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Supplementary Materials for

Flexible control of vocal timing in bats enables escape from acoustic interference

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Materials and Methods

Animals

72 adult bats (24 female) of the species *Carollia perspicillata* were used in this study. Bats were taken from a breeding colony at the Institute for Cell Biology and Neuroscience at Goethe University Frankfurt in Frankfurt am Main, Germany. All experiments were conducted in accordance with the Declaration of Helsinki and local regulations in the state of Hessen (experimental permit FU1126 and FR2007, Regierungspräsidium Darmstadt). Animals had access to food (a mixture of banana pulp, oatmeal and honey) and water *ad libitum* when recordings were not taking place. 48 bats (16 female) were used in experiment 1, while 24 (8 female) were used in experiment 2.

Stimuli

Experiment 1

Two types of masking noise were generated for this experiment, a broadband white noise (carrier frequencies 10-96 kHz) "full-band masker" and a narrower-band (carrier frequencies 50-96 kHz) "half-band masker" (60 seconds each). Each noise segment was then duplicated and amplitude modulated at 8 and 15 Hz, separately. The carrier frequencies for the broadband white noise were selected in order to spectrally mask the peak frequencies used by *Carollia perspicillata* bats for communication calls and echolocation pulses, and only echolocation pulses, respectively(*1*, *2*). Amplitude modulation rates were chosen to query temporal rates above and below the peak temporal modulation rate of the colony's spontaneous calling, based on previous analysis of acoustic recordings made in the colony (~11Hz) (Fig. S1).

Experiment 2

A 90 second segment of the full-band masker noise (carrier frequencies 10-96 kHz) was generated and calibrated to account for the dB roll-off induced by the speaker. The calibration curve used to calibrate the stimuli was computed using a custom Matlab GUI (MathWorks), by playing various pure tones through the speaker which were picked up by a Brüel & Kjær microphone positioned roughly at the location in the experimental chamber where the bats tended to congregate. The full-band masker noise was then used to generate eight masking noises with different modulation rates: 4, 8, 16, 25, 33, 40, 50, and 80 Hz. For each modulation rate, we then generated a 7.5 minute long audio file. The eight 7.5 minute files were then randomly permuted and concatenated together to form a 60 minute acoustic stimulus. We then generated a 15 minute long "random masker" by randomly permuting and concatenating together single amplitude modulation cycles for each rate. This was done four times, and the 15 minute sequences were randomly permuted and concatenated together to form a 60 minute acoustic stimulus. The precise sequence in which stimuli were presented was determined by two randomizations, each of which was presented to two groups of bats.

Procedure

Experiment 1

Audio and video were recorded from each of eight groups of bats (4 males, 2 females in each group) in an anechoic chamber over five consecutive recording days. On each day, recordings were first made in three one-hour blocks ("playback conditions"): a silent baseline was followed in the second and third blocks by acoustic playback of the full-band and half-band masking noise ("masking conditions"). (Presentation order of the two masking noises was counterbalanced across groups). Full- and half-band masking noise played to each group of bats was either amplitude modulated at 8 or 15 Hz. Hence, each group only ever heard playback noise modulated at one temporal rate, but with different spectral components.

A computer running Matlab 2021a and Avisoft ultrasound recording software (Avisoft-RECORDER USGH, version 4.3.00) controlled simultaneous audio playback, video acquisition and audio recording. A custom Matlab script played the 60-second audio stimuli (16-bit, 192 kHz sampling rate) 60 times to a directional speaker via a RME Fireface 400 FireWire soundcard and amplifier. Stimuli were played at ~70 dB SPL measured at a distance of ~20 cm from the speaker. A webcam with infrared filter removed was placed in the cage with a view to the bats' roosting corner and illuminated by an infrared LED light. Two trigger channels were used to synchronize audio and video recordings with the start of acoustic playback or, in the silent condition, the start of the recording block: the first sent a TTL pulse to the Avisoft recording device (UltraSoundGate 116Hm), which in turn triggered the recording software to begin acquisition from a condenser microphone (250 kHz sampling rate, Avisoft-Bioacoustics CM16); the second illuminated a red photodiode placed in view of the webcam for aligning video and audio offline.

Experiment 2

Procedure was similar to that in experiment 1, with the following exceptions: Four groups of bats were tested, each of which was presented with the same acoustic conditions. Acoustic playback in the second and third recording blocks consisted of the steady-state and random masker noise. Precise presentation order and randomizations were counterbalanced between groups. A custom Matlab script controlled simultaneous audio playback, video acquisition and audio recording. 60 minute audio stimuli were played to the speakers.

Data Analysis

Experiment 1

First, any silent periods preceding or following the onset and offset of the masking noise were manually removed (except for groups 1 & 2 in the 8 Hz context, see below). Raw audio files (60 minutes long) were split into segments of 7.5 minutes in duration (all groups except groups 1 & 2 from the 8 Hz condition, for which the raw audio files were 1 minute in duration).

For groups 1 & 2 in the 8 Hz context only: raw data files were saved as 60 second long audio files and featured a brief silence (~250 ms) at the end of each file, corresponding to the delay caused by the program re-initializing for the next stimulus presentation. These brief silences were trimmed by cross-correlating the amplitude envelope at the end of each file with the amplitude envelope of a recording of the auditory stimulus in the experimental booth without any animals present ("envelope cross-correlation"). Trimmed audio files were visually checked to make sure the end of the file corresponded with the trough of the last amplitude modulation cycle in the file. For files recorded in the silent condition, the final 250 ms of each file was trimmed. For all other groups in this experiment, raw data files were 60 minute long audio files and featured a brief, silent pre- and post-trigger period (~2 and 0.75 s, respectively). These brief silences were trimmed via envelope cross-correlation. For files recorded in the silent condition, the first 2 and final 0.75 seconds were removed. Files were visually checked and manually edited where the envelope cross-correlation failed to adequately remove artifactual silences.

Vocalization events were detected using *Deep Audio Segmenter* (DAS, v0.28.3)(*3*), a deep neural network developed for the annotation of acoustic signals, and Python (v3.8.3). First, a subset of the dataset was manually annotated. Next, training and test datasets were created from these annotations for the silent and masking conditions, separately. We trained several DAS models using different hyperparameters until we achieved satisfactory prediction and/or a plateau in model improvement. Performance was calculated as the F1 score, the geometric mean of precision and recall. Prediction parameters the same for all runs: 1 ms minimum event duration and 0.9 ms minimum time between event boundaries. Precision, recall, F1 scores, and temporal errors for call onset detection were calculated based on a tolerance of 1.5 ms. Call offsets were detected and used to estimate call durations for the purpose of gaining a broad impression of the proportion of echolocation to communication calls, but otherwise not analyzed, since offsets in our dataset were not very well-defined (i.e. calls frequently featured a decay rather than a sharp offset, or appeared "smeared" due to the appearance of the echo on the recording following the echolocation pulse). Hyperparameters and model performance measures are reported in Tables 1 & 2, respectively.

Finally, we labelled each vocalization event detected in the masking conditions with a value corresponding to the instantaneous phase of the amplitude modulation at the time of call onset. Each audio file was bandpass filtered (10.1-10.5 kHz, 3rd order butterworth filter) to remove acoustic artifacts. The Hilbert envelope of the filtered audio was then downsampled by a factor of 10 and passed through a temporal bandpass filter (modulation rate ±1 Hz, 2nd order butterworth filter) to preserve the amplitude modulation signal while removing other acoustic features. The signal was then demeaned and zero-padded at both ends (20 samples). Next, we detected the troughs of the amplitude modulation signal and used these to reconstruct a phase model (0:2pi) of the amplitude modulation envelope, with each trough as the beginning of the next cycle. Time differences between detected troughs were used to estimate the temporal accuracy of the instantaneous phase model (fig. S6). Detected vocalizations were finally tagged with the corresponding phase value at call onset. For audio files from the silent condition, calls were tagged according to a simulated instantaneous phase signal modelled as a cosine aligned to the start of the file. This cosine model featured the same modulation rate as the corresponding playback conditions.

	Condition	Chunk [samples]	STFT downsample	TCN stacks	Kernel size [samples]	Kernel
Experiment 1	Silence	8192	16x	2	16	32
	Masking	8192	16x	4	16	32
Experiment 2	Silence	8192	16x	2	32	32
	Masking	8192	16x	2	16	32

Table 1. Hyperparameters for final models

		Call Onset Detection			
		Precision	Recall	F1 score	Median temporal error (ms)
Experiment 1	Silence	0.97	0.64	0.77	0.35
	Masking				
	predict 8Hz	0.94	0.65	0.75	0.37
	predict 15Hz	0.96	0.45	0.61	0.38
Experiment 2	Silence	0.90	0.62	0.73	0.32
	Masking	0.90	0.61	0.73	0.21

Table 2. Model performance and temporal error in predicting test set

Experiment 2

First, any silent periods preceding or following the onset and offset of the masking noise were manually removed. For audio files from the silent condition, the first and final 2.2 seconds (corresponding to the pre- and post-trigger period) was removed. Raw audio files from the silent and steady-state conditions were then split into segments of 7.5 minutes in duration, in the latter case corresponding to the playback duration of each individual modulation rate. Files from the random conditions were split into segments of 15 minutes, corresponding to the duration of pseudo-random blocks of modulation rate sequences.

The same procedure was used as in experiment 1 to detect the vocalization events. Model hyperparameters and performance measures are reported in Tables 1 & 2, respectively. To ensure that the model was not biased towards detecting (or failing to detect) vocalizations at particular phases of the amplitude envelope, we computed the instantaneous phase of a subset of predicted call events in the test set (from recordings during the random masker playback, which included samples from all modulation cycles), and grouped them by whether DAS detected a true positive, false positive, or false negative. We found no prominent bias in the detection of call events at any particular phase (fig. S7).

The same procedure was used as in experiment 1 to label vocalization events with the instantaneous amplitude phase for call detected in the silent and stead-state conditions. For calls detected in the random condition: Each audio file was bandpass filtered (15-60 kHz, 3rd order butterworth filter) to remove acoustic artifacts. The Hilbert envelope of the filtered audio was then downsampled by a factor of 10 and passed through a temporal lowpass filter (70 Hz, 2nd order butterworth filter) to preserve principally the amplitude modulation signal. The signal was then smoothed with a 12-point moving average filter. The sequence of amplitude modulation cycles that comprised the stimulus in each audio file was then used to construct a cosine phase model, which was cross-correlated with the derived modulation signal to obtain an amplitude envelope fit to the recorded audio file. This signal was then demeaned and zero-padded at the ends (20 samples). Next, we detected the troughs of the amplitude modulation signal and used these to reconstruct a phase model (0:2pi) of the amplitude modulation envelope, with each trough as the beginning of the next cycle. Time differences between detected troughs were used to estimate the temporal accuracy of the instantaneous phase model (fig. S6). Detected vocalizations were finally tagged with the corresponding phase value at call onset. For the random condition, data from all modulation cycles of the same temporal rate were pooled together.

Statistical Analyses

All statistical analyses were carried out in R (v4.2.1) and RStudio (v2022.7.2.576).

To determine if the presence of amplitude modulated noise affected the timing of emitted calls, we compared the density distribution of call onsets within the real/simulated modulation cycle for each playback condition and modulation rate. To describe the distributions in each condition, we computed a battery of circular summary statistics including the angular mean, mean resultant vector length, circular variance, circular standard deviation, and maximum likelihood bootstrapped von Mises parameters μ (sample mean) and κ (sample concentration).

We used Rayleigh's test of uniformity to compare distributions in each condition to the null hypothesis of a circular uniform distribution. We used Mardia-Watson-Wheeler non-parametric tests to test for overall differences between playback conditions within each modulate rate. To test for differences in the angular means or in the resultant vector lengths (polar concentrations) of call onset distributions between playback conditions within each modulation rate, we computed Rao's test of homogeneity. To determine which playback conditions varied significantly from each other on either measure, we computed post-hoc Rao's tests on pairs of conditions where omnibus Rao's tests were significant for either means or concentrations. These tests were carried out on the entire dataset despite differences in sample size between comparison groups, since the smallest group across both experiments had a sample size of over 5,000 and frequentist circular statistics are only sensitive to sample size at very small Ns(*4*).

To determine whether masking noise influenced the rate of calling, we modelled the number of observed calls in each experimental block (group x recording day x playback condition) using a negative binomial regression using playback condition as predictor, for each modulation rate separately, as follows:

$$ln(\widehat{n_i}) = Intercept + \beta_1 I(condition_j = 2) + \beta_2 I(condition_j = 3)$$

Where n is the number of observed call events, I is the predictor variable of playback condition with two levels j as well as an $Intercept$ (silence), and i is the modulation rate.

In R, models are implemented as follows:

$$n \sim 1 + condition, data = data[data\$modulation == x,].$$

The negative binomial regression was selected for this analysis, since a Poisson model with the same formula yielded highly over-dispersed models. Dispersion for all models used was close to 1. A Type II, partial likelihood ratio ANOVA was computed on the negative binomial models to determine significant predictors. Incidence rates and confidence intervals derived from the model were used to estimate the degree to which calling behavior increased or decreased for a given combination of predictors. Post-hoc comparisons evaluated differences in estimated marginal means (predicted calling rates) between pairs of masking conditions. This analysis was repeated for the temporally overlapping calls.

Wherever multiple hypothesis tests were carried out, p-values were adjusted for multiple comparisons by Bonferroni correction. For all hypothesis tests, an alpha level of 0.05 was used.

For the linear discriminant classification analysis, two measures of call onset timing were first computed from bootstrapped angular means as follows:

$$(1)\ \ t\ from\ peak = \mu - \frac{1/f}{2} \qquad (2)\ t\ to\ trough = \frac{1}{f} - \mu$$

where μ is the angular mean computed from an MLE von Mises distribution and f is the modulation rate of the current cycle. Thus, time-from-peak values were positive if call onsets occurred on average after the modulation peak in the latter half of the cycle, and negative if call onsets occurred before the peak. Time-to-trough values give the time remaining between average call onset and the final moment in the cycle, the terminal trough. Data from the broadband masking conditions only (experiment 1: full-band masker, experiment 2: steady-state and random masker) was then divided into a training and validation set with 0.6:0.4 split.

Next, three models were fed the training data (0.6:0.4 split stratified on modulation rate groups) and asked to determine modulate rate classes predicted by either or both measures, as follows:

$$\text{full model: } modulation \sim t_{trough} + t_{peak}$$

$$\text{troughs model: } modulation \sim t_{trough}$$

$$\text{peaks model: } modulation \sim t_{peak}$$

Models (using the *lda* algorithm implemented in the *caret* package) were trained using 10-fold cross-validation (repeated 10 times) and predictors were centered and scaled. Each model was then used to predict modulation rate classes for the validation set. Confusion matrices for observed versus predicted classes from the validation data is shown in Figure 4.

We then computed ROC curves and AUC values for each model from each experiment.

Manipulated Variables

In experiment 1, one half of the bat groups (4 of 8) were housed together starting on the first recording day and subsequently only for the duration of the experiment (5 days). The other four groups were housed together for a seven-day "familiarization period" prior to the first recording day (12 days in total). An early hypothesis was that groups that did not have the familiarization period may vocalize more, since at the time of data collection all bats that were not part of the experiment were housed separately by sex. Thus, a mixed-sex group could lead to an unusually high level of vocal activity. No clear difference between these two groups emerged based on preliminary results from experiment 1. All analyses were done without respect to this grouping variable.

Data Exclusion for Experiment 1

For groups 1 & 2 in the 8 Hz context, some recording blocks had buffer issues which caused improper logging of data. Audio files for these blocks were visually checked and sections with corrupted data were removed from the corresponding file if the error was minor (i.e. < 1 second long, or < 3 times per file). If errors were more extensive, the file was removed from analysis. Altogether, approx. 15 minutes of data was removed from the raw data for these two groups combined. For all remaining groups, the first 15 hours of recordings were visually checked for buffer issues. As only a few such occurrences were found, we did not proceed with the visual check. Original raw data for this experiment amounted to 120 hours of audio recording (approx. 105 hours after data exclusion).

Supplementary Figures

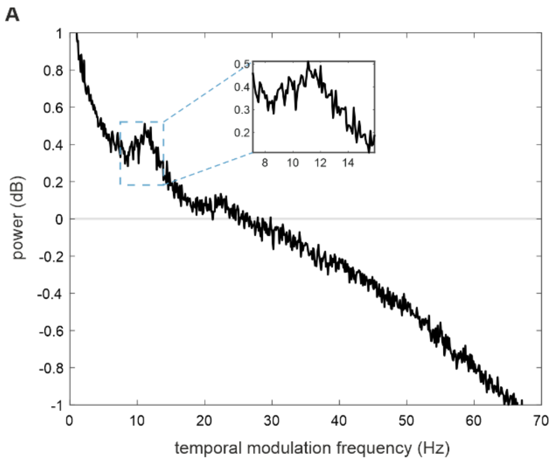

Fig. S1.

Temporal modulation rate of spontaneous vocalizations in C. perspicillata colony is ~ 11 Hz. (**A)** Audio recordings made in our colony of *Carollia* bats (160 minutes total) were highpass filtered (10 kHz) before amplitude envelopes were extracted via the secant method (interpolation over every 5,000 points). The power spectrum density (PSD) of the envelope was computed for each audio segment (10 s each) and averaged across segments. A "control" PSD was computed by randomly permuting sections of the amplitude envelopes in each segment and averaging the permuted-segment PSDs. The "control" PSD was subtracted from original average PSD to produce a power spectrum normalized for ambient noise/power in the signal. The peak of this power spectrum was at ~ 11 Hz (inset), indicating the temporal modulation rate of spontaneous calling in the colony.

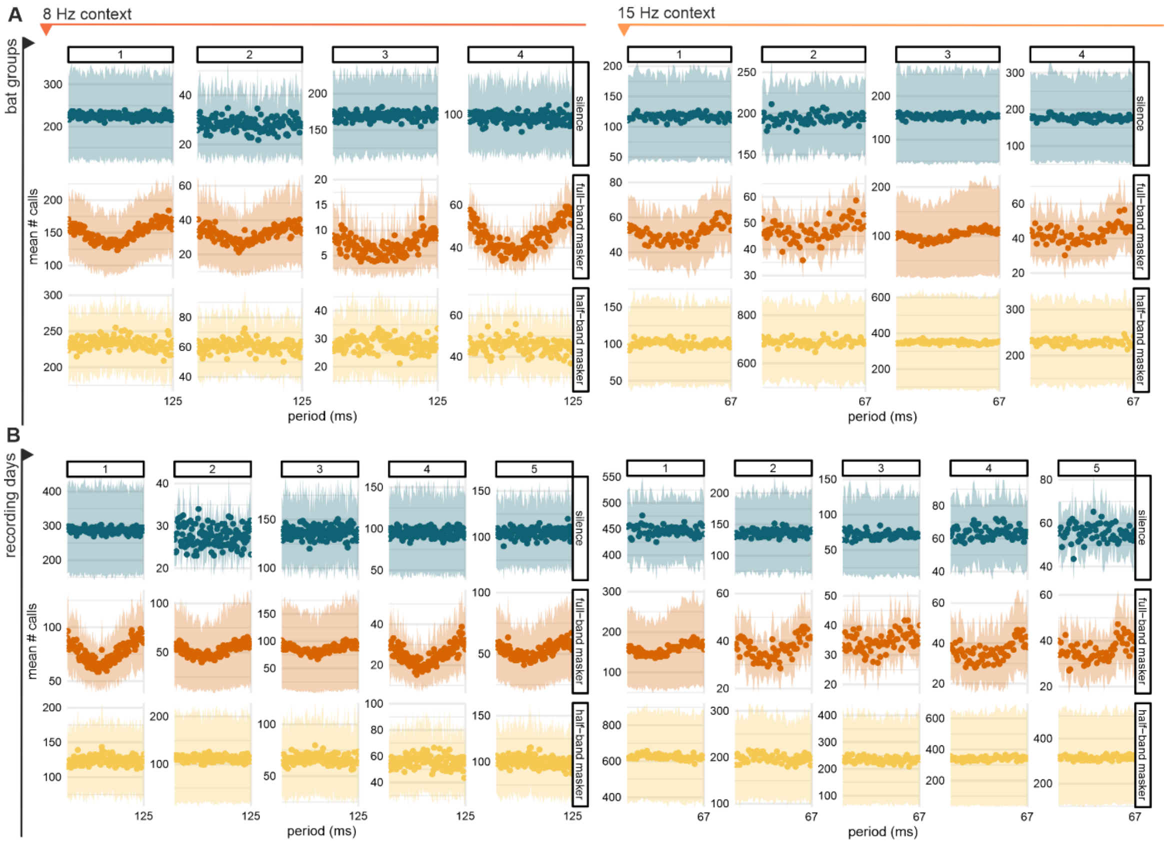

Fig. S2.

Experiment 1: Anti-phase calling is present in all groups and all recording days.

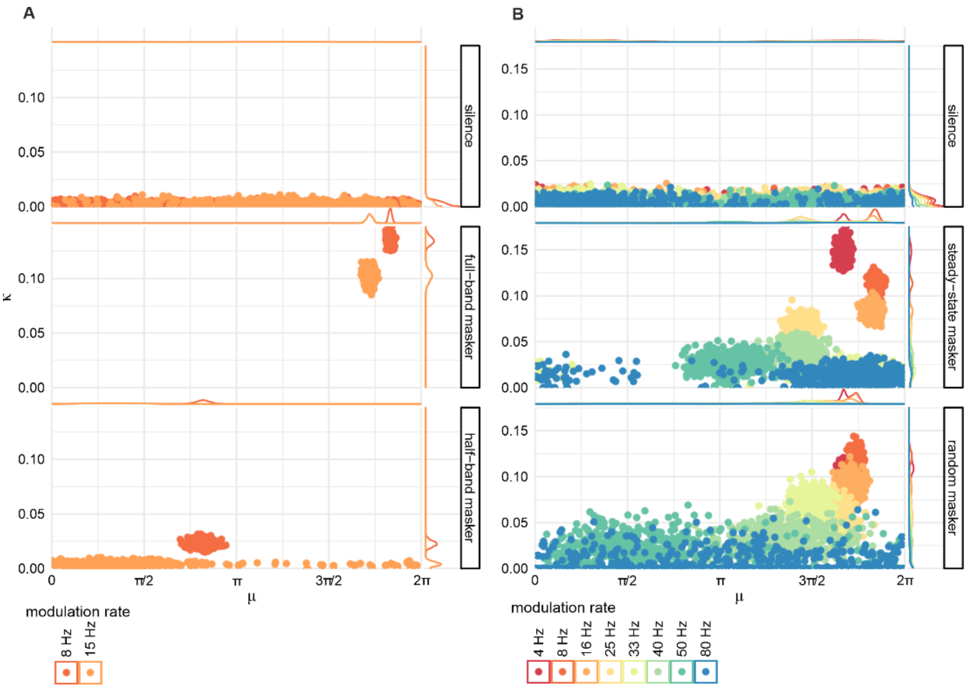

Fig. S3.

Bootstrapped von Mises parameters mean (μ) and concentration (κ) in the cartesian plane. (A) Parameters from experiment 1 data. **(B)** Parameters from experiment 2 data.

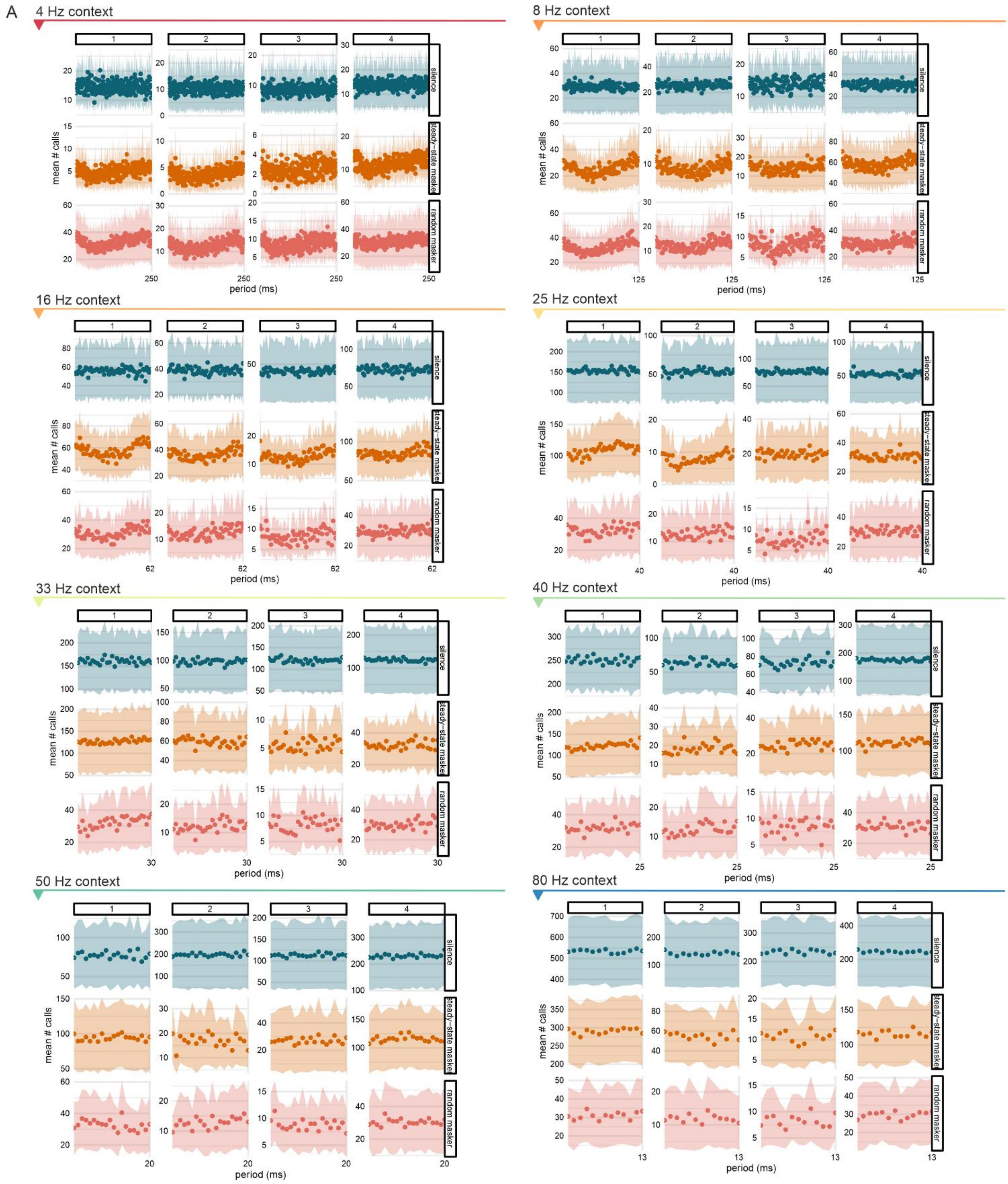

Fig. S4.

Experiment 2: Anti-phase calling is present in all groups for modulation rate conditions 4, 8 and 16. 25 Hz context reveals a slight modulation in calling pattern for some groups between the two masking conditions.

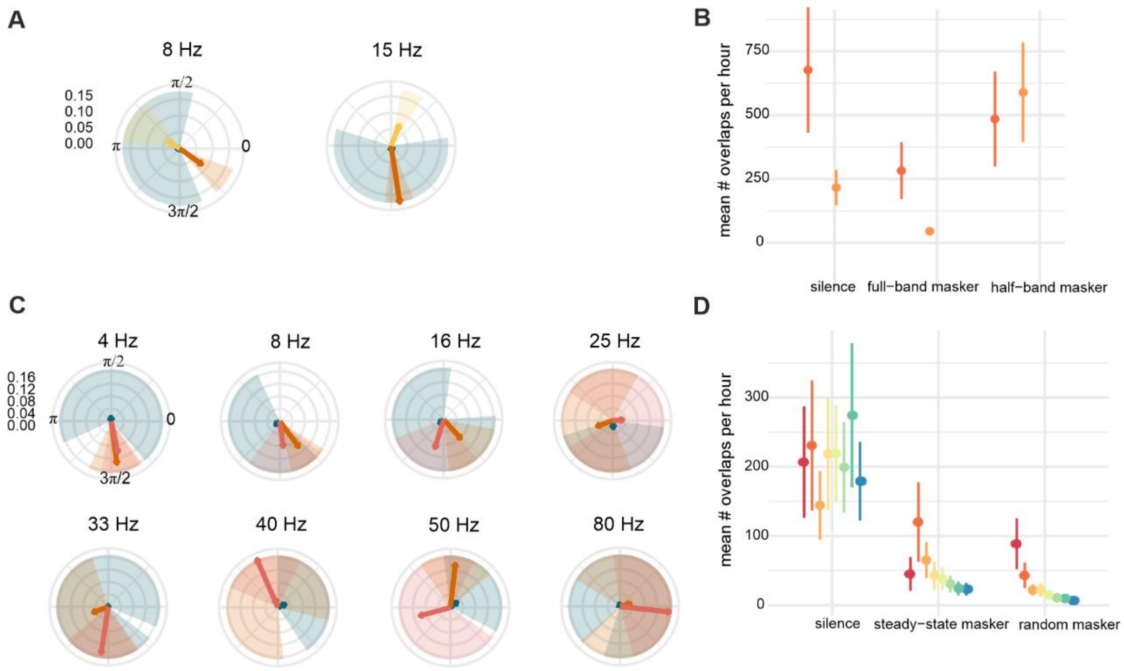

Fig. S5.

Temporal overlap between calls is reduced in the presence of noise. (A) Angular vectors indicate angular mean and concentration for overlapping calls. Shaded segments indicate 95% confidence intervals for angular means. Significant clustering is seen in the 8Hz full-band and 15Hz half-band masking condition. **(B)** For experiment 1, mean number of overlapping calls observed per hour are reduced in broadband masking noise compared to baseline. **(C)** For experiment 2, overlapping calls are significantly clustered only at 8 and 16Hz in the steady-state condition. (**D)** For experiment 2, mean overlapping calls dropped significantly between silent baseline and masking conditions for all modulation rates except 4 Hz.

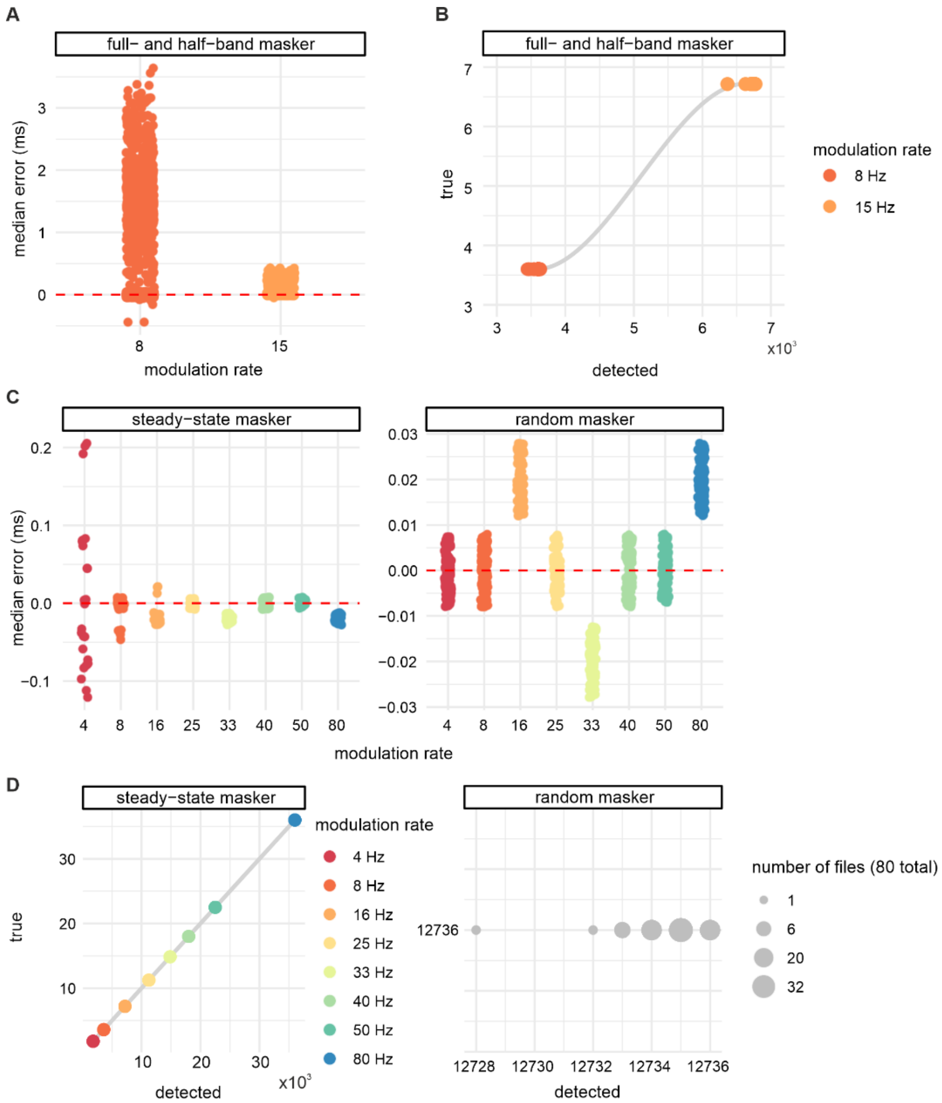

Fig. S6.

Temporal and cycle-wise accuracy of instantaneous phase models. (A) For experiment 1, the median deviation error between expected modulation periods (1/*f*) and derived periods in the instantaneous phase model for all cycles across the entire data set. Errors were mostly between 0 and 3 ms for both modulation rate contexts. **(B)** For experiment 1, the number of true cycles in each one-hour recording block vs. the number of detected cycles in the instantaneous phase model. On average, 5 more cycles were detected in recording blocks in the 8Hz context, and 19 fewer cycles were detected in the 15Hz contexts. **(C)** For experiment 2, median deviation error between expected and derived periods for each modulation rate were less than ±0.3 ms for all rates in both masking conditions. **(D)** For experiment 2, true vs. detected number of cycles were almost perfectly matched for the steady-state condition. On average, detected cycles were ± 2 cycles from expected values (estimated per 7.5 minute block). For the random condition, true vs. detected cycles were calculated irrespective of modulation rate, but were accurate to 0:-4 cycles per 15 minute block (file).

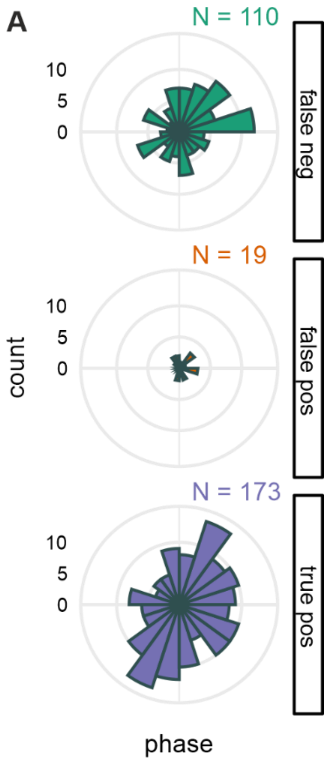

Fig. S7.

DAS-predicted call events by class, as a function of call onset phase. Phase tagging of detected call events from a representative test set (experiment 2: random masker) showed that DAS is not strongly biased to detect calls at particular phases in the amplitude modulation cycle.

Supplementary Tables

Table S1.

Estimated proportion of echolocation to communication calls. A total of 2,673 calls were classified as echolocation or communication calls by visual inspection of spectrograms from all four masking conditions used in both experiments (spectrogram segments sampled from randomly selected groups and files). A weighed average of the proportion of echolocation pulses to communication calls (weighted by the total duration of audio data inspected for each condition) was then computed.

	Playback Condition			
	Silence	**Full-band masker/Steady-state masker**	**Half-band masker**	**Random masker**
Total duration scanned (s)	180	240	90	90
Condition-wise mean prop. echo	0.79	0.96	0.94	0.78
Weighted mean prop. echo		0.88		

Table S2.

Experiment 1: Circular statistics for call onsets with respect to the amplitude modulation cycle

		Circular Statistics											
		Summary Statistics					**Rayleigh's Test**			**MLE von Mises**			
modulation	**condition**	**n**	$\bar{\boldsymbol{\theta}}$	$\bar{\boldsymbol{r}}$	**Vm**	**sd**	**R**	***p***	$\boldsymbol{P_{Bonferroni}}$	$\boldsymbol{\mu_{MLE}}$	$\mathbf{CI_{lo}}$	$\mathbf{CI_{hi}}$	$\boldsymbol{\kappa_{MLE}}$
8Hz	silence	325,333	0.738	0.001	0.999	3.722	0.001	0.279	1	0.738	4.534	4.327	0.002
8Hz	full-band masker	146,187	5.752	0.067	0.933	2.324	0.058	0.000	<0.001	5.752	5.698	5.808	0.135
8Hz	half-band masker	229,311	2.579	0.012	0.989	2.989	-0.010	1.000	1	2.579	2.295	2.836	0.023
15Hz	silence	202,822	3.933	0.001	0.999	3.661	-0.001	0.709	1	3.933	1.962	0.506	0.002
15Hz	full-band masker	78,197	5.403	0.051	0.949	2.442	0.032	0.000	<0.001	5.403	5.306	5.504	0.102
15Hz	half-band masker	443,217	1.042	0.002	0.998	3.524	0.001	0.170	1	1.042	6.003	2.560	0.004

N = number of observations. $\bar{\theta}$ = Mean resultant direction. $\bar{r}$ = Mean resultant length. Vm = circular variance. sd = circular standard deviation. R = test statistics for Rayleigh's test of uniformity. p = p value. $P_{Bonferroni}$ = Bonferroni corrected p-values for the family of all tests in the table. μ_{MLE} = Mean parameter estimated from the maximum likelihood von Mises distribution. CI_{lo}, CI_{hi} = Boostrapped upper and lower thresholds for the 95% confidence interval for the MLE mean parameter. κ_{MLE} = Concentration parameter estimated from the MLE von Mises distribution.

Table S3.

Experiment 1: Rao's test for differences in angular means or dispersions in distributions of call onsets between playback conditions

Rao test for homogeneity of angular means & dispersions within mod rates						
modulation	**condition**	**test**	**statistic**	**df**	***p***	***P**$_{Bonferroni}$*
8Hz	Omnibus	polar vectors	0.477	2	0.788	1.000
8Hz	Omnibus	dispersions	346.680	2	0.000	<0.001
15Hz	Omnibus	polar vectors	2.708	2	0.258	0.516
15Hz	Omnibus	dispersions	100.345	2	0.000	<0.001
8Hz	silence vs. Full-band masker	polar vectors	0.422	1	0.516	1.00
8Hz	silence vs. Full-band masker	dispersions	332.013	1	0.000	<0.001
8Hz	silence vs. Half-band masker	polar vectors	0.444	1	0.505	1.00
8Hz	silence vs. Half-band masker	dispersions	14.766	1	0.000	<0.001
8Hz	full-band masker vs. Half-band masker	polar vectors	0.054	1	0.817	1.00
8Hz	full-band masker vs. Half-band masker	dispersions	307.346	1	0.000	<0.001
15Hz	silence vs. Full-band masker	polar vectors	0.739	1	0.390	0.78
15Hz	silence vs. Full-band masker	dispersions	100.231	1	0.000	<0.001
15Hz	silence vs. Half-band masker	polar vectors	0.045	1	0.832	1.00
15Hz	silence vs. Half-band masker	dispersions	0.193	1	0.660	1.00
15Hz	full-band masker vs. Half-band masker	polar vectors	1.975	1	0.160	0.32
15Hz	full-band masker vs. Half-band masker	dispersions	100.029	1	0.000	<0.001

Table S4.

Experiment 1: Negative binomial model results for calls emitted both modulation rate contexts

Observed calls per hour in 8Hz modulated noise

Predictors	**Incidence Rate Ratios**	**CI**	***p***
(Intercept)	16266.65	10048.04 – 28874.24	<0.001
condition [full-band masker]	0.45	0.21 – 0.95	0.034
condition [half-band masker]	0.70	0.33 – 1.49	0.355
Observations	60		
R^2 Nagelkerke	0.097		
Deviance	72.505		
AIC	1239.835		

Observed calls per hour in 15Hz modulated noise

Predictors	**Incidence Rate Ratios**	**CI**	***p***
(Intercept)	10674.84	6729.32 – 18413.99	<0.001
condition [full-band masker]	0.39	0.19 – 0.79	0.008
condition [half-band masker]	2.19	1.07 – 4.46	0.030
Observations	57		
R^2 Nagelkerke	0.395		
Deviance	67.547		
AIC	1171.104		

Note that the p-values in the table above are not Bonferroni corrected, as they represent p-values for model coefficients.

Table S5.

Experiment 1: Incidence rate ratios derived from negative binomial models

		Incidence Rate Ratios		
modulation	**coefficient**	**Estimate**	**2.5 %**	**97.5 %**
8Hz	(Intercept)	16266.65	10048.04	28874.24
8Hz	full-band masker	0.45	0.21	0.95
8Hz	half-band masker	0.70	0.33	1.49
15Hz	(Intercept)	10674.84	6729.32	18413.99
15Hz	full-band masker	0.39	0.19	0.79
15Hz	half-band masker	2.19	1.07	4.46

Table S6.

Experiment 1: ANOVA Analysis of variance for the predictor of playback condition for each modulation rate model, separately.

		Type II Analysis of Deviance		
model	**predictor**	**LR Chi-square**	**df**	***p***
8Hz	condition	4.37	2	0.11
15Hz	condition	21.34	2	<0.001

Table S7.

Experiment 2: Estimated marginal means of call incidence rates per condition

Estimated Marginal Means

modulation	**contrast**	**IRR**	**se**	**CI_{lo}**	**CI_{hi}**	**Z ratio**	***p***
8Hz	silence / (full-band masker)	2.22	0.84	0.90	5.50	2.12	0.10
8Hz	silence / (half-band masker)	1.42	0.54	0.57	3.51	0.92	1.00
8Hz	(full-band masker) / (half-band masker)	0.64	0.24	0.26	1.58	-1.19	0.70
15Hz	silence / (full-band masker)	2.59	0.94	1.09	6.15	2.64	0.03
15Hz	silence / (half-band masker)	0.46	0.16	0.19	1.08	-2.17	0.09
15Hz	(full-band masker) / (half-band masker)	0.18	0.06	0.07	0.42	-4.81	<0.001

IRR = Incidence rate ratios.

Table S8.

Experiment 2: Circular statistics for call onsets with respect to the amplitude modulation cycle

		Circular Statistics											
		Summary Statistics				**Rayleigh's Test**				**MLE von Mises**			
modulation	**condition**	**n**	$\bar{\theta}$	$\bar{r}$	**Vm**	**sd**	**R**	p	$p_{Bonferroni}$	μ_{MLE}	**CI**$_{lo}$	**CI**$_{hi}$	κ_{MLE}
4Hz	silence	59,635	6.203	0.003	0.997	3.388	0.003	0.134	1	6.203	4.212	3.124	0.006
4Hz	steady-state masker	28,938	5.246	0.074	0.926	2.282	0.038	0.000	<0.001	5.246	5.140	5.358	0.148
4Hz	random masker	105,990	5.245	0.054	0.946	2.416	0.027	0.000	<0.001	5.245	5.170	5.319	0.108
8Hz	silence	62,203	5.480	0.002	0.998	3.462	0.002	0.270	1	5.480	3.523	2.293	0.005
8Hz	steady-state masker	65,446	5.795	0.057	0.943	2.395	0.050	0.000	<0.001	5.795	5.702	5.891	0.114
8Hz	random masker	51,939	5.459	0.061	0.939	2.366	0.041	0.000	<0.001	5.459	5.356	5.554	0.122
16Hz	silence	65,769	0.858	0.003	0.997	3.376	0.002	0.213	1	0.858	5.075	3.812	0.007
16Hz	steady-state masker	60,482	5.732	0.042	0.958	2.520	0.036	0.000	<0.001	5.732	5.603	5.871	0.084
16Hz	random masker	25,543	5.376	0.046	0.955	2.486	0.028	0.000	<0.001	5.376	5.178	5.575	0.091
25Hz	silence	67,403	4.819	0.003	0.997	3.373	0.000	0.448	1	4.819	2.541	0.274	0.007
25Hz	steady-state masker	32,743	4.535	0.032	0.968	2.618	-0.006	0.928	1	4.535	4.299	4.766	0.065
25Hz	random masker	16,600	5.056	0.027	0.973	2.689	0.009	0.050	1	5.056	4.653	5.478	0.054
33Hz	silence	78,179	0.895	0.004	0.996	3.313	0.003	0.153	1	0.895	5.646	2.632	0.008
33Hz	steady-state masker	34,843	5.359	0.008	0.992	3.093	0.005	0.092	1	5.359	4.466	0.165	0.017
33Hz	random masker	12,830	4.688	0.034	0.966	2.599	-0.001	0.552	1	4.688	4.358	5.069	0.068
40Hz	silence	68,797	0.196	0.001	0.999	3.668	0.001	0.331	1	0.196	4.283	2.335	0.002
40Hz	steady-state masker	34,176	4.486	0.020	0.980	2.801	-0.004	0.877	1	4.486	4.063	4.874	0.040
40Hz	random masker	10,531	4.241	0.015	0.985	2.891	-0.007	0.844	1	4.241	3.404	5.347	0.031
50Hz	silence	61,956	5.052	0.002	0.998	3.564	0.001	0.419	1	5.052	2.940	1.454	0.004
50Hz	steady-state masker	25,425	3.302	0.013	0.987	2.937	-0.013	0.999	1	3.302	2.584	4.017	0.027
50Hz	random masker	8,487	1.776	0.009	0.991	3.055	-0.002	0.599	1	1.776	5.797	3.788	0.019
80Hz	silence	75,144	0.679	0.002	0.998	3.457	0.002	0.221	1	0.679	4.565	3.322	0.005
80Hz	steady-state masker	30,675	5.427	0.007	0.993	3.166	0.004	0.139	1	5.427	3.897	0.352	0.013
80Hz	random masker	5,260	4.324	0.002	0.998	3.561	-0.001	0.527	1	4.324	1.952	2.322	0.004

Table S9.

Experiment 2: Watson-Wheeler tests for the circular homogeneity of distributions of call onsets

Watson-Wheeler test for homogeneity of groups (within modulation rates)			
modulation	**statistic**	***p***	$\boldsymbol{p_{Bonferroni}}$
4Hz	281.693	<0.001	<0.001
8Hz	273.637	<0.001	<0.001
16Hz	143.040	<0.001	<0.001
25Hz	45.416	<0.001	<0.001
33Hz	32.695	<0.001	<0.001
40Hz	20.606	<0.001	<0.001
50Hz	8.775	0.067	0.536
80Hz	2.286	0.683	1.000

Table S10.

Experiment 2: Rao's test for differences in angular means or dispersions between playback conditions
Omnibus tests were carried out for each modulation rate to test if differences existed between the three playback conditions. For all tests with significant differences in either polar vectors or polar dispersions, post-hoc tests were computed on pairs of playback conditions.

Rao test for homogeneity of angular means & dispersions

modulation	condition	test	statistic	df	*p*	$p_{Bonferroni}$
4Hz	Omnibus	polar vectors	3.110	2	0.211	0.422
4Hz	Omnibus	dispersions	232.370	2	<0.001	<0.001
8Hz	Omnibus	polar vectors	18.883	2	<0.001	<0.001
8Hz	Omnibus	dispersions	199.932	2	<0.001	<0.001
16Hz	Omnibus	polar vectors	6.895	2	0.032	0.064
16Hz	Omnibus	dispersions	77.400	2	<0.001	<0.001
25Hz	Omnibus	polar vectors	3.853	2	0.146	0.292
25Hz	Omnibus	dispersions	22.588	2	<0.001	<0.001
33Hz	Omnibus	polar vectors	1.668	2	0.434	0.868
33Hz	Omnibus	dispersions	7.870	2	0.020	0.040
40Hz	Omnibus	polar vectors	0.897	2	0.639	1.000
40Hz	Omnibus	dispersions	7.848	2	0.020	0.040
50Hz	Omnibus	polar vectors	0.106	2	0.948	1.000
50Hz	Omnibus	dispersions	2.521	2	0.284	0.568
80Hz	Omnibus	polar vectors	0.806	2	0.668	1.000
80Hz	Omnibus	dispersions	0.492	2	0.782	1.000
4Hz	silence vs. steady-state masker	polar vectors	2.985	1	0.084	0.168
4Hz	silence vs. steady-state masker	dispersions	79.850	1	0.000	0.000
4Hz	silence vs. random masker	polar vectors	3.087	1	0.079	0.158
4Hz	silence vs. random masker	dispersions	153.051	1	0.000	0.000
4Hz	steady-state masker vs. random masker	polar vectors	0.000	1	0.983	1.000
4Hz	steady-state masker vs. random masker	dispersions	15.231	1	0.000	0.000
8Hz	silence vs. steady-state masker	polar vectors	0.046	1	0.830	1.000
8Hz	silence vs. steady-state masker	dispersions	104.750	1	0.000	0.000
8Hz	silence vs. random masker	polar vectors	0.000	1	0.985	1.000
8Hz	silence vs. random masker	dispersions	95.520	1	0.000	0.000
8Hz	steady-state masker vs. random masker	polar vectors	18.858	1	0.000	0.000
8Hz	steady-state masker vs. random masker	dispersions	0.944	1	0.331	0.662
8Hz	silence vs. steady-state masker	polar vectors	0.046	1	0.830	1.000
8Hz	silence vs. steady-state masker	dispersions	104.750	1	0.000	0.000
8Hz	silence vs. random masker	polar vectors	0.000	1	0.985	1.000
8Hz	silence vs. random masker	dispersions	95.520	1	0.000	0.000
8Hz	steady-state masker vs. random masker	polar vectors	18.858	1	0.000	0.000
8Hz	steady-state masker vs. random masker	dispersions	0.944	1	0.331	0.662

Table S11.

Experiment 2: Incidence rate ratios derived from negative binomial models

		Incidence Rate Ratios		
modulation	**coefficient**	**Estimate**	**2.5 %**	**97.5 %**
4Hz	(Intercept)	2981.75	1675.19	6085.74
4Hz	steady-state masker	0.49	0.19	1.21
4Hz	random masker	1.78	0.71	4.45
8Hz	(Intercept)	3110.15	1655.22	6909.31
8Hz	steady-state masker	1.11	0.40	3.12
8Hz	random masker	0.83	0.30	2.31
16Hz	(Intercept)	3288.45	1895.48	6456.38
16Hz	steady-state masker	0.92	0.38	2.20
16Hz	random masker	0.39	0.16	0.93
25Hz	(Intercept)	3370.15	1815.43	7344.02
25Hz	steady-state masker	0.51	0.19	1.41
25Hz	random masker	0.25	0.09	0.67
33Hz	(Intercept)	3908.95	2136.58	8324.83
33Hz	steady-state masker	0.45	0.17	1.17
33Hz	random masker	0.16	0.06	0.43
40Hz	(Intercept)	3620.89	2003.11	7568.02
40Hz	steady-state masker	0.50	0.19	1.28
40Hz	random masker	0.15	0.06	0.37
50Hz	(Intercept)	3097.80	1667.09	6760.91
50Hz	steady-state masker	0.41	0.15	1.11
50Hz	random masker	0.14	0.05	0.37
80Hz	(Intercept)	3757.20	2122.84	7602.55
80Hz	steady-state masker	0.41	0.16	1.01
80Hz	random masker	0.07	0.03	0.17

Table S12.

Experiment 2: ANOVA. Analysis of variance for the predictor of playback condition for each negative binomial model, separately.

Type II Analysis of Deviance				
model	**predictor**	**LR Chi-square**	**df**	***p***
4Hz	condition	7.55	2	0.02
8Hz	condition	0.31	2	0.86
16Hz	condition	5.07	2	0.08
25Hz	condition	7.55	2	0.02
33Hz	condition	12.74	2	<0.001
40Hz	condition	15.16	2	<0.001
50Hz	condition	14.36	2	<0.001
80Hz	condition	27.63	2	<0.001

Table S13.

Experiment 2: Estimated marginal means for incidence rates of calling

		Estimated Marginal Means					
modulation	**contrast**	**IRR**	**se**	**CI_{lo}**	**CI_{hi}**	**Z ratio**	***p***
4Hz	silence / (steady-state masker)	2.06	0.95	0.69	6.20	1.57	0.35
4Hz	silence / random masker	0.56	0.26	0.19	1.69	-1.25	0.63
4Hz	(steady-state masker) / random masker	0.27	0.13	0.09	0.82	-2.82	0.01
8Hz	silence / (steady-state masker)	0.90	0.47	0.26	3.10	-0.20	1.00
8Hz	silence / random masker	1.20	0.61	0.36	4.04	0.36	1.00
8Hz	(steady-state masker) / random masker	1.33	0.68	0.39	4.55	0.55	1.00
16Hz	silence / (steady-state masker)	1.09	0.48	0.38	3.10	0.19	1.00
16Hz	silence / random masker	2.58	1.13	0.90	7.34	2.16	0.09
16Hz	(steady-state masker) / random masker	2.37	1.04	0.83	6.75	1.97	0.15
25Hz	silence / (steady-state masker)	1.96	0.99	0.58	6.54	1.33	0.55
25Hz	silence / random masker	4.06	2.02	1.23	13.36	2.82	0.01
25Hz	(steady-state masker) / random masker	2.08	1.05	0.62	6.94	1.45	0.44
33Hz	silence / (steady-state masker)	2.24	1.09	0.70	7.16	1.67	0.29
33Hz	silence / random masker	6.09	2.95	1.91	19.44	3.73	<0.001
33Hz	(steady-state masker) / random masker	2.72	1.32	0.85	8.66	2.06	0.12
40Hz	silence / (steady-state masker)	2.01	0.95	0.65	6.26	1.48	0.42
40Hz	silence / random masker	6.88	3.22	2.24	21.08	4.12	<0.001
40Hz	(steady-state masker) / random masker	3.42	1.60	1.11	10.47	2.62	0.03
50Hz	silence / (steady-state masker)	2.44	1.22	0.74	8.04	1.79	0.22
50Hz	silence / random masker	7.30	3.64	2.21	24.08	3.99	<0.001
50Hz	(steady-state masker) / random masker	3.00	1.49	0.91	9.88	2.20	0.08
80Hz	silence / (steady-state masker)	2.45	1.11	0.82	7.28	1.97	0.15
80Hz	silence / random masker	14.29	6.50	4.80	42.50	5.84	<0.001
80Hz	(steady-state masker) / random masker	5.83	2.66	1.96	17.35	3.87	<0.001

Table S14.

Experiment 2: Estimated marginal means across modulation rates

Estimated Marginal Means							
modulation	**contrast**	**IRR**	**se**	**CI_{lo}**	**CI_{hi}**	**Z ratio**	***p***
silence	4Hz / 8Hz	0.96	0.47	0.20	4.49	-0.09	1.00
silence	4Hz / 16Hz	0.91	0.45	0.19	4.24	-0.20	1.00
silence	4Hz / 25Hz	0.88	0.44	0.19	4.14	-0.25	1.00
silence	4Hz / 33Hz	0.76	0.38	0.16	3.57	-0.55	1.00
silence	4Hz / 40Hz	0.82	0.41	0.17	3.93	-0.39	1.00
silence	4Hz / 50Hz	0.96	0.48	0.21	4.50	-0.08	1.00
silence	4Hz / 80Hz	0.79	0.39	0.17	3.71	-0.47	1.00
silence	8Hz / 16Hz	0.95	0.47	0.20	4.43	-0.11	1.00
silence	8Hz / 25Hz	0.92	0.46	0.20	4.32	-0.16	1.00
silence	8Hz / 33Hz	0.80	0.39	0.17	3.72	-0.46	1.00
silence	8Hz / 40Hz	0.86	0.43	0.18	4.10	-0.30	1.00
silence	8Hz / 50Hz	1.00	0.50	0.22	4.70	0.01	1.00
silence	8Hz / 80Hz	0.83	0.41	0.18	3.87	-0.38	1.00
silence	16Hz / 25Hz	0.98	0.48	0.21	4.57	-0.05	1.00
silence	16Hz / 33Hz	0.84	0.42	0.18	3.94	-0.35	1.00
silence	16Hz / 40Hz	0.91	0.46	0.19	4.34	-0.19	1.00
silence	16Hz / 50Hz	1.06	0.52	0.23	4.97	0.12	1.00
silence	16Hz / 80Hz	0.88	0.43	0.19	4.10	-0.27	1.00
silence	25Hz / 33Hz	0.86	0.43	0.18	4.04	-0.30	1.00
silence	25Hz / 40Hz	0.93	0.47	0.20	4.44	-0.14	1.00
silence	25Hz / 50Hz	1.09	0.54	0.23	5.09	0.17	1.00
silence	25Hz / 80Hz	0.90	0.44	0.19	4.20	-0.22	1.00
silence	33Hz / 40Hz	1.08	0.54	0.23	5.16	0.15	1.00
silence	33Hz / 50Hz	1.26	0.62	0.27	5.90	0.47	1.00
silence	33Hz / 80Hz	1.04	0.51	0.22	4.87	0.08	1.00
silence	40Hz / 50Hz	1.17	0.58	0.24	5.58	0.31	1.00
silence	40Hz / 80Hz	0.96	0.48	0.20	4.60	-0.07	1.00
silence	50Hz / 80Hz	0.82	0.41	0.18	3.86	-0.39	1.00
steady-state masker	4Hz / 8Hz	0.42	0.21	0.09	2.05	-1.71	1.00
steady-state masker	4Hz / 16Hz	0.48	0.24	0.10	2.29	-1.47	1.00
steady-state masker	4Hz / 25Hz	0.84	0.43	0.17	4.10	-0.34	1.00
steady-state masker	4Hz / 33Hz	0.83	0.42	0.17	3.97	-0.37	1.00
steady-state masker	4Hz / 40Hz	0.80	0.41	0.16	3.93	-0.43	1.00
steady-state masker	4Hz / 50Hz	1.14	0.57	0.24	5.44	0.26	1.00
steady-state masker	4Hz / 80Hz	0.94	0.47	0.20	4.51	-0.12	1.00
steady-state masker	8Hz / 16Hz	1.14	0.58	0.23	5.56	0.26	1.00
steady-state masker	8Hz / 25Hz	2.00	1.03	0.40	9.95	1.35	1.00
steady-state masker	8Hz / 33Hz	1.98	1.00	0.41	9.65	1.34	1.00
steady-state masker	8Hz / 40Hz	1.92	0.98	0.38	9.54	1.26	1.00
steady-state masker	8Hz / 50Hz	2.71	1.38	0.56	13.22	1.96	1.00
steady-state masker	8Hz / 80Hz	2.25	1.14	0.46	10.96	1.59	1.00
steady-state masker	16Hz / 25Hz	1.75	0.89	0.36	8.56	1.11	1.00
steady-state masker	16Hz / 33Hz	1.74	0.87	0.36	8.30	1.10	1.00
steady-state masker	16Hz / 40Hz	1.68	0.85	0.34	8.20	1.02	1.00
steady-state masker	16Hz / 50Hz	2.38	1.19	0.50	11.37	1.73	1.00
steady-state masker	16Hz / 80Hz	1.97	0.99	0.41	9.43	1.35	1.00
steady-state masker	25Hz / 33Hz	0.99	0.50	0.20	4.83	-0.02	1.00
steady-state masker	25Hz / 40Hz	0.96	0.49	0.19	4.77	-0.08	1.00
steady-state masker	25Hz / 50Hz	1.36	0.69	0.28	6.62	0.60	1.00
steady-state masker	25Hz / 80Hz	1.12	0.57	0.23	5.48	0.23	1.00
steady-state masker	33Hz / 40Hz	0.97	0.49	0.20	4.73	-0.06	1.00

Estimated Marginal Means							
modulation	**contrast**	**IRR**	**se**	**CI_{lo}**	**CI_{hi}**	**Z ratio**	***p***
steady-state masker	33Hz / 50Hz	1.37	0.69	0.29	6.55	0.63	1.00
steady-state masker	33Hz / 80Hz	1.14	0.57	0.24	5.43	0.25	1.00
steady-state masker	40Hz / 50Hz	1.42	0.72	0.29	6.91	0.68	1.00
steady-state masker	40Hz / 80Hz	1.17	0.60	0.24	5.72	0.31	1.00
steady-state masker	50Hz / 80Hz	0.83	0.42	0.17	3.96	-0.38	1.00
random masker	4Hz / 8Hz	2.04	0.88	0.53	7.82	1.66	1.00
random masker	4Hz / 16Hz	4.15	1.78	1.08	15.89	3.31	0.03
random masker	4Hz / 25Hz	6.38	2.74	1.67	24.46	4.31	<0.001
random masker	4Hz / 33Hz	8.26	3.55	2.16	31.65	4.91	<0.001
random masker	4Hz / 40Hz	10.06	4.33	2.63	38.56	5.37	<0.001
random masker	4Hz / 50Hz	12.49	5.37	3.26	47.85	5.87	<0.001
random masker	4Hz / 80Hz	20.15	8.67	5.26	77.22	6.98	<0.001
random masker	8Hz / 16Hz	2.03	0.87	0.53	7.79	1.65	1.00
random masker	8Hz / 25Hz	3.13	1.34	0.82	11.98	2.65	0.22
random masker	8Hz / 33Hz	4.05	1.74	1.06	15.51	3.25	0.03
random masker	8Hz / 40Hz	4.93	2.12	1.29	18.90	3.71	0.01
random masker	8Hz / 50Hz	6.12	2.63	1.60	23.45	4.21	<0.001
random masker	8Hz / 80Hz	9.87	4.25	2.58	37.84	5.32	<0.001
random masker	16Hz / 25Hz	1.54	0.66	0.40	5.89	1.00	1.00
random masker	16Hz / 33Hz	1.99	0.86	0.52	7.63	1.60	1.00
random masker	16Hz / 40Hz	2.43	1.04	0.63	9.29	2.06	1.00
random masker	16Hz / 50Hz	3.01	1.29	0.78	11.53	2.56	0.29
random masker	16Hz / 80Hz	4.86	2.09	1.27	18.61	3.67	0.01
random masker	25Hz / 33Hz	1.29	0.56	0.34	4.96	0.60	1.00
random masker	25Hz / 40Hz	1.58	0.68	0.41	6.04	1.06	1.00
random masker	25Hz / 50Hz	1.96	0.84	0.51	7.50	1.56	1.00
random masker	25Hz / 80Hz	3.16	1.36	0.82	12.10	2.67	0.21
random masker	33Hz / 40Hz	1.22	0.52	0.32	4.67	0.46	1.00
random masker	33Hz / 50Hz	1.51	0.65	0.39	5.79	0.96	1.00
random masker	33Hz / 80Hz	2.44	1.05	0.64	9.35	2.07	1.00
random masker	40Hz / 50Hz	1.24	0.53	0.32	4.76	0.50	1.00
random masker	40Hz / 80Hz	2.00	0.86	0.52	7.68	1.61	1.00
random masker	50Hz / 80Hz	1.61	0.69	0.42	6.19	1.11	1.00

Table S15.

Number of temporally overlapping calls across both experiments in each condition

	Silent	Full-band masker (Steady-state masker)	Half-band masker	Random masker
Experiment 1	17,645	5,627	19,346	-
Experiment 2	24,903	4,093	-	2,946

Table S16.

Estimated marginal means for overlapping calls. Estimated marginal mean differences in call incidence rates calculated on negative binomial models for overlapping calls for each modulation rate, separately.

			Estimated Marginal Means					
experiment	**modulation**	**contrast**	**IRR**	**se**	**CI_{lo}**	**CI_{hi}**	**Z ratio**	***p***
1	8Hz	silence / (full-band masker)	2.40	1.28	0.66	8.65	1.63	0.31
	8Hz	silence / (half-band masker)	1.40	0.74	0.39	4.94	0.63	1.00
	8Hz	(full-band masker) / (half-band masker)	0.58	0.32	0.16	2.17	-0.98	0.98
	15Hz	silence / (full-band masker)	4.73	2.19	1.56	14.36	3.35	<0.001
	15Hz	silence / (half-band masker)	0.37	0.17	0.12	1.11	-2.17	0.09
	15Hz	(full-band masker) / (half-band masker)	0.08	0.04	0.03	0.24	-5.44	<0.001
2	4Hz	silence / (steady-state masker)	4.58	3.04	0.94	22.45	2.29	0.07
	4Hz	silence / random masker	2.33	1.33	0.60	9.11	1.49	0.41
	4Hz	(steady-state masker) / random masker	0.51	0.34	0.10	2.58	-1.00	0.96
	8Hz	silence / (steady-state masker)	1.92	1.21	0.43	8.65	1.04	0.90
	8Hz	silence / random masker	5.36	3.16	1.31	21.96	2.85	0.01
	8Hz	(steady-state masker) / random masker	2.79	1.78	0.60	12.88	1.61	0.32
	16Hz	silence / (steady-state masker)	2.21	1.16	0.63	7.77	1.52	0.39
	16Hz	silence / random masker	6.56	3.32	1.95	22.02	3.72	0.00
	16Hz	(steady-state masker) / random masker	2.96	1.60	0.81	10.83	2.00	0.14
	25Hz	silence / (steady-state masker)	5.14	3.10	1.21	21.80	2.71	0.02
	25Hz	silence / random masker	9.89	5.80	2.43	40.26	3.91	0.00
	25Hz	(steady-state masker) / random masker	1.93	1.27	0.40	9.37	0.99	0.96
	33Hz	silence / (steady-state masker)	5.72	3.07	1.58	20.69	3.24	0.00
	33Hz	silence / random masker	14.70	7.47	4.35	49.66	5.28	0.00
	33Hz	(steady-state masker) / random masker	2.57	1.50	0.64	10.41	1.62	0.32
	40Hz	silence / (steady-state masker)	6.48	3.29	1.92	21.87	3.68	0.00
	40Hz	silence / random masker	18.39	9.20	5.55	60.93	5.82	0.00
	40Hz	(steady-state masker) / random masker	2.84	1.53	0.78	10.35	1.93	0.16
	50Hz	silence / (steady-state masker)	11.27	6.43	2.88	44.16	4.25	0.00
	50Hz	silence / random masker	27.70	15.51	7.26	105.80	5.93	0.00
	50Hz	(steady-state masker) / random masker	2.46	1.45	0.60	10.12	1.52	0.38
	80Hz	silence / (steady-state masker)	7.69	3.88	2.30	25.73	4.04	0.00
	80Hz	silence / random masker	26.34	13.56	7.68	90.35	6.35	0.00
	80Hz	(steady-state masker) / random masker	3.43	1.94	0.89	13.24	2.18	0.09

Table S17.

Call timings relative to acoustic landmarks

			Mean Call Onset Timings			
			time from peaks (ms)		**time to trough (ms)**	
experiment	**modulation**	**condition**	**median**	**iqr**	**median**	**iqr**
1	**All**	full-band masker	37.7	27.9	10.1	1
	8Hz	full-band masker	52.0	0.7	10.5	0.7
	15Hz	full-band masker	24.1	0.7	9.6	0.7
2	**All**	steady-state masker	9.3	28.7	8.4	5.8
	All	random masker	9.6	26.5	9.0	8.4
	4Hz	steady-state masker	83.7	2.8	41.3	2.8
	4Hz	random masker	83.7	2.0	41.3	2.0
	8Hz	steady-state masker	52.8	1.3	9.7	1.3
	8Hz	random masker	46.1	1.4	16.4	1.4
	16Hz	steady-state masker	25.8	0.9	5.0	0.9
	16Hz	random masker	22.2	1.3	8.6	1.3
	25Hz	steady-state masker	8.9	1.0	11.1	1.0
	25Hz	random masker	12.2	1.7	7.8	1.7
	33Hz	steady-state masker	10.5	2.9	4.3	2.9
	33Hz	random masker	7.4	1.2	7.4	1.2
	40Hz	steady-state masker	5.3	1.0	7.2	1.0
	40Hz	random masker	4.4	2.5	8.1	2.5
	50Hz	steady-state masker	0.5	1.4	9.5	1.4
	50Hz	random masker	-4.1	3.8	14.1	3.8
	80Hz	steady-state masker	4.2	1.8	2.5	1.8
	80Hz	random masker	0.5	5.8	6.2	5.8