringelbach, 2012).

It is noteworthy that due to design and methodological limitations in fMRI studies, such as limited time resolution, the brain activity patterns and regional involvement assigned to the different phases of the response cycle may partly overlap. Therefore, it is difficult to disentangle activity related to eliciting sexual desire from that involved in the early processing of sexual stimuli. Thus, the brain regions and networks assigned to the desire-phase or the sexual interest network may represent activity related to an evaluation process, but also sexual desire building and/or early arousal.

Nevertheless, given the known functions of the brain regions involved in the 'sexual interest network', it was proposed that these, at least partly, reflect evaluation processes, as they entail brain areas involved in visual information processing, (hedonic) reward value and salience representation, interoceptive experience, and emotional memory (Georgiadis & Kringelbach, 2012; Georgiadis et al., 2012; Toates, 2009). Speculatively, this could be linked to evaluating sexual stimuli with regard to a reference aligned with one's personal sexual preference. Such an internal sexual reference has been proposed to be determined by contextual factors, as well as previous sexual experiences and current internal states (Georgiadis & Kringelbach, 2012). However, the exact nature of the required reference remains unknown.

The primary objective of this article is to propose a theory regarding the nature of this reference, suggesting how it may evolve, and offering an explanation for both heterosexuality and any diverse forms of sexuality, encompassing various sexual interests.

Sexual Motivation and the Incentive Motivation Model

While in the above model the start or entering phase of the *sexual response cycle* consists of generating sexual desire, the described phases do not necessarily need

to occur in this order. They can vary depending on stimuli type, individual, and context, and there may be different pathways between them (Ågmo & Laan, 2022, 2023, 2024; Basson, 2001; Georgiadis & Kringelbach, 2012; Georgiadis et al., 2012; Toates, 2009). In this context, sexual motivation plays an important role, and researchers have proposed complementary models that take this factor into account. The *sexual incentive motivation model* emphasizes the influence of sexual motivation driving or motivating sexual behavior by the anticipation of rewards or positive outcomes (Ågmo & Laan, 2022, 2023; Toates, 2009; Ventura-Aquino & Ågmo, 2023). The model proposes that incentive stimuli, i.e., stimuli that have the potential to evoke an incentive for motivating behavior, induce sexual motivation and sexual approach behavior.

In brief, if a stimulus has been determined to be sexually relevant or attractive, e.g., by detection of an attractive conspecific or stimuli associated with them, motivation is induced, and approach behaviors are activated. Once such approach has been accomplished, sexual behaviors are executed, that can lead to orgasm. Arousal has a modulatory influence on each of these steps, but can also directly be triggered by incentives (Ågmo & Laan, 2022, 2023). As described by Toates et al. (2009), stimuli-based factors, including stimulus properties and/or memories of these, as well as cognition-based factors need to be considered, especially in humans, as they often perform cognitive evaluations before initiating approach behavior. Such cognitive evaluation may take into account mental representations or memories, e.g., of previous sexual experiences, but also contextual factors such as place and time of day, social context, cultural aspects, or simply predictions about potential responses of the subject emitting the incentive stimulus. These cognitive processes interact with intentions, reward assessments, and decision making and can modulate incentive value and arousal (Ågmo & Laan, 2022, 2023; Toates, 2009). While some cognitive factors can enhance arousal, others can lower or inhibit it. Common examples of this are fear of performance failure or the detection of aversive stimuli (Ågmo & Laan, 2023; Toates, 2009). Thus, cognitive evaluation may conclude that further approach might have aversive consequences or is not associated with sexual reward. This is why, especially in humans, incentive-induced approach behaviors are often not initiated or aborted before sexual activity has been initiated.

While these late (controlled) cognitive processes rely on internal comparison processes, they are mainly based on referencing against memories of past (sexual) experiences. Concerning internal references in early processes, the model by Toates, for instance, mentions the "detection of an attractive conspecific" based on stimulus properties, but these processes, including the required internal comparator, have not been further elaborated on. Thus, while the *incentive motivation model* complements the *human sexual response cycle* by implementing important psychological and cognitive aspects to human sexual response, motivation, and behavior, it lacks in-depth explanations for the initial processes. Hence, this article does not focus on late or higher-order cognitive evaluations, well covered by previous models, but rather on early processes that explain how an external stimulus is determined to be of sexual relevance or attractive. In the context of the *incentive motivation model*, this would relate to processes that describe how an external stimulus, first detected by sense organs, acquires the meaning of a sexual incentive in the first place.

Neurobiology of Sexual Orientation

This section offers a concise overview of the neurobiology of sexual orientation to assist in the understanding of the model proposed below. For a more in-depth understanding of this topic, the author directs readers to the references listed below.

Although opinions on the existence of sex differences in the brain may diverge, sex differences in the human brain have frequently been reported and are supported by a large body of evidence (Abé et al., 2021b; DeCasien et al., 2022; Forde et al., 2020; Lotze et al., 2019; Ritchie et al., 2018; Ruigrok et al., 2014; Sowell et al., 2007; Wierenga et al., 2022; Williams et al., 2021). These differences are assumed to be influenced by genetic and hormonal factors, e.g., those of sex steroids, and similar mechanisms are believed to play a role in sexual orientation development (Bailey et al., 2016; Ganna et al., 2019; Hines, 2011; Långström et al., 2010; Rahman, 2005; Swaab & Garcia-Falgueras, 2009; VanderLaan et al., 2023). Brain differences related to sexual orientation have therefore been hypothesized. Various neuroimaging studies have been conducted, where brain structure and function were compared between self-identified heterosexual and homosexual individuals, see (Abé et al., 2014, 2018, 2021b; Clemens et al., 2023; Frigerio et al., 2021; Hu et al., 2008; Kranz & Ishai, 2006; LeVay, 1991; Ponseti et al., 2006, 2007; Safron et al., 2017; Votinov et al., 2021; Wang et al., 2020) and references therein. Thus, evidence for neural correlates to sexual orientation has recently been accumulating.

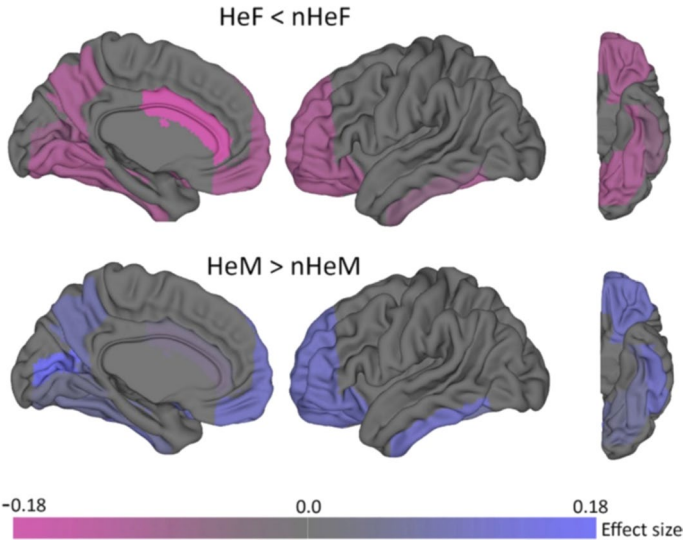

Fig. 3 Sexual orientation-related cross-sex shifts in brain structure. Effect sizes of same-sex sexual behavior-related cross-sex shifts in cortical volume. Color shades correspond to the observed effect size (Cohen's d) obtained from pairwise group comparisons. Top: heterosexual females (HeF) versus non-heterosexual females (nHeF). Bottom: heterosexual males (HeM) vs. non-heterosexual males (nHeM). Negative effect sizes (magenta) reflect HeF < nHeF patterns (nHeF shifted toward HeM). Positive effect sizes (blue) reflect HeM > nHeM patterns (nHeM shifted toward HeF). Overall, a HeF < nHeF < nHeM < HeM pattern was observed indicative for same-sex sexual behavior-related cross sex-shifts in brain structure. Figure obtained from Abé et al. (2021b)

The picture that emerges from these studies is that in some brain areas homosexual males tend to be more female-typical, and homosexual females tend to be more male-typical (Abé et al., 2021b). This is known as a cross-sex shift, which is also found in various behavioral traits (Allen & Robson, 2020; Bailey et al., 2016; Li et al., 2017; Xu et al., 2017). This cross-sex-shift was confirmed in the largest brain imaging-genetics study to date, which included brain scans of 18,645 individuals (Abé et al., 2021b) (Fig. 3). The study robustly replicated findings from smaller previous studies, suggesting that a sexual orientation-related cross-sex shifted brain structure can predominantly be observed in visuo-sensory brain areas (Abé et al., 2021b). The study also observed associations between brain structural outcomes and an individual's genetic predisposition for same-sex sexual behavior, indicating a genetic influence on sexual behavior related brain structure.

Although none of these studies allow conclusions with respect to causality nor can they reveal if and how the observed brain differences relate to differences in sexual behavior per se, it is not farfetched to assume that cognitive and behavioral differences, including sexual behavior and attraction patterns, may be mirrored to some extent in the observed sexual orientation-related brain differences. Nevertheless, such previous studies strongly support a neurobiological basis to the variation in human sexuality.

Sex, Sexual Orientation, and the Sexual Stimuli Paradox

To further support the assumption that variations in the brain related to sex and sexual orientation are plausible, a natural phenomenon will be discussed to introduce a scenario, here referred to as the *sexual stimuli paradox*. For simplicity, the perception of visual sexual stimuli is employed as a representative example to illustrate this paradox.

Most of us would likely agree that heterosexuality is the most common sexual orientation among humans (Bailey et al., 2016), meaning most males are generally sexually attracted to females, and most females to males – of course with few exceptions. Moreover, not every male is attracted to all females, and vice versa. Thus, the experience of attraction, desire, or arousal requires that a perceived sexual stimulus not only possesses basic visual features of the opposite sex, but also characteristics aligned with the observer's specific preferences. However, for simplicity, the latter requirement will be overlooked in the following example, as it is not pertinent to the comprehension of the sexual stimuli paradox (this subjective preference aspect is considered in sections below).

Given these assumptions, only when a heterosexual male (heM) visually perceives a female stimulus, sexual desire/arousal processes are activated in the male's brain. The same applies when a heterosexual female (heF) perceives a male stimulus (Fig. 4A). Further, when a heM visually perceives a male, or, equivalently, a heF perceives a female stimulus, sexual desire/arousal processes are not initiated (Fig. 4B). Hence, while the ultimate outcome, i.e., the activation of the desire/arousal network, remains the same, heM and heF rely on different stimuli to achieve this. If it is assumed that cerebral sex-differences do not exist, i.e., the structural and functional organization and in turn internal processing would be identical in

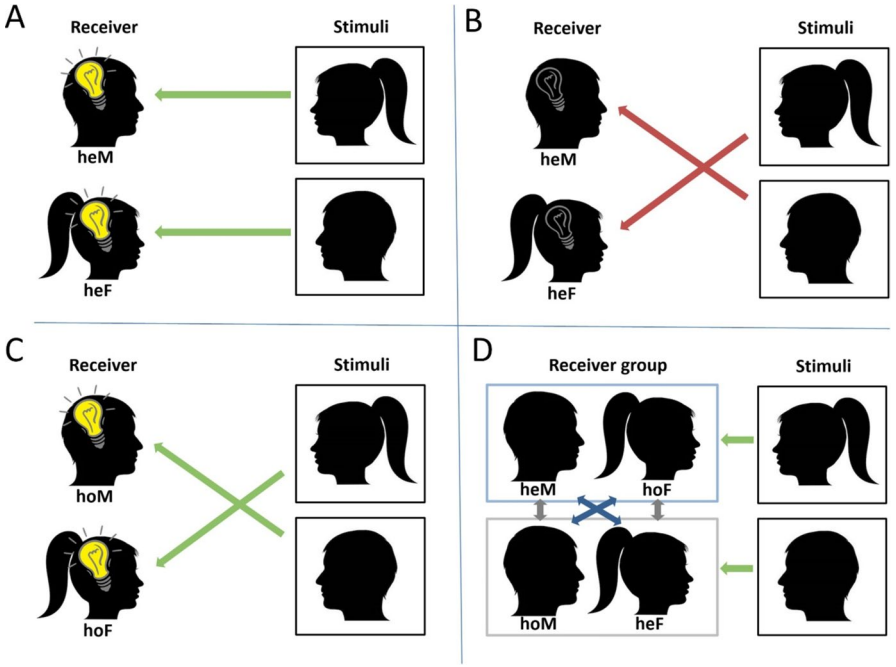

Fig. 4 Sexual stimuli paradox. Simplified scheme in which silhouettes of human heads were used to illustrate the sexual stimuli paradox. The different panels are more elaborated in the main text. While acknowledging that these depictions may rely on stereotypes, for simplicity, in this representation, females (F) are portrayed with long hair and a ponytail, and males (M) are portrayed with short hair. Heterosexual (he) and homosexual (ho) sexual orientations are indicated. Arrows indicate visual stimuli source origin (black frame) and the perceiving target individual (receiver). Green arrows in combination with a lit-up bulb indicate the perception of a sexually attractive stimulus associated with an activated sexual desire/arousal network. Red arrows in combination with a turned-off bulb indicate mismatching sexual stimuli and an inactive desire/arousal network. **A** Heterosexual individuals perceiving an opposite-sex sexual stimulus initiating sexual desire/arousal. **B** Heterosexual individuals perceiving a same-sex sexual stimulus not initiating sexual desire/arousal. **C** Homosexual individuals perceiving a same-sex sexual stimulus initiating sexual desire/arousal. **D** Sex and sexual orientation grouping based on which type of stimuli induces desire/arousal. heM and hoF require a stimulus that is different from heF and hoM to achieve an activation of the sexual desire/arousal network. Groups of individuals with presumed similar internal reference for evaluation processes are framed. The two different frame colors blue (heM and hoF) and grey (hoM and heF) indicate that the groups' internal references and therefore brain organization differs, implying both sex- (blue arrows) and sexual orientation-related differences (grey arrows)

males and females, the same external input (e.g., male stimulus) would induce the same outcome, which is evidently not the case. This paradox can only be resolved by assuming differential sex-specific stimuli processing, which implies the presence of sex-related differences in the brain, at least on a functional level.

Expanding on this point, considering a switch in sexual orientation from heterosexual to homosexual in the two stimuli-receiving observers, in the homosexual male (hoM) the desire/arousal processes would be activated upon perception of the male stimulus, and arousal/desire processes in homosexual female (hoF) would be triggered by the female stimulus (Fig. 4C). Note that in this hypothetical example

the stimulus inducing desire/arousal perceived by heM and hoF is a female stimulus. Equivalently, the desire/arousal inducing stimulus perceived by heF and hoM is a male stimulus (Fig. 4D). Again, while the final outcome, an activated desire/arousal network, is consistent across all individuals, heM and hoF require different stimuli than heF and hoM to achieve this. This concludes four points:

1) Evaluation processes of visual sexual stimuli are similar in heM and hoF
2) Evaluation processes of visual sexual stimuli are similar in in hoM and heF
3) Evaluation processes of visual sexual stimuli differ between hoM and heM
4) Evaluation processes of visual sexual stimuli differ between hoF and heF

Conclusions 3) and 4) suggest differential functional brain organization not only related to sex but also to sexual orientation, and are in line with the notion that sex- and sexual orientation-related differences in the brain exist. As outlined above, if such differences did not exist, the same external male stimulus would be processed and evaluated in the same way by heM and hoM and ultimately lead to sexual desire/arousal in both, which it evidently does not. In line with this notion, Ponseti et al. demonstrated in both hetero- and homosexual males and females that the sexual preference of the observer determines their neuronal responsiveness to male and female sexual stimuli. Notably, the neuronal responses to preferred sexual stimuli were consistent across all groups (Ponseti et al., 2006). Conclusions 1) and 2) align with the aforementioned *cross-sex shift* theory and would imply that homosexual males process the same stimulus in a similar way as heterosexual females, and vice versa.

The key processing mechanism of relevance here is the evaluation of sexual stimuli. Particularly, the above discussion suggests that the internal reference for sexual stimuli evaluation, necessary for inducing sexual desire/arousal, is both sex- and sexual orientation-specific. More precisely, this means that the internal reference for stimuli evaluation must differ between heM and heF. Furthermore, the reference in hoF must be similar to that in heM, and the reference in hoM must be similar to that in heF. This conclusion will be further elaborated in the next sections.

The Concept of Sexual Priors in the Brain

In this section, the idea of the existence of sexual priors in the brain is more elaborated. In previous sections, it was explained that sexual stimuli need to undergo internal evaluation to determine their sexual/erotic content and attractiveness in order to evoke sexual motivation, desire, or arousal. To evaluate, an internal reference needs to be present against which external information is compared. Furthermore, such reference is assumed to be sex- and sexual orientation-specific.

Here, it is proposed that such reference exists and is represented by a sexual prior, which, similar to other prior types discussed earlier, may entail a mental representation or an internal ‘image’ of what we regard as sexually desirable and/or attractive. This mental image should not be understood as a visual image per se but may

comprise stored information of visual features related to, e.g., bodily shape and size, skin and hair colors, etc. In addition, it may comprise non-visual information, such as auditory information or memories of scent, taste, and touch. Examples of this may include the smell of body odors or the sound of specific vocal characteristics. It may further include memories of emotions and specific past (sexual) experiences integrated over time, further elaborated in the discussion. Together, these types of information would form the overall reference ´picture´ that makes up the mental representation here referred to as sexual prior. Note that the memories and experiences referred to in this context should not be confused with those contributing to late cognitive evaluations, e.g., those interacting with reward assessments and decision-making. Such late processes are assumed to take place after a stimulus was evaluated as attractive, with the latter being the key aspect of the sexual prior model.

The proposed sexual stimuli evaluation process then entails that a stimulus perceived through sense organs, may it be visual or of other nature, is internally and

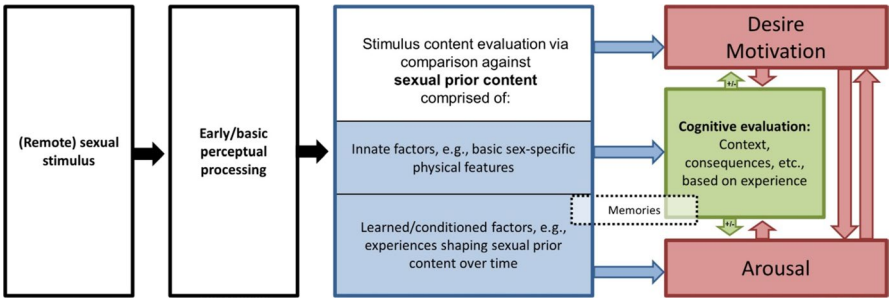

Fig. 5 Sexual stimuli processing model via sexual priors. The model proposes that a (remote) sexual stimulus is first perceived through sense organs (black box) and then first evaluated through internal comparison against sexual priors (blue box). If a perceived stimulus matches the prior information (to a sufficient degree), the stimulus is evaluated as sexually 'attractive' or 'desirable'. In context of the sexual incentive motivation model, this process may be understood as the assignment of incentive to a stimulus. Sexual prior information is based on innate but also learned/conditioned factors (see discussion section for more details). Through rapid processing, an attractive (or incentive) stimulus can directly induce sexual desire or motivation but can also directly induce arousal. Desire/motivation influences arousal and vice versa. Another pathway that can lead to desire/motivation or arousal is via (late higher-order) cognitive evaluation processes (green box), that take, e.g., contextual factors and memories of experiences into account playing a role in reward assessments, consequence determination, and decision making. Cognition modulates and interacts with desire/motivation and arousal and can enhance (+) or inhibit (−) both. The black dashed box labeled "memories" intends to display the different nature of memories of experiences contributing to sexual prior content and cognitive evaluations. Memories contributing to sexual priors are those that contribute to its content through adding refined detail information over time, e.g., specific physical features, that may be learned or conditioned, leading to rapid detection of attractive stimuli not requiring higher-order cognitive evaluations. Memories playing a role in cognitive evaluation are those that contribute to reward assessments and decision making, e.g., through determination of consequences of actions, comparisons to similar previous situations, contextual appropriateness, etc. Note that orgasm, which potentially follows arousal, and subsequent refraction phases are omitted in this graph, since the focus of this model is the initial sexual stimuli processing mechanism involving sexual priors. For the same reason, processes following sexual prior-based evaluations (red and green boxes) are simplified and represent the basic processes in sexual response and incentive motivation models. For detailed insights into these models see references provided in the main text

rapidly compared against the sexual prior (Fig. 5). Only if a perceived stimulus matches the prior information (to a substantial degree), will the stimulus be evaluated as 'attractive', and that information is integrated to cascade into neural processes subsequently evoking sexual desire, motivation, and/or arousal, i.e., to enter the *sexual response/motivation cycle*, via different pathways (Fig. 5).

As discussed before, internal references, thus, sexual priors, are proposed to be sex- and sexual orientation-specific. Heterosexual individuals must exhibit a sexual prior that predominantly comprises information about distinctive features of the opposite biological sex. This means that sexual priors in heterosexual males entail female-typical features, and sexual priors in heterosexual females entail male-typical features. Figure 6A illustrates this on the example of heterosexual human males and females. Furthermore, the present concept proposes that sexual priors are partly innate and exhibit a basic rudimentary form initially that shapes over lifetime into a more detailed and individualized 'image'. This could occur through sexual learning or conditioning and is more elaborated in the discussion section. In the discussion below, it is further explained how a 'switch' of sex-specific priors can explain same-sex sexual attraction (Fig. 6B), as well as other forms of sexual preference and attraction patterns. Propositions on how sexual priors may have emerged and developed, and a rationale behind their species-specific nature are also provided.

Discussion

Understanding how the brain processes sexual stimuli is crucial for advancing our knowledge of the origins of sexuality and its variations. While fast early (automated) and slower late (controlled) processes play a role (Ågmo & Laan, 2022; Janssen et al., 2000; Toates, 2009), most previous models elaborate on the influence of late cognitive processes on sexual motivation, arousal, and behavior, which are largely influenced by memories of past (sexual) experiences. Mechanistic explanations for the fast early processes remain scarce. In the context of early processes, terms like evaluating stimuli against "a personal sexual reference" (Georgiadis & Kringelbach, 2012), excitation "based on stimulus properties and memories of these" (Toates, 2009), or sexual appraisal-based "matching of stimuli in memory" (Janssen et al., 2000) have been used, but never further discussed. This article focuses on such fast processes and primarily on the nature of the internal comparator required for early sexual stimuli evaluation.

Here, the existence of partly innate sexual priors in the brain is proposed. Such priors may embody mental 'images' or representations, to be understood as a collection of stored information of what we regard as sexually attractive. Importantly, internal representations making up sexual priors are different from those influencing late cognitive processes. Sexual priors are proposed to act as reference in early evaluation processes of sexual stimuli, rapidly assigning attractiveness (or incentive) to a stimulus if a sufficient alignment between prior information and stimuli is attained. Only after assignment of these attributes an external stimulus gains the potential to trigger sexual desire, motivation, and arousal processes. Thus, evaluations against sexual priors are suggested to be the first step in any sexual stimuli processing

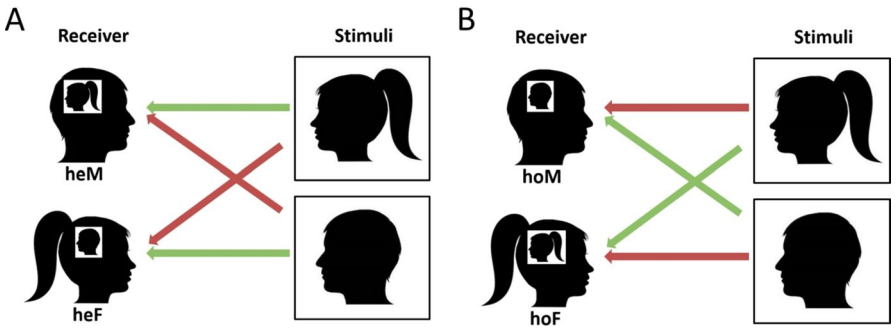

Fig. 6 Sexual priors and stimuli matching. Solving the stimuli paradox. The different panels are more elaborated in the main text. Same depiction style as in Fig. 4 is used. Heterosexual (he) and homosexual (ho) sexual orientations are indicated. Internal sexual priors are depicted as white boxes within the confines of an individual's head area. Note that this is a simplified illustration, and it is not suggested that priors only consist of visual information. Furthermore, the local placement of the boxes does not have any particular meaning. Arrows indicate visual stimuli source origin (black frame) and the perceiving target individual (receiver). Green arrows indicate a match between sexual prior and stimulus content, i.e., the perception of an attractive stimulus, creating the potential for an activated sexual desire/arousal network. Red arrows indicate a mismatch between sexual prior and stimulus content and a deactivated desire/arousal network. **A** Sexual priors in heterosexual individuals comprise featural information of the opposite sex. **B** Sexual priors in homosexual individuals comprise featural information of the same sex, required to internally assign attractiveness and to initiate sexual desire/arousal

model, including sexual response and incentive motivation models. Moreover, as suggested by previous evidence, sexual priors are proposed to be sex-, sexual orientation-, and species-specific.

It should be noted that the discussion below is speculative in nature and solely aimed at presenting potential explanations for a selection of example phenomena to underscore the applicability of the sexual prior concept to a wide range of sexual attraction patterns and conditions observed in humans, and potentially other species.

Development and Evolution of Sexual Priors

In the presence of sexual priors, questions about their origin and development may arise. The presented concept indeed aligns with the framework of evolutionary theory, particularly natural and sexual selection. While natural selection more generally is the process by which organisms with traits that enhance survival and reproduction are more likely to pass on their genes to the next generation, sexual selection is a concept within evolutionary biology that explains how certain traits evolve due to their influence on an organism's reproductive success. First introduced by Charles Darwin in 1871, sexual selection has been suggested to operate through two main mechanisms: intrasexual competition and intersexual choice. Intrasexual competition involves direct competition between members of the same sex for access to mates, while intersexual choice occurs when individuals of one sex choose mates based on specific traits. The theory helps explain the development of sexual dimorphic and secondary sexual characteristics, i.e., distinct male and female features

within a species, such as size, coloration, or even vocalizations (Andersson & Simmons, 2006; Campbell, 2017; Darwin, 1871; Mendelson & Safran, 2021; Puts et al., 2016; Ryan, 2021) (see Fig. 7 for examples)**.** These distinct features play a crucial role in the reproductive strategies of each sex within species.

Hence, sexual priors might have potentially emerged as a consequence or manifestation of natural or sexual selection processes. One could argue that organisms that developed sex- and species-specific sexual priors are more likely to replicate than those without such priors. Sexually dimorphic organisms able to perceive their opposite sex counterpart, but not developing and possessing a matching sexual prior, would not have a reference 'image' required to detect and select an opposite sex sexual partner, thus, would not predominantly direct their sexual behavior towards them. In contrast, organisms that developed sexual priors that contain featural information of the opposite sex specific to their species would be more likely to identify the sexual partner required to replicate. In turn, this could support the formation of species-specific sexual priors over time. Moreover, it is plausible that males would possess priors that entail female characteristics and vice versa, favoring replication and, thus, the development of heterosexuality. In other words, sexual priors that internally store species-specific sexually dimorphic features may have naturally developed as part of the evolutionary process.

The above-described targeted replication may also favor replications of genetic factors involved in the formation of sexual priors. Therefore, the present theory proposes that sexual priors or factors that cause their development are, at least partly, genetically encoded and therefore innate. This aligns with previous notions and propositions of innate sexual instincts and biologically 'prepared' or 'pre-programmed' stimuli (Ågmo & Laan, 2022; Brom et al., 2014; Everaerd, 1995; McDougall, 1914; Salu, 2011). These may be similar to those described in innate fear, taste aversion, or other models describing biologic preparedness (Chambers, 2018; Dunlap, 2017; Öhman & Mineka, 2001; Seligman, 2016). Most humans and other species exhibit a positive emotional response to sex, and conditions most likely exist that are innately pleasurable (e.g., local stimulation of the genitals and the experience of orgasm) (Everaerd, 1995). The human body is naturally equipped with sensory receptors,

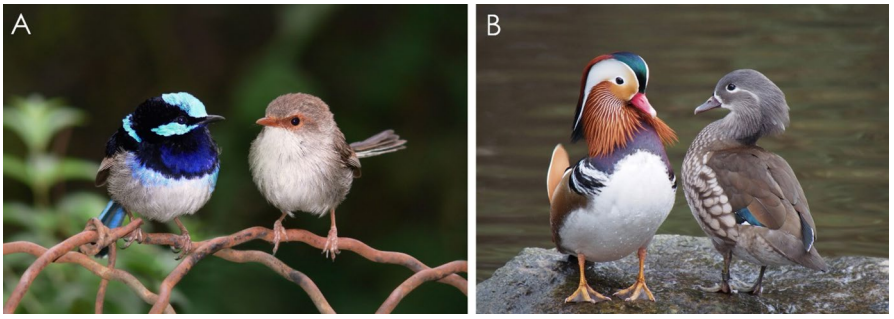

Fig. 7 Representative examples of sexual dimorphism. **A** Male (left) and female (right) superb fairywrens (*Malurus cyaneus*). **B** Male (left) and female (right) Mandarin ducks (*Aix galericulata*) and their distinctive coloration features

that can respond to touch and contribute to sexual arousal. These conditions form the base for desire and motivation for tactile sexual stimulation. While the interpretations of tactile sexual stimuli may be shaped by cultural, social, and individual factors, such physiological responses can still be (and are often) considered innate (Everaerd, 1995), as they are part of the basic biological makeup of humans.

How can Sexual Priors Explain Different Sexual Orientations

While the aforementioned paragraph may explain the development of heterosexuality, the sexual prior concept can also be applied to explain variations in human sexual orientation. As outlined above, to resolve the sexual stimuli paradox, one needs to assume that sexual priors in homosexual males are more similar to the sexual priors of heterosexual females, and vice versa (Fig. 6). The factors causing such a prior 'switch' could be similar to those involved in the formation of sexual orientation-related brain differences, believed to be of genetic and/or hormonal origin (Bailey et al., 2016; Ganna et al., 2019; Hines, 2011; Långström et al., 2010; Rahman, 2005; Swaab & Garcia-Falgueras, 2009). Non-heterosexual individuals repeatedly displayed structural and functional brain features that are more similar to that of their opposite sex heterosexual counterpart (cross-sex shift), predominantly in visuo-sensory brain areas (Abé et al., 2021b). If the observed brain differences and their underlying mechanisms are linked to prior manifestations is unclear, but, considering the cross-sex shifts observed in brain structure, function, and behavioral traits (Allen & Robson, 2020; Bailey et al., 2016; Li et al., 2017; Xu et al., 2017), it is reasonable to entertain the idea that a cross-sex shift in sexual prior content may be present. While a complete sexual prior 'switch' could well explain the observation that homosexual individuals are attracted to people of same sex, in individuals attracted to both sexes, a sexual prior 'shift' may result in sexual priors containing both male and female featural information. Therefore, and given the proposed involvement in fast and early automated processing, sexual priors are suggested to significantly influence, or potentially determine, sexual orientation.

How can Sexual Priors Explain Variations in General Sexual Interest

The following elaborates on how the sexual prior concept can offer an explanation for the variety of sexual interests within a specific sexual orientation. While the model proposes that sexual priors are innate, they may exhibit a basic rudimentary form initially that shapes over lifetime into a more detailed and individualized 'image', giving rise to the large variety of sexual preferences and attraction patterns we observe in humans. Hence, the term "prior" is suitable in this context, as it implies a dynamic process with updates occurring over time. Sexual prior updates may be determined through internal biological processes, including genetic and hormonal factors (e.g., during puberty), and other external environmental factors, such as experiences. For example, situations that lead to pleasurable experiences might contribute to updating or shaping an individual's sexual prior. This may involve experiencing pleasure during sexual intercourse with an individual who possesses

specific visual features or characteristics of other nature. These life events may result in the internal retention of these features, adding to the existing set of stored information building a sexual prior. Therefore, it is conceivable that via sexual prior update processes information and detail can be added to the internal reference 'image' over time, which may explain variations in sexual interest and the diversity of sexuality across individuals, including the subjective sense of what type of individual we regard as attractive or which sexual act as pleasurable.

The above suggestion is in line with the concept of sexual learning and with theories that assume that sexual stimuli obtain arousing properties through learning processes (Brom et al., 2014; Domjan & Gutiérrez, 2019; Georgiadis & Kringelbach, 2012; Hoffmann, 2012; Pfaus et al., 2001). Sexual learning involves acquiring behaviors and sexual preferences through social, cultural, and personal experiences. Sexual learning may occur during any phase of the sexual response cycle, and it may explain how variations in sexual interests over time can gain access to the cycle (Georgiadis & Kringelbach, 2012). Notably, such experience-based shaping of preference has been proposed in foundational works of John Money, introducing the concept of "love maps" (Money, 1986), and in "sexual Gestalt" theory (Pfaus et al., 2012). In sexual Gestalt theory, it is suggested that preference-features are shaped through early formative and rewarding experiences during critical phases of development. In this context, sexual priors may initially represent the fundamental starting point as an innate baseline representation of attraction and sexual orientation. Thus, with continuous updates over a lifetime, sexual priors may indeed interact or even intersect with representations that form sexual Gestalt. Note, however, that the experiences shaping sexual priors should not be confused with experiences and memories contributing to late or higher-order cognitive evaluations. Instead, they pertain to those encoding information specific to the content details of sexual priors involved in the rapid automated detection of attractive stimuli. Whether or which sexual learning processes may be related to—or directly reflect—sexual prior updates remains to be investigated.

Sexual Priors in the Context of Psychiatric Conditions

The sexual prior concept can be further applied to conditions that involve altered or atypical sexual desire or attraction patterns, such as paraphilias, including pedophilia, or hypersexual (or compulsive sexual behavior) disorders. These conditions have been related to variations in brain structure and function with variable origins (Abé et al., 2021a; Engel et al., 2023; Golec et al., 2021; Görts et al., 2023; Lett et al., 2018; Liberg et al., 2022; Mannfolk et al., 2023; Poeppl et al., 2015). Regardless of the causes, the brain differences observed in those conditions may partly reflect, relate to, or affect the development of sexual priors.

For example, in compulsive sexual behavior disorder, which is characterized by a persistent pattern of intense sexual desire and impulses resulting in repetitive sexual behavior (World Health Organization, 2019), one could speculate that sexual priors are less-specific, i.e., include a wide range of featural information, increasing the likelihood that external stimuli and internal reference match. In the example of

pedophilia or pedophilic disorder, which is characterized by a sexual attraction to prepubescent children, sexual priors may exhibit child-typical features, which could potentially be caused by developmental disturbances. To elaborate on this, pedophilic disorder is believed to have a neurodevelopmental origin (Abé et al., 2021a; Fazio, 2018; Jahnke et al., 2022), and has—at least in sexual offenders against children—been associated with emotional congruence with children, which includes a cognitive and emotional affiliation with children and a child-like self-concept (Fraser et al., 2023; McPhail et al., 2013, 2018). As outlined above, internal priors, including sexual priors, may have a strong component related to one-self. If there is a mechanism that ages our self-image or sexual priors, and that mechanism is altered due to developmental disturbances, in pedophilia, one could speculate that the sexual prior content may not 'age' in the same way as the individual possessing it.

It is crucial to emphasize that the preceding examples are merely a subset of potential instances, and there exists a spectrum of compulsive sexual behavior and paraphilic sub-types, each characterized by distinct origins and underlying mechanisms. For instance, compulsive sexual behavior in certain individuals may stem from addiction-like mechanisms, aspects of compulsivity, and/or heightened sexual motivation states (Ågmo & Laan, 2022; Derbyshire & Grant, 2015; Kor et al., 2013; Kraus et al., 2016; Kühn & Gallinat, 2016; Liberg et al., 2022). Importantly, these factors do not negate the previously mentioned idea of less specific sexual priors and can coexist simultaneously. Thus, the examples provided are not meant to imply a broad generalization, nor is the intention to stigmatize or marginalize individuals experiencing these disorders, but rather to foster clinical support and comprehension.

Moreover, the aim of this article is not to delve into the mechanistic details of sexual prior development. Instead, the intention is to present the concept, and, while acknowledging the speculative nature of this discussion, the examples provided serve as illustrative cases for its applicability to a broad spectrum, if not all, observed sexual interest, desire, and attraction patterns in humans. Hence, it underscores the importance of further exploring and understanding the potential role of sexual priors, as this can provide insights into the development and manifestation of various sexual interests and maladaptive behaviors.

Target Brain Areas and Future Research

Brain areas that can serve as relevant targets for future research providing insights into the neural underpinnings of sexual priors may be those that are involved in the early phases of sexual stimuli processing, differ between sexes, are related to different sexual orientations and interests, or differ between individuals with atypical sexual desire patterns. Thus, various previous studies may already point to brain regions and networks involved.

For example, brain regions engaged in the early processing of sexual stimuli, such as those comprising the 'sexual interest network' discussed by Georgiadis and Kringelbach (2012), include the hypothalamus, ventral striatum, and amygdala, anterior insula, pregenual anterior cingulate cortex, orbito-frontal cortex (OFC),

the superior parietal lobule, and the ventrolateral occipitotemporal cortex (visual stream). These brain regions are involved in visual processing, reward value representation, interoceptive experience, and emotional memory, including memories of sexual experiences (Bianchi-Demicheli & Ortigue, 2009; Georgiadis & Kringelbach, 2012). As these are processes proposed to be relevant for sexual stimuli evaluation, they serve as pivotal candidates for brain areas potentially contributing to networks establishing sexual priors. Internally stored visual information may be among the most critical components contributing to sexual priors. Intriguingly, brain regions processing visual information have also been shown to be engaged in visual imagery and visual memory (Pearson et al., 2015), and sexual orientation-related functional differences (Frigerio et al., 2021; Hu et al., 2008) as well as structural cross-sex shifts in visual brain areas, such as the lingual gyrus and cuneus, have consistently been reported (Abé et al., 2014, 2018, 2021b). Speculatively, a cross-sex shift in those brain areas may be linked to shifts in visual feature information content of sexual priors, yet to be elucidated. Moreover, a previous meta-analytic review proposed a neural circuit encoding sexual preference in humans, rendering the thalamus, the septal area, and the perirhinal parahippocampus as additional study targets (Poeppl et al., 2016). In addition, as male and female voices are typically distinct and exhibit easily discernible characteristics, it was proposed that the auditory system could play a role in a genetically embedded mechanism involved in the development of sexual orientation (Salu, 2011). Therefore, auditory areas also emerge as potential candidates worthy of exploration within the framework of the sexual prior model.

To further investigate brain regions and mechanisms potentially involved in shaping sexual priors, thereby assisting in the validation of the sexual prior concept, researchers can employ various methods and designs, each offering unique insights into the neurobiology of sexual preferences and related phenomena. Employing fMRI is a powerful tool to investigate neural activity in response to sexual stimuli, offering insights into brain areas that become activated during different experimental conditions. For instance, with carefully designed experimental paradigms, researchers may analyze how the brain responds differently to various types of sexual stimuli, exploring distinctions in neural processing related to different aspects of sexuality, utilizing visual, auditory, or tactile cues. Moreover, sexual priors are unlikely to be confined to one or a few specific brain areas. More likely, they constitute hierarchical networks, potentially involving various sexual prior types and their interaction. Investigating functional connectivity using techniques like resting-state fMRI allows researchers to understand how different brain regions communicate with each other, and examining connectivity patterns can provide information about the networks involved. Notably, previous resting-state fMRI studies have detected distinct connectivity patterns related to sexual orientation (Clemens et al., 2023; Frigerio et al., 2021; Hu et al., 2013).

To obtain refined temporal insights, e.g., into early sexual stimuli processing phases, methods such as magnetoencephalography (MEG) can be utilized, a neuroimaging technique measuring the magnetic fields generated by the electrical activity of neurons in the brain. The primary advantage of MEG over MRI is that MEG can capture the dynamics of neural activity with millisecond precision, while MRI offers a temporal resolution in the magnitude of seconds. Further, structural MRI provides

detailed images of the brain's anatomy. Examining structural differences in the brains of individuals with distinct sexual interests, orientations, or even disorders, may help identify specific brain regions that consistently show differences across diverse groups. This, in turn, can reveal potential correlations between specific brain regions and the development of sexual interests and their underlying mechanisms. Another important aspect to consider is the use of longitudinal designs, tracking individuals over an extended period of time. By following individuals as their sexual preferences and experiences evolve, especially during critical phases such as puberty, researchers may be able to identify changes in brain activation patterns and structural characteristics associated with the development and modification of sexual priors over time. Such designs could also help determine and distinguish between innate and learned factors contributing to sexual priors.

In summary, various imaging methods can be utilized to further investigate the sexual prior concept. Apart from imaging studies, the prior concept may be investigated using other research instruments, such as neurocognitive tools, and particularly when combined with Bayesian statistics and predictive coding algorithms. Given the proposed developmental pathway, it may be valuable to explore the genetic and epigenetic factors associated with sexual preferences to provide additional insights into how they influence the structure and function of brain regions involved.

Additional Considerations and Future Perspectives

Sexual stimuli can be of various nature and include visual, auditory, olfactory, tactile, and even imaginative cues. Tactile sexual cues involve physical stimulation and are therefore distinct from other sensory cues given the involvement of sensory mechanoreceptors. The activation of mechanoreceptors in specific body areas, such as the genitalia, can (rapidly) elicit physiological responses associated with sexual arousal and pleasure (Georgiadis & Kringelbach, 2012; Masters & Johnson, 1966), even in the absence of preceding sexual desire or motivation. The sense of touch provides a direct stimulus, involving immediate physical contact, while remote sensory modalities, such as vision and hearing, rely on indirect stimuli to convey information about the external world. Furthermore, sexual fantasies are often determined through mental images (Lehmiller & Gormezano, 2023), and arousal can be triggered by mental imagery (Ågmo & Laan, 2022; Whipple et al., 1992; Wise et al., 2016). Despite the different nature of these stimuli types, the processing of imaginative and tactile stimuli is still covered by the concept proposed. Internally generated imaginative stimuli may be evaluated against sexual priors in the same way as external visual stimuli. Pleasurable tactile sensory information could be stored in sexual priors which may interact with the physical mechanosensory pathway. Hence, while the concept presented here is primarily aimed at providing solutions for the rapid evaluation of external remote sexual stimuli, it can still apply to and be investigated in the context of other stimuli sources underlying different processing pathways.

Another important consideration is the existence of sex differences in attraction and arousal patterns. Females have reportedly a wider arousal and attraction pattern compared with males, and males and females may even experience sexual arousal

differently (Bailey et al., 2016; Chivers, 2005; Chivers et al., 2004; Graziottin, 2004; Laan & Janssen, 2007; Paterson et al., 2014; Rupp & Wallen, 2008). In women, sexual stimuli also tend to trigger a wider range of cognitions as compared to men (Dewitte, 2016; Laan & Janssen, 2007; Rupp & Wallen, 2008; Toates, 2009). Hence, if and how sex-specific sexual priors relate to these observations may be valuable to explore.

While there may be potential overlaps, another future perspective may entail the disentanglement of learned/conditioned factors contributing to sexual prior contents over time and those playing a role in high-order cognitive evaluations. In this context, exploring a potential hierarchical manner in which sexual prior content is evaluated may offer an avenue for future research. Moreover, although gender identity, pertaining to the internal sense of one's own gender, is distinct from sexual orientation, considering the notion that sexual priors may be linked to self-referential processes, the sexual prior concept may also deserve further exploration within the context of gender identity and gender incongruence.

Limitations

The concept presented builds on a specific body of literature, which may not capture all aspects of human sexuality, particularly those from underrepresented populations. Therefore, the concept may not fully account for all atypical or highly individualized sexual variations. Unintended biases in study selection may further limit the comprehensiveness of the review, and it may not capture the full complexity of processes involved in sexuality development and its dynamics. Additionally, as the framework is partly derived from pre-existing models and some conclusions are built on prior study findings, it may inherit certain limitations from those sources. While suggestions for further investigation have been presented, operationalizing the concept of sexual priors for empirical testing may pose some challenges, especially when relying on individual methods. An interdisciplinary approach is likely to be more successful in validating the concept. Finally, as neuroscience and sexuality research evolve, future findings may require revisions to this theory to maintain its relevance and accuracy.

Summary and Conclusion

We know little about the origins and neurobiological underpinnings of human sexuality, especially in relation to how a specific sexual interest or sexual orientation, including heterosexuality, develops. This article presents the concept of sexual priors, proposing that they act as reference in early evaluation processes of sexual stimuli. By integrating the concept into sexual stimuli processing, Bayesian statistics, and predictive coding frameworks, it addresses the gaps in the initial phases of current sexual response and incentive motivation models. It further extends existing theories on the formation of sexual preference by positing initial sex- and sexual

orientation-specific internal references that evolve over time. Thereby, the concept provides possible explanations for variations in sexual orientation, interests, and attraction patterns.

This manuscript aims to encourage researchers to further explore the sexual prior concept and its neural correlates, enhancing our understanding of human sexuality. This line of research could increase societal awareness, foster tolerance, reduce stigma, and promote psychological well-being, facilitating more informed and compassionate approaches to sexual diversity and minorities.

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Author Contributions CA conceptualized the present work, outlined the theoretical framework, and critically evaluated its implications within the context of existing literature. CA created all Figures, wrote the manuscript, and approved the submitted version.

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Declarations

Conflict of interest The author declares no financial or non-financial conflict of interest.

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