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Sociality Predicts Enhanced Auditory Thresholds and Binaural Hearing Processing Across Rodent Species

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Abstract

Sociality has evolved repeatedly in rodents, yet whether sociality has shaped auditory processing remains unclear. Here, we used auditory brainstem responses (ABRs) to examine the relationship between sociality and auditory processing in nine wild-caught rodent species that are not closely related evolutionarily. Phylogenetic comparative analyses revealed that sociality is correlated with enhanced auditory processing: social species (both monogamous and group-living) generally exhibited lower auditory thresholds for tone and click stimuli than solitary species. Group-living species also showed faster normalized latencies and higher relative amplitudes of the binaural interaction component (BIC) across tested interaural time differences (ITDs) than solitary species. In contrast, we found no differences in monaural ABR interpeak latencies or amplitude ratios of ABR waves I and IV among social groups with increasing sound intensities. Together, these findings indicate that sociality is associated with heightened auditory sensitivity in rodents and suggest that the evolution of complex social behavior may have favored enhanced auditory systems that facilitate effective social communication.

INTRODUCTION

Animal behavior has long been recognized as capable of reshaping organisms' selective pressures, a phenomenon particularly evident in social communication settings where signals mediate interactions among individuals. Acoustic communication, in particular, plays a central role in animal social dynamics by mediating key biological behaviors, such as territorial defense, collective movement, group cohesion, mate attraction, predator avoidance, and the transmission of information about individual identity or emotional states[1–7]. Because behavior both reflects and shapes the ecological challenges animals face, recurrent social interactions create consistent selective pressures on the sensory and signaling systems involved. As a result of these diverse and crucial functions, acoustic signals are under strong selective pressures that shape both their structural and perceptual properties[8].

For decades, comparative studies have primarily focused on the sender side of the mammalian acoustic communication, demonstrating that interspecific variation in body size, sexual selection pressures, and formant-related cues are major drivers of vocal signal diversity [9–12]. However, effective communication also depends on the receiver's auditory system, which natural selection is expected to tune to the acoustic properties of conspecific signals to ensure efficient information transfer[13–15]. This co-evolutionary relationship between behavior, signal production, and sensory perception highlights how behavioral demands can structure the evolution of communication systems. Despite this expectation, the auditory processing abilities of most vocalizing vertebrates remain poorly characterized, and the extent to which vocal signal complexity influences auditory sensitivity is largely unknown.

Rodents make up nearly 40% of all described mammals and are an excellent model system for behavioral and auditory research owing to their extensive variation in social structure[16]. However, comparative analyses of rodent hearing, especially among wild-caught species, remain scarce. To date, approximately twenty-five behavioral and physiological audiograms have been published for rodents,

primarily involving model species such as the laboratory house mouse (*Mus musculus*) and the Norway rat (*Rattus norvegicus*)[17]. These studies reveal substantial interspecific variation in auditory processing, with some species showing peak sensitivity to low-frequency, while others exceed human capabilities in detecting higher frequencies[18]. For instance, the Zambian mole-rat (*Fukomys amatus*), Ansell mole-rat (*Fukomys anselli*), and the common mole-rat (*Cryptomys hottentotus*) exhibit the lowest frequency hearing thresholds between 0.8 to 1.4 kHz, whereas the house mouse (*Mus musculus*), hispid pocket mouse (*Chaetodipus hispidus*), prairie vole (*Microtus ochrogaster*), and members of the genus *Peromyscus* show the greatest auditory sensitivity at frequencies between 8 to 46 kHz[19–25]. Despite these findings, direct cross-species comparisons, specifically species that exhibit different form of social organizations, remain challenging owing to methodological differences that often lead to inconsistent results. Therefore, standardized comparative studies on rodent auditory perception are increasingly necessary to better understand variation in auditory acuity across species and social groups.

Sociality has evolved multiple times in tetrapods, and extensive research has examined the relationship between acoustic communication and sociality[26–29]. In social primates, birds, and cetaceans, group living correlated with increased complexity of vocal signals[30–32]. Similarly, studies have showed that primates tend to expand their vocal repertoires as group size increases to support a broader range of social and ecological interactions[33]. A classic example is the ring-tailed lemur (*Lemur catta*) which produces high frequency, modulated calls to alert dispersed group members to predators or convey urgency[34]. While much attention has been devoted to the correlation between sociality and vocal signal production, far fewer studies have examined auditory perception in relation to social structure. Consequently, comparative studies of auditory sensitivity among species with differing social structures are crucial to elucidate how sociality shapes auditory processing.

The main goal of this study was to examine the relationship between sociality and auditory processing using nine wild-caught rodent species that are not closely related evolutionarily (Fig. 1). We measured auditory sensitivity through auditory brainstem responses (ABRs) including frequency response thresholds, click thresholds (Fig. 2A), interpeak latencies, amplitude ratios, binaural normalized latencies and binaural relative amplitudes across social groups (solitary, monogamous, and group-living). We hypothesized that social rodents (group-living and monogamous) would exhibit more sensitive auditory systems characterized by lower frequency ABR thresholds and click thresholds across socially relevant frequencies compared to solitary species. We also predicted that group-living species would show higher amplitude, shorter latency responses to click stimuli, and a broader ITD range with higher amplitude binaural responses than other social groups.

RESULTS

Phylogenetic heritability

Phylogenetic comparative analyses indicated weak phylogenetic signals in auditory thresholds and ABR wave characteristics across social groups, consistent with generally low phylogenetic heritability estimates. Phylogenetic heritability estimates were 0.23 (95% Credible Interval (95% CI): 0.00 to 0.61) for frequency response thresholds, 0.06 (95% CI: 0.00 to 0.47) for click thresholds, 0.13 (95% CI: 0.03 to 0.38) for interpeak latency, 0.08 (95% CI: 0.01 to 0.31) for amplitude ratio, 0.10 (95% CI: 0.01 to 0.39) for BIC normalized latency, and 0.02 (95% CI: 0.00 to 0.13) for BIC relative amplitude, suggesting strong functional constraints on auditory function.

Hearing thresholds differ across social groups

All social groups exhibited the greatest hearing sensitivity (i.e., lowest ABR frequency thresholds) between 8 and 24 kHz (Fig. 2B, see supplementary Fig. 1 for species hearing sensitivity). Bayesian phylogenetic generalized linear mixed models (PGLMMs) revealed that group-living species had significantly lower frequency response thresholds than solitary species (Posterior Mean (PM) = 12.28; 95% CI = 2.87 to 21.36; Bayesian Markov Chain Monte Carlo P-value (P_{MCMC}) = 0.021). Similarly, monogamous rodents had lower frequency peak response thresholds than solitary species (PM = 10.16; 95% CI = 2.87 to 17.21; P_{MCMC} = 0.011). Bayesian pairwise contrast showed that group-living species displayed lower frequency thresholds than solitary species at 1 kHz (P_{MCMC} = 0.02), 2 kHz (P_{MCMC} = 0.018), 4 kHz (P_{MCMC} = 0.038), 8 kHz (P_{MCMC} = 0.021), 16 kHz (P_{MCMC} = 0.023), 24 kHz (P_{MCMC} = 0.09), and 32 kHz (P_{MCMC} = 0.097). Likewise, monogamous species showed lower frequency response thresholds than solitary species at 1 kHz (P_{MCMC} = 0.011), 2 kHz (P_{MCMC} = 0.002), 4 kHz (P_{MCMC} = 0.004), 8 kHz (P_{MCMC} = 0.010), and 16 kHz (P_{MCMC} = 0.050). Monogamous and group-living species exhibited similar frequency-response thresholds across tested frequencies (PM = 2.11; 95% CI = − 7.82 to 12.25; P_{MCMC} = 0.618).

Click thresholds were also substantially lower for group-living compared to solitary species (PM = 9.41; 95% CI = 2.44 to 16.2; P_{MCMC} = 0.008, Fig. 2C, see supplementary Fig. 2 for species click thresholds). Likewise, monogamous species had lower click thresholds than solitary species (PM = 8.59; 95% CI = 1.72 to 14.6; P_{MCMC} = 0.011). No significant differences were detected in click thresholds between monogamous and group-living species (PM = 0.82; 95% CI = − 6.83 to 9.46; P_{MCMC} = 0.427). These findings suggest that social rodents have lower ABR frequency and click response thresholds than solitary rodents, specifically at lower frequencies.

No differences in ABR interpeak latency and amplitude ratio across social groups

To assess differences in monaural ABR wave characteristics, we calculated interpeak latency and amplitude ratio of ABR waves I and IV across tested intensities (90–50 dB SPL, see supplementary Fig. 4 for latency and amplitude of ABR wave I and IV). Interpeak latency was measured as the difference

between the peak latencies of wave I and wave IV at each intensity level for the left and right pinnae, while amplitude ratio was calculated by dividing the value of wave IV amplitude by the value of wave I amplitude for the right and left pinnae at each intensity. As expected, interpeak latency of wave I and wave IV decreased with increasing intensity (Fig. 3A). However, our PGLMM indicated no significant differences in interpeak latency among social groups. Specifically, interpeak latency did not differ either between group-living and solitary species (PM = -0.07; 95% CI = − 0.47 to 0.29; P_{MCMC} = 0.690), or between group-living and monogamous species (PM = 0.10; 95% CI = − 0.32 to 0.51; P_{MCMC} = 0.604). We also found no difference in interpeak latency of ABR wave I and IV between monogamous and solitary species (PM = − 0.17; 95% CI = − 0.48 to 0.12; P_{MCMC} = 0.248).

Overall, amplitude ratio increased with increasing intensities, with wave I consistently showing larger values than wave IV across the tested intensity range (90 − 50 dB SPL; Fig. 3B). However, the PGLMM revealed no significant differences in the wave IV/I amplitude ratio between group-living and solitary species (PM: − 0.12; 95% CI: − 0.34 to 0.10; P_{MCMC} = 0.234). Similarly, no significant differences were observed in wave IV/I amplitude ratio either between group-living and monogamous species (PM: 0.005; 95% CI: − 0.23 to 0.26; P_{MCMC} = 0.976), or between monogamous and solitary species (PM: − 0.13; 95% CI: − 0.32 to 0.06; P_{MCMC} = 0.176). Taken together, these results indicate no differences in monaural hearing ability between social and solitary rodents.

Binaural hearing differences across social groups

To quantify binaural hearing sensitivity for each social group, we extracted the peak latency and amplitude of the binaural ABR data at each ITD and transformed to BIC normalized latency and BIC relative amplitude with respect to ITD at 0 ms (see Laumen et al., 2016, for details). The average BIC normalized latency and BIC relative amplitude were used to compare binaural hearing sensitivity as a function of ITD across social groups. PGLMM revealed that BIC normalized latency was faster in group-living compared to solitary species (PM: 0.28; 95% CI: − 0.02 to 0.58; P_{MCMC} = 0.062, Fig. 3C). Similarly, monogamous species had faster BIC normalized than solitary species across tested ITDs (PM: 0.26; 95% CI: 0.001 to 0.50; P_{MCMC} = 0.050). Bayesian pairwise contrast showed that group-living species exhibited faster BIC normalized latency than solitary species at 0.5 ms ITD (P_{MCMC} = 0.062), 1.0 ms ITD (P_{MCMC} = 0.068), and 1.5 ms ITD (P_{MCMC} = 0.004). Similarly, monogamous species exhibited faster BIC normalized latency than solitary species at 0.5 ms ITD (P_{MCMC} = 0.050), 1.0 ms ITD (P_{MCMC} = 0.008), 1.5 ms ITD (P_{MCMC} = 0.002), and 2.0 ms ITD (P_{MCMC} = 0.099). No significant difference in BIC normalized latency was detected between group-living and monogamous species (PM: 0.026; 95% CI: − 0.29 to 0.37; P_{MCMC} = 0.870).

Lastly, the PGLMM model revealed that group-living species had higher BIC relative amplitude than solitary species (PM: − 13.19; 95% CI: − 23.06 to -2.82; P_{MCMC} = 0.015, Fig. 3D). Bayesian pairwise contrast showed that group-living species exhibited higher BIC relative amplitude than solitary species at

0.5 ms ITD (P_{MCMC} = 0.015), 1.0 ms ITD (P_{MCMC} = 0.002), 1.5 ms ITD (P_{MCMC} = 0.001), and 2.0 ms ITD (P_{MCMC} = 0.054). There were, however, no significant overall differences in BIC relative amplitude either between monogamous and solitary species (PM: -3.81; 95% CI: − 13.37 to 6.80; P_{MCMC} = 0.456) or between monogamous and group-living species (PM: -9.38; 95% CI: − 21.28 to 2.64; P_{MCMC} = 0.123), illustrating similar BIC relative amplitude among these social groups. Although no significant differences were detected in overall BIC relative amplitude between monogamous and solitary species, the Bayesian pairwise contrast showed that monogamous species had higher relative amplitude than solitary species at 1.0 ms ITD (P_{MCMC} = 0.072) and 2.0 ms ITD (P_{MCMC} = 0.030). Likewise, group-living had higher relative amplitude than monogamous species at 1.5 ms ITD (P_{MCMC} = 0.036). These findings indicate that group-living rodents have more sensitive binaural hearing ability than solitary rodents, characterized by faster BIC normalized latency and higher BIC relative amplitude across ITDs.

DISCUSSION

In this study, phylogenetic comparative analyses were used to investigate the relationship between sociality and auditory processing across nine wild-caught rodent species, representing three social organizations. All species showed the greatest auditory sensitivity between 8 and 24 kHz (Fig. 2, Supplementary Fig. 1), consistent with previous reports showing that small-headed mammals of similar size exhibit the lowest auditory sensitivity around this frequency range[21–23,25,36–38]. Our analyses revealed that social-living rodents exhibited lower hearing thresholds than solitary rodents. Similarly, we found that social rodents exhibited faster binaural responses to auditory stimuli and higher BIC relative amplitude responses than solitary living rodents. In contrast, we detected no significant differences in monaural ABR wave interpeak latency and amplitude ratio among social groups. Overall, these results indicate that rodents' auditory processing varies systematically with social organization, with socially living rodents generally exhibiting enhanced auditory sensitivity, lower click thresholds, faster binaural latencies, and higher binaural amplitudes than solitary rodents.

Our results demonstrated that social species displayed auditory thresholds that were 10–20 dB lower than those of solitary species across both low (1–8 kHz) and high (16–64 kHz) frequencies. For instance, at 1–4 kHz, group-living and monogamous rodents detected sounds nearly 15 dB quieter than solitary rodents. Similarly, social rodents responded to sound 10 dB quieter than solitary rodents across 8–64 kHz. We also found differences in click thresholds among social groups, with group-living rodents showing the lowest thresholds overall. These findings suggest that sociality is consistently associated with enhanced hearing sensitivity in rodents. Notably, this pattern parallels results in primates, where species living in larger groups exhibit improved auditory sensitivity and broader high-frequency hearing ranges[39]. Together, these cross-taxonomic parallels suggest that recurrent social interactions may impose similar evolutionary pressures on auditory systems across mammals. Accordingly, our data support our first hypothesis that species engaging in more frequent or complex social communication evolve more sensitive auditory mechanisms, particularly across socially relevant frequency ranges.

The social drive hypothesis posits that sociality can drive the evolution of improved perceptual and communicative abilities[39]. This hypothesis has been well supported in birds and primates, where species living in larger or more complex social groups tend to produce more diverse vocal repertoires, exhibit greater auditory sensitivity, and increase high frequency limits[12,30,39]. In primates specifically, group size correlates with vocal repertoire size and improved detection of quieter signals[12,39], consistent with the notion that greater social complexity imposes stronger selection on both the production and perception of acoustic information. The evolutionary pressures underlying this pattern are likely multifaceted. Firstly, group-living individuals must discriminate among a greater number of conspecific vocalizations across a wide range of acoustic contexts; and secondly, they may experience more variable environmental pressures in which efficient signal detection is of paramount importance for group cohesion, mate attraction, and predator avoidance. Enhanced auditory sensitivity in social species, particularly at lower/high frequencies could therefore provide adaptive advantages by facilitating long distance communication, recognition of individual-specific vocal cues, and rapid detection of alarm calls. The similarity between our findings in rodents and those previously reported in primates suggests that sociality and auditory sensitivity may have coevolved repeatedly across mammals, revealing common selective pressures on communication systems in social species.

ABR-derived audiograms showed broadly similar shapes among social groups, with peak sensitivity occurring between 8 and 24 kHz. Although social species had significantly lower thresholds at frequencies below 8 kHz than solitary rodents, overall sensitivity in this range remained relatively poor (40 to 65 dB SPL). Small-headed mammals, like most members of the order Rodentia, are unable to extract reliable directional information from low-frequency sounds due to minimal interaural cues. Instead, they rely on high-frequency cues for sound localization, which likely explained their reduced sensitivity to low frequencies[40–43]. In addition, all species tested in this study emit sonic and ultrasonic vocalizations spanning approximately from 2.5 to 110 kHz, with peak energy occurring between 10 and 35 kHz[44–48]. While all species were sensitive to frequencies that overlapped with their ultrasonic calls, social species showed greatest sensitivity for 8–16 kHz tones. Therefore, relatively better low-frequency sensitivity in social species could have important social and ecological importance by facilitating long-distance perception and transmission of vocal signals, whereas high-frequency call components may support short-range communication and thus may mediate social behaviors such as mother-pup interactions, group cohesion, courtship, territoriality, alarm calling, and aggression[37,49].

We further quantified interpeak latency and amplitude ratio of ABR waves I and IV across social groups with increasing stimulus intensities. In small-headed rodents, wave I typically occurs around 1.5–2.5 ms, likely reflecting neuronal activity in the auditory nerve and cochlear nucleus, whereas wave IV occurs at 4.5–5.5 ms, likely corresponding to input from the nucleus of the lateral lemniscus and/or early input to the inferior colliculus[50,51]. Consistent with previous studies[22,23,50,52], wave I – IV interpeak latency decreased with increasing stimulus intensity, with wave IV exhibiting the greatest latency shift. However, our analyses revealed no significant differences in interpeak latency or amplitude ratio among social groups. These findings suggest that variation in these ABR measures is not explained by sociality or

shared evolutionary history. However, confirmation will require broader taxonomic sampling and complementary approaches using ecologically relevant acoustic stimuli.

Our binaural ABR results accord well with previous comparative studies showing that BIC normalized latency increases and BIC relative amplitude decreases with increasing ITD[22,23,25,53,54]. Our results revealed significant effect of social groups on normalized DN1 latency, with social species generally showing faster binaural responses than solitary species. Similarly, we detected differences in relative BIC amplitude among social groups, with group-living rodents generally exhibiting higher relative BIC amplitude than solitary rodents. These findings suggest that even moderate shifts toward increased social interaction are linked to more rapid and sensitive binaural processing in rodents. Rodents rely on ITDs, and interaural level differences (ILDs) to localize sound, which are primarily processed by neurons of the medial and lateral superior olives[55,56]. While it remains unclear whether the relative amplitude and normalized latency differences observed among social groups are driven by variation in craniofacial features or the number of neurons within the superior olivary complex, comparative studies quantifying volume of the medial nucleus of the trapezoid body (MNTB), as well as excitatory and inhibitory cell populations in the medial superior olive (MSO), and lateral superior olive (LSO) of each species would be valuable for assessing these influences. Importantly, the faster normalized latency observed in social species may reflect selection for more rapid sound localization, which could provide advantages in detecting conspecific calls, avoiding predators, localizing prey, coordinating group behaviors, and maintaining group cohesion. These findings support our second prediction that group-living rodents would show a broader ITD range, characterized with faster latency and higher amplitude binaural responses than other social groups.

CONCLUSION

The present comparative work extends our understanding of how social organization shapes auditory processing in wild-caught rodents. We showed that social species possess enhanced auditory sensitivity, characterized by lower frequency response thresholds and click thresholds, and exhibit faster and more sensitive binaural responses than solitary species. These findings suggest that auditory systems may have evolved in concert with social complexity, potentially facilitating more efficient communication and coordination among group-members. More broadly, our results highlight a potential evolutionary link between sociality and sensory processing, confirming similar trends observed in other vertebrates. Future comparative and neuroanatomical studies, including those incorporating sex differences, ecological variables, and broader phylogenetic sampling across rodents and other tetrapods will be essential to determine the generality of these relationships and elucidate the neural and morphological adaptations underlying them.

METHODS

Animals

Experiments were conducted on 90 wild-caught male rodents, representing 9 species (Fig. 1), captured from five locations in Oklahoma and Kansas: Packsaddle wildlife management area, James Collin wildlife management area, Selman living laboratory, Kansas University field station, and Stillwater, Oklahoma. At each location, trapping was carried out along two trap-lines that consisted of twenty aluminum Sherman non-folding traps (3 in. x 3 in. x 10 in.) (H.B Sherman Traps, Inc., Tallahassee, FL) laid out in 5–10 meters intervals between traps. The traps were supplied with whole grain oats and peanut butter. Traps were generally placed in brushes or vegetation to prevent heat stress and rain and sun exposure and were provisioned with 2–3 cotton balls for warmth from mid-December to mid-April of each year (from 2022 to 2025). Traps were set each evening at dusk (between 18:00 and 20:00 PM) and checked the following morning at sunrise (between 06:00 and 09:00 AM). Upon capture, rodents were placed in an unsealed plastic bag for visual identification of species and sex according to Caire[57]. Species identity was verified using extraction of DNA on tail snips, with a method that was previously published[22,23] (see supplementary materials for details). Animals were moved to an Innovive (Animal Specialties and Provisions, LLC, Quakertown, PA) disposable plastic mouse cage (14.7 in. length x 9.2 in. width x 5.5 in. height) and transported to the laboratory for ABR measurement and genetic identification[23]. All animal collection was authorized by the Oklahoma Department of Wildlife Conservation and the Kansas Department of Wildlife and Parks. Field sampling and animal handling complied with the laws in the United States, followed the guidelines and recommendations of the American Society of Mammologists[58], and permitted by the University of Central Oklahoma (UCO) Selman Living Laboratory (SLL) and the Kansas University (KU) Field Station. All experimental protocols adhered to the ethical guidelines of the institution and were approved by the Institutional Animal Care and Use Committee (IACUC) (protocol number: 22 – 09).

Classification of Social Organization

Sociality encompasses interactions among individuals that form associations across diverse contexts (i.e., shelter use, defense, and foraging), and varies across rodents species [59–61]. We used the criteria described by Lukas and Clutton-Brock[62] to classify the social organization of rodents into three groups: solitary, monogamous, and group-living (Fig. 1). These definitions were based on the degree of parental care and the occurrence of breeding adults in the population using data from primary literature. Species were classified as solitary if parental care duties were provided only by females and breeding females maintained separated home ranges, despite occasionally sharing feeding or sleeping sites[63–65]. In this group, social interaction is limited only to mating encounters and relations between mothers and offspring. Species were classified as monogamous if both females and males shared parental care duties in raising offspring, and breeding females occupied a home range with a single male for more than one year, without cohabiting with other breeding individuals of the same species[66,67]. Species were classified as group-living if parental care duties were provided only by females, and two or more breeding females occupied the same home range or breeding places and females tolerated each other's presence and shared all areas within their home ranges[65,68].

ABR Recordings and Acoustic Stimulations

We applied click (0.1 ms) and tone burst [4 ms (1 ms rise and 1 ms fall ramps (2 ms ± 1 ms rise/fall ramps)] sounds for ABR measurements, similar to previous publications[22,23,25,36]. In brief, ABR recordings were acquired in a sound-attenuating chamber and data were filtered using a second-order bandpass filter (50-3000 Hz) and averaged over a 10–12 ms window across 500–1000 stimulus repetitions. Sound stimuli were presented at an interstimulus interval of 30 ms and a standard deviation of 5 ms, at different intensities (90, 80, 70, 60, 50, 40, 30, 20, 10, 5 dB SPL), starting with the loudest sound levels. Acoustic stimuli were generated either through multi-field speakers (MF-1, Tucker-Davis Technologies, Fl, USA) for clicks and frequencies ranging from 1 to 24 kHz or electrostatic speakers (EC-1, Tucker-Davis Technologies, Fl, USA) for frequencies between 32 and 64 kHz, which were positioned at the animal's left and right ear canals for close-field recording. The ABR signals were measured with subdermal needle electrodes (Viasys Healthcare, Madison, WI, USA), which were inserted under the skin (approximately 3–5 mm) between the pinnae at the vertex (active electrode), behind the apex at the nape (reference electrode), and the right back leg (ground electrode). During the measurement, animals were intraperitoneally anesthetized with a cocktail of ketamine (60 mg/kg) and xylazine (10 mg/kg) and kept sedated with ketamine (25 mg/kg) and xylazine (12 mg/kg) dose supplements. Animals body temperature was maintained at 37°C using a water pump heating pad.

ABR Data Processing

Data analysis followed previously established procedures[22,23,25,36]. In short, during pre-processing, ABR data were normalized relative to the pre-stimuli baseline, and the resulting ABR waveforms were statistically tested for differences across social groups. Auditory sensitivity was assessed quantitatively using frequency response thresholds and click thresholds according to Brittan-Powell and Dooling[69]. We constructed audiograms (using pure tone stimuli) for each species across frequencies (1, 2, 4, 8, 16, 32, 46, 64 kHz) and intensities (90 – 5 dB SPL) to determine hearing thresholds. Hearing thresholds were considered to be between the intensity at which the waveforms were no longer visible and the previous intensity at which they were visible by both left and right monaural stimuli. Click threshold was measured by gradually reducing the intensity of the click stimulus in 5–10 dB SPL increments until the ABR waveforms were no longer noticeable (Fig. 2A). Click threshold was described as the difference in intensity between the last level where ABR waveforms were observed and the level at which they disappeared (i.e., if ABR waveforms were observable at 40 dB SPL and no longer observable at 30 dB SPL, the click threshold was estimated to be 35 dB SPL for this animal).

Individual wave latencies and amplitudes were detected for wave I and wave IV of the ABR recorded at each intensity level for the left and right pinnae. We next estimated interpeak latency and amplitude ratio for each social group. We then used the average values to compare interpeak latency and amplitude ratio at each intensity across social groups[22,23,50]. Binaural ABR measurement was also assessed as previously published[22,23,25]. In short, we presented broadband alternating polarity click stimuli to both pinnae of the anesthetized animal simultaneously or with an ITD at 90 dB SPL to elicit evoked binaural auditory responses. we used the BIC (measured as the sum of the monaural left and right absolute latency and absolute amplitude responses from the binaural evoked ABR recordings) to determine

species' binaural hearing ability. BIC latency and amplitude were calculated using custom Python Software, with latency measured as the time point corresponding to the peak of the prominent negative peak (DN1) component, while amplitude was measured referenced to the recording baseline as previously described[22,23,25]. Because DN1 latency is shortest at 0 ITD and DN1 amplitude is highest at 0 ITD, latency and amplitude values for ITD shifts were transformed to BIC normalized latency and BIC relative amplitude, with respect to 0 ms to normalize the binaural ABR data[53]. The average BIC normalized DN1 latency shift and BIC relative DN1 amplitude data were used to compare binaural ABR responses as a function of ITD across social groups.

Statistical analyses

Data were analyzed using phylogenetic generalized linear mixed models (PGLMMs), with Bayesian posterior distributions estimated via Markov Chain Monte Carlo (MCMC) sampling to account for phylogenetic relatedness. We obtained a species-level time-calibrated phylogenetic tree by pruning the phylogeny of Upham et al.[70] in the R package APE[71] to include only the species represented in this study. Separate models were fit for each response variable (frequency thresholds, click thresholds, interpeak latency, amplitude ratio, BIC normalized DN1 latency and BIC relative DN1 amplitude), all treated as Gaussian response variables. Predictor variables include sociality, intensity, frequency, ABR peak number, and ITD, while phylogenetic relationships among species and animal id were modeled as random effects. To calculate phylogenetic signals, we used the phylogenetic heritability as $H^2 = \frac{\sigma^2 a}{(\sigma^2 a + \sigma^2 e)}$, where $\sigma^2 a$ represents the phylogenetic variance and $\sigma^2 e$ represents the residual (non-phylogenetic) variance based on the best selected models[72].

For the MCMC sampling, we used the default diffuse Gaussian prior in MCMCglmm for fixed effects (mean = 0, variance = 10^{10}) and a weakly informative inverse-Gamma prior (V = 1) for random effects with shape and scale parameters set to 0.001. Each model was run for 260,000 interactions, with a burn-in of 10,000 and thinning every 250 steps to reduce autocorrelation in the chains. Each model was run with three independent chains, and we used the German-Rubin test to confirm model convergence[73–75]. Across models, a scale reduction factor of one suggested that the chains were identical and had therefore converged. This was verified for all models.

To select the model that best fit each response variable, we ran three models: a null model which include the random effects and one predictor variable (frequency, intensity, or ITD), an additive model which include random effects and two additive predictor variables (sociality + frequency, sociality + intensity, or sociality + ITD), and a full model which include random effects and additive and interaction terms of two predictor variables (sociality * frequency, sociality * intensity, or sociality * ITD). We then used the Deviance Information Criterion (DIC) to determine the best-fitting model (Supplementary Table 1). For all analyses, DIC comparisons indicated strong support for the full model, except for the amplitude ratio and interpeak latency data where the additive model yields lower DIC score. In all cases, a fixed effect was considered to be present when the 95% credible intervals (CI) did not include 0. To test for differences in frequency, intensity, or ITD among social groups, we performed a Bayesian pairwise

contrast test. This test is a bicaudal test of overlap between the posterior distributions. All PGLMM models were fitted using the MCMCglmm package[75,76]. All figures were generated in Python and R Studio version 4.0.3[77], using the “ggplot2” packages[78].

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Figures

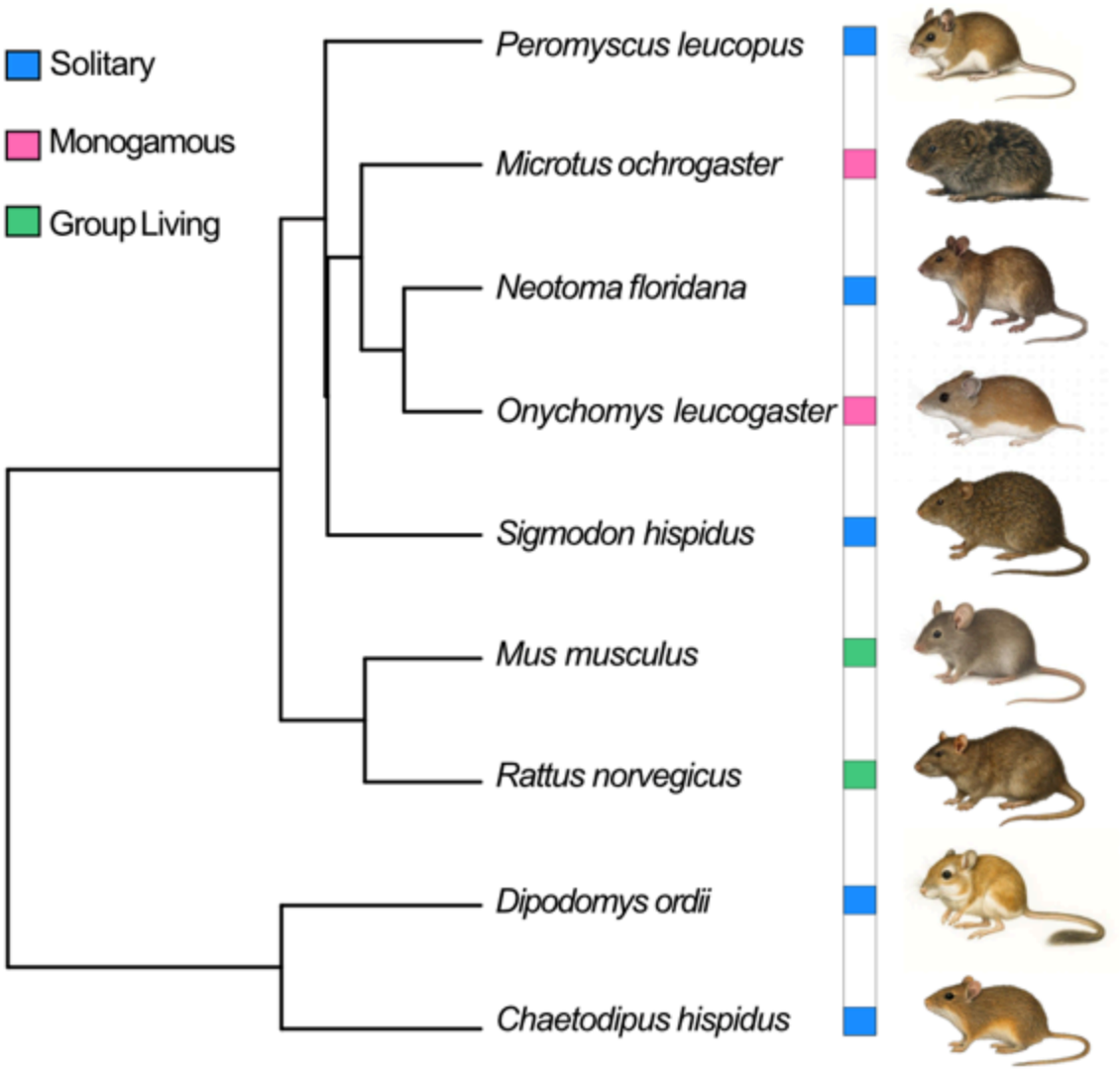

Figure 1

Phylogeny of the wild-caught rodents used in this study, reconstructed from the mammalian tree generated by Upham et al., (2019) based on the Basic Local Alignment Search Tool (BLAST) of National Center for Biotechnology Information (NCBI) nucleotide database. Rodents' photos were generated using Microsoft Copilot using the following prompt: Give me a realistic drawing (as realistic as possible) of a [insert species name], make sure to include the entire animal in the image and make the background all white.

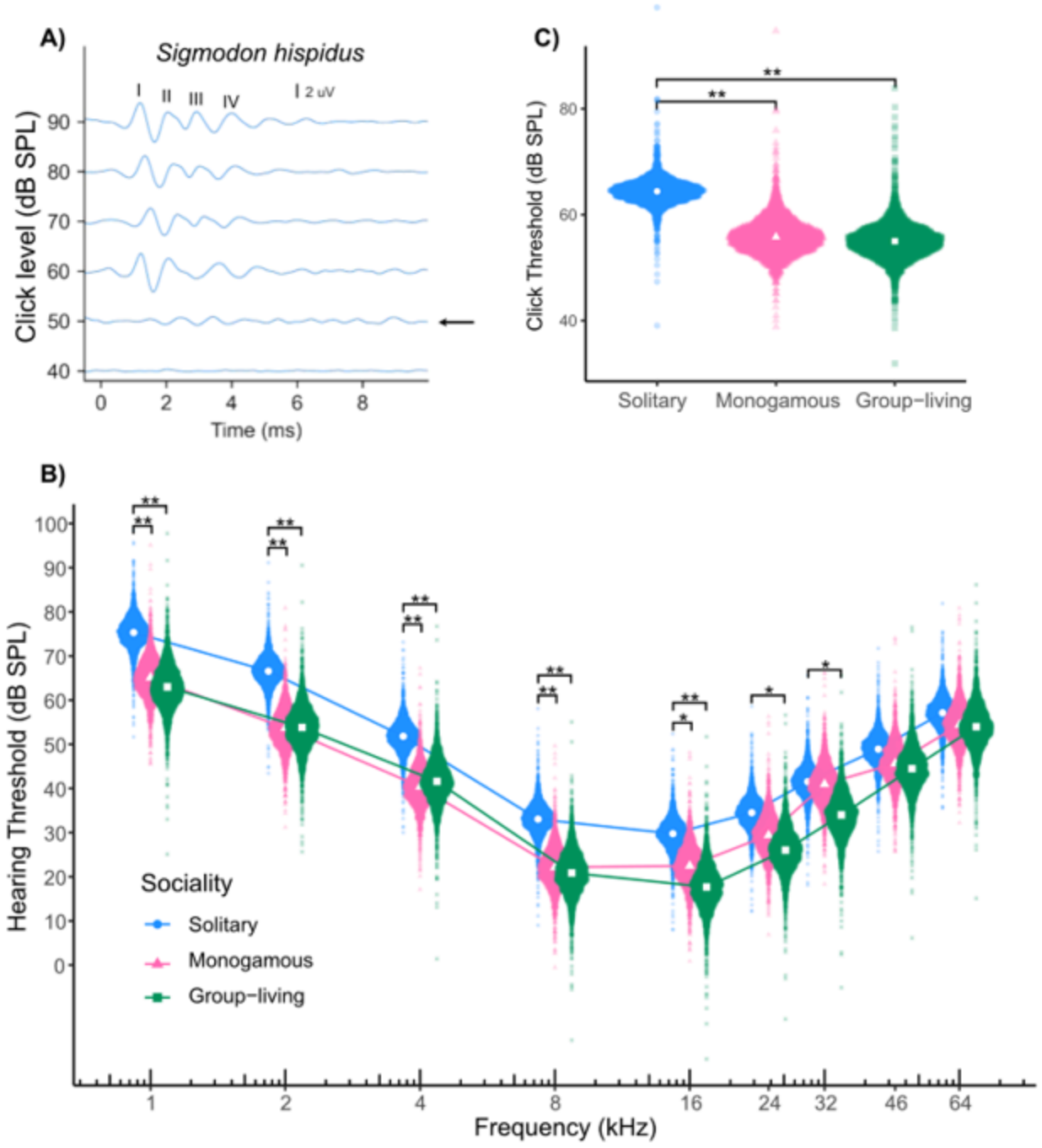

Figure 2

A. ABR traces to click stimuli for a representative male solitary species (*Sigmodon hispidus*) included in this study. In Fig 2A, waves I – IV are labeled in the 90 dB SPL and the arrow at the 50 dB SPL shows the last ABR waves seen for determine click thresholds (See supplementary Fig 3 for an example of each tested species). **B.** Mean auditory brainstem response thresholds in solitary, monogamous, and group-living wild-caught rodents across tested frequencies (n = 90, 10 individuals per species). **C.** Click response thresholds across social groups (solitary = blue, monogamous = pink, group-living = green). White circle (solitary), white triangle (Monogamous), and white square (Group-living) represent the mean

value for each group. Significant differences were detected in click thresholds and frequency response thresholds across social groups. Asterisks represent Bayesian statistical differences across social groups with $p < 0.05$ **, $p \leq 0.1$ *.

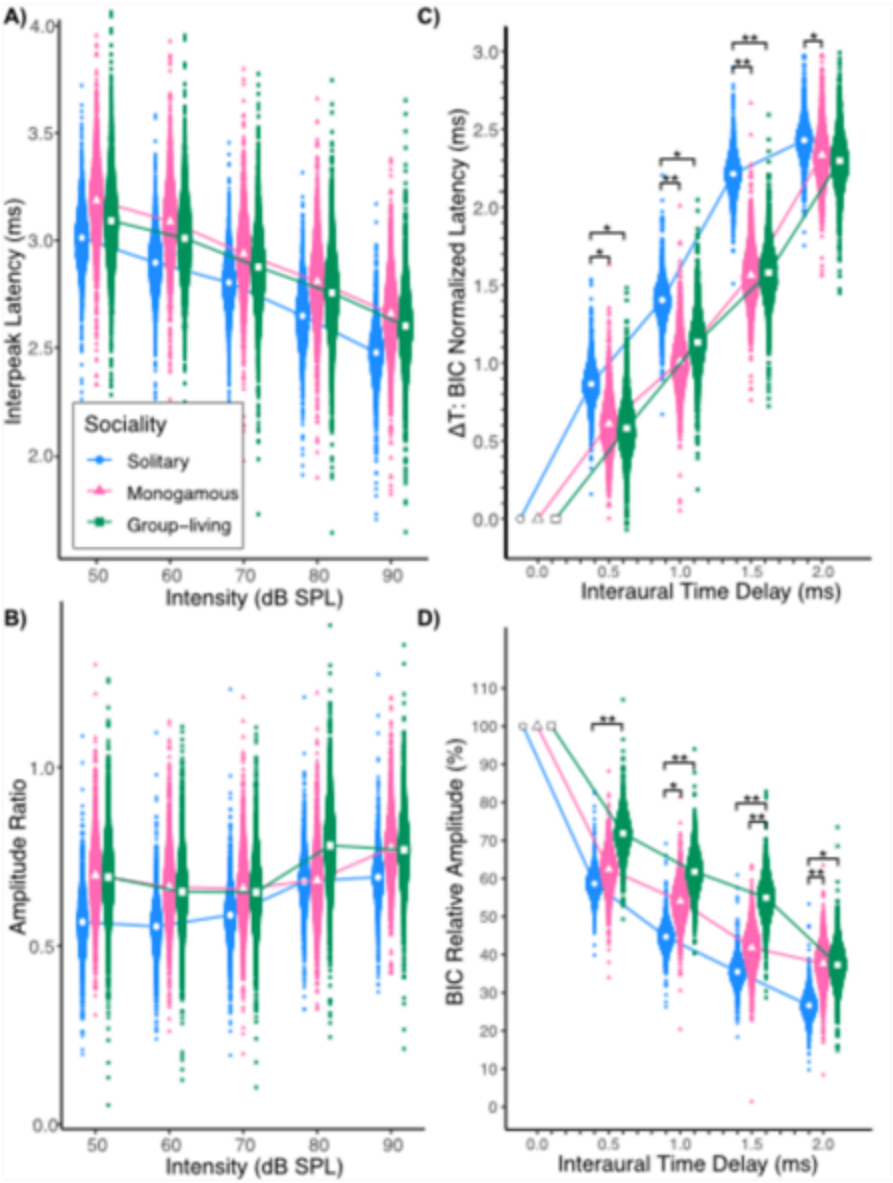

Figure 3

A. The average interpeak latency of ABR waves I and IV determined with clicks of different intensities (blue represents solitary species, pink represents monogamous species, and green represents group-living species). **B**. The average ABR waves IV/I amplitude ratio determined with clicks of different intensities. No significant differences were detected in interpeak latency and amplitude ratio across social groups. **C.**Mean BIC normalized latency in solitary, monogamous, and group-living wild-caught rodents across tested ITD (n = 90, 10 individuals per species). **D.**Mean BIC relative amplitude across groups. Significant differences were detected in BIC normalized latency and BIC relative amplitude across social groups. White circle (solitary), white triangle (Monogamous), and white square (Group-

living) represent the mean value for each group. Asterisks represent Bayesian statistical differences across social groups with $p < 0.05$ **, $p \leq 0.1$ *.

Supplementary Files

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