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The contribution of ultrasonic vocalizations to mouse courtship

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Vocalizations transmit information to social partners, and mice use these signals to exchange information during courtship. Ultrasonic vocalizations from adult males are tightly associated with their interactions with females, and vary as a function of male quality. Work in the last decade has established that the spectrotemporal features of male vocalizations are not learned, but that female attention toward specific vocal features is modified by social experience. Additionally, progress has been made on elucidating how mouse vocalizations are encoded in the auditory system, and on the olfactory circuits that trigger their production. Together these findings provide us with important insights into how vocal communication can contribute to social interactions.

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Introduction

Males and females across the animal kingdom use vocalizations to exchange information during courtship. Vocalizations can be rapidly modulated in response to short time-scale shifts in the environment or state of a social partner, but are also constrained by physical limitations, such as vocal tract length or energy expenditure. This link between acoustics and physical limitations makes vocal behavior an honest signal of mate quality and thus informative for mate choice decisions [1].

The production of ultrasonic vocalizations (USVs: vocalizations with frequencies above the human-audible range) during courtship is widespread among Murid rodents [2] (Figure 1). USVs were first observed in adult laboratory mice in the sixties, and slow but steady progress was made in understanding the role they play in social interactions from then until the turn of the century. In 2005, Holy and Guo showed that mice produce multiple syllable types and individual males produce 'songs' with characteristic temporal structure [3]. This study, which drew analogies between mouse vocal behavior and that of songbirds [4], brought attention to the possibility of studying song perception and production in a genetic model organism. In particular, it spurred interest in whether the production of mouse vocalizations, like birdsong, is learned. Since then the number of investigators interested in understanding the neural underpinnings of mouse vocal behavior has grown enormously.

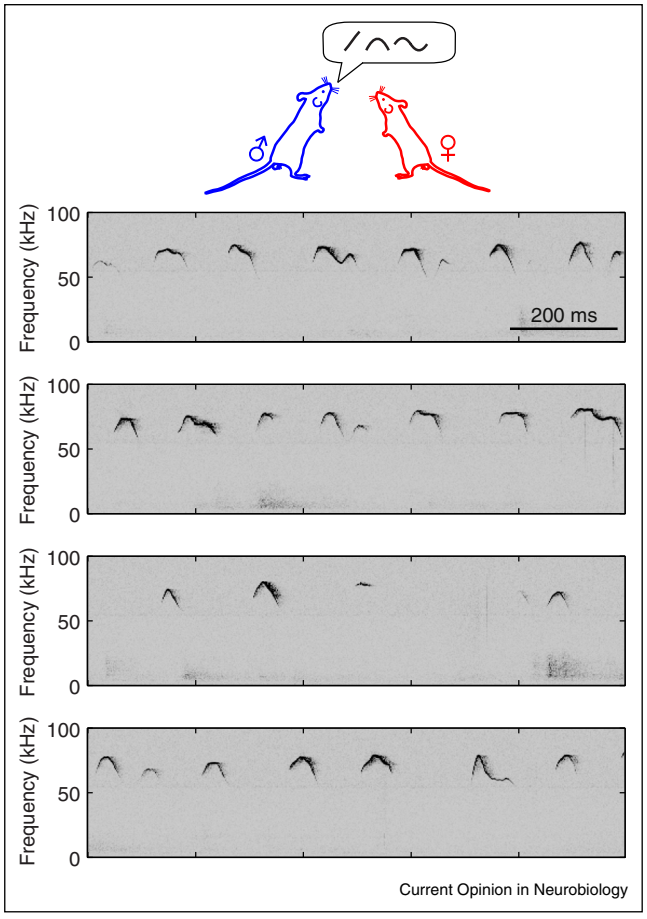
Here we will focus on ultrasonic courtship vocalizations produced by adult mice. We'll discuss the evidence that these vocalizations play a role in courtship, the progress that has been made on whether their production or perception is learned, and what is currently known about the neural mechanisms underlying this behavior.

Evidence that USVs can function as courtship vocalizations

Three types of evidence support the belief that male mice produce USVs specifically for courtship. First, male USVs are associated with courtship interactions. Male mice produce vocalizations in response to females [5] and female odors [2], but not to males or male odors [6], indicating that male vocalizations are female-directed and not a response to general conspecific interactions. Further, these vocalizations are emitted when the male sniffs the female and during mounting [2,5,7]. Immediately following mounting events, when there is a lull in courtship, the vocalization rate drops dramatically [7]. Together these observations indicate that male vocalizations produced during interactions with females express the male's desire to mate.

Second, beyond providing information regarding the male's behavioral state, courtship vocalizations in other species, notably songbirds [8,9], often provide information about male quality by varying as a function of male fitness, which contributes to female mate choice. The same may be true for mouse courtship USVs—male vocal behavior is androgen dependent [10,11] and associated with dominance [12]—providing a link between vocal structure and fitness in mice. In addition, the acoustic structure of male mouse vocalizations varies across males [3] and across genetic backgrounds [13], raising the possibility that females may be able to use male courtship vocalizations to detect male genetic quality and avoid inbreeding.

Figure 1



Spectrograms of mouse vocalizations produced during a courtship interaction between a male and female.

Finally, females respond to male courtship vocalizations. They spend more time near vocalizing males than near surgically de-vocalized males [14], consistent with male USVs playing a role in maintaining the sexual interest of a potential partner. Recent experiments have demonstrated that females will also approach a speaker playing male USVs [15], showing that USVs alone are sufficient to elicit female attention and allowing for more controlled tests of female vocal preference. This method has been used to show that female mice preferentially approach the vocalizations of unfamiliar males [16], as would be expected if females use USV structure to avoid inbreeding. However, female approach habituates quickly, in as little as a single trial [15,17], limiting its utility as an assay. Two manipulations have been shown to improve female attention to playbacks: recent interactions with males [17] and adding male urine to the testing chamber [18], both of which suggest that olfactory cues modulate responses to USVs. Experiments that allow females to choose between males with different vocal characteristics are needed to determine whether these observed approach preferences translate into mate choice decisions in female mice.

In contrast to males, female mice do not produce vocalizations in response to male odors [6] or anesthetized males [19], and temporally overlapping vocalizations that would indicate two vocalizers have not been reported during male–female interactions [7]. This has led to the belief that female mice do not vocalize during courtship. However, female mice do produce USVs during interactions with other females [20,21] and their vocalizations are acoustically similar to those produced by males [21], suggesting both that females have the ability to vocalize with males and, if they do so, that it would be difficult to detect. Recent work using a microphone array to assign specific vocalizations to individual mice in a social group found that female mice produce vocalizations that are temporally coordinated with male vocalizations during courtship chases [22•], suggesting that females may vocally participate during courtship. Whether disruption of these vocal interactions affects mating behavior still needs to be determined.

Female vocal preference, but not USV structure, is experience dependent

Much of the work on mouse USVs in the past 10 years has focused on whether or not the production of courtship vocalizations is learned. In contrast to songbirds, which require exposure to a 'tutor' song during a juvenile critical period to produce a normal adult song [23,24], there is little evidence for production plasticity in mouse USVs (reviewed in [25]). Although the spectrotemporal shape of USVs does vary between males [3], across inbred lines [13], and across genetically separate wild populations [26], as is the case with birdsong [27], this variation does not appear to be learned. Vocal structure is unaffected by deafness [28•,29], cross-fostering [30], or removal of the cortex [31•]. Additionally, USVs are unchanged in mice with a humanized version of Foxp2 [32], a transcription factor implicated in vocal learning in humans and songbirds [33]. While the lack of production plasticity does not diminish the role of USVs during courtship, it does provide insight into candidate neural mechanisms underlying mouse vocal production.

Although mice do not display production plasticity, recent work provides evidence that the types of vocalizations that females prefer may be experience dependent [34••]. The observation that female mice preferentially approach a speaker playing unfamiliar male vocalizations [16,34••] suggests that either females have intrinsic vocal preferences or that they learn those preferences during development. In support of the latter, cross-fostering experiments show that females prefer vocalizations they were not exposed to during development, regardless of genotype [34••]. Intriguingly, this preference depends on experience with an adult male; females reared without a