Higher songs of city birds may not be an individual response to noise

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Supplementary Materials

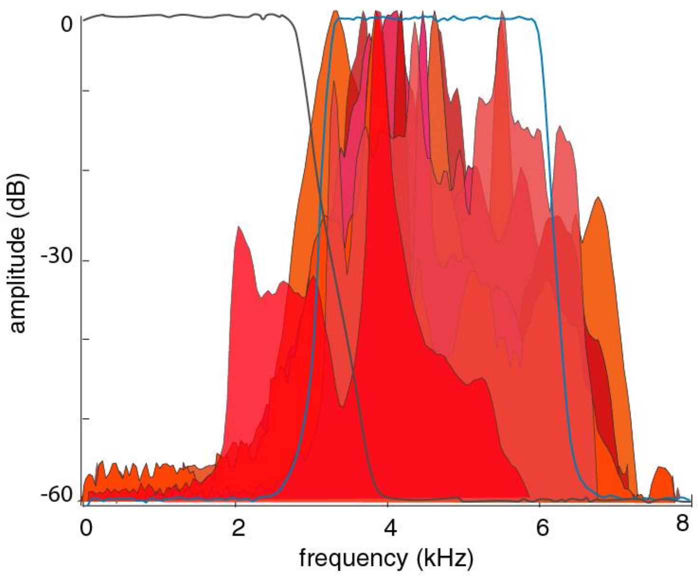

Figure S1. Spectra of the two noise playback treatments, CITY (grey line) and CONTROL (blue line), and of each tutor song (red-orange filled spectra, each song type is depicted in a different color). The CITY Noise treatment was designed to maximize any effects that low frequency traffic noise might have on song ontogeny and production since our treatment had higher sound energy throughout the low frequency range (0-3 kHz), than typical traffic noise, for which the intensity decreases from 1 to 4 kHz in a more gradual slope (with the relative sound level peak below 1 kHz, decreasing fairly linearly by -30 dB by 4 kHz [1]) The overall playback amplitude was designed to match that of the average noise levels in a busy urban environment. Additionally, our treatment is more extreme than most anthropogenic noise situations in that the playback level of the noise was constant, rather than fluctuating. These differences mean that our playback stimuli were more extreme than what might be encountered by birds in an urban environment and thus should have resulted in even stronger vocal adjustments than those which have been observed in wild populations. The CONTROL noise treatment was then designed to contain the same bandwidth of noise, but in a different frequency band. The CONTROL treatment was presented to control for any perturbing effects of noise itself that may have resulted in an increased pitch regardless of whether such a shift would provide a release from masking by low frequency traffic noise. The CONTROL noise also allowed us the opportunity to test whether high frequency noise exposure might result in a lowering of pitch, as has been suggested by other studies [2].

Table S1. Degree of masking at the minimum frequencies and peak frequencies of corresponding syllable in each tutor song in the two noise treatments. We calculated the playback levels for each of the 9 tutor songs at minimum frequency (f_{min}) and peak frequency of the syllable containing the minimum frequency (f_{peak}), and the relative playback level of the CITY (upper table) and CONTROL (lower table) noise treatments at those frequencies. Playback levels were measured from the spectrum level units calculated in Avisoft SASLab (Avisoft Bioacoustics, v.5.2.08), (5.5 Hz evaluation window bandwidth, 2.5 Hz frequency resolution, Hann window function) of each of 12 repetitions of the syllable, and then averaged. Noise levels were measured from recordings made in the room where the birds were housed, and calibrated against a tone of known amplitude. Playback levels were used to then calculate the signal-to-noise ratio for each syllable type f_{min} and f_{peak}, which we then compared to published critical masking ratios (CR) known for great tits [3]. The CR at any particular frequency represents the signal-to-noise ratio necessary for detection of a tone of that frequency in wide-band noise. In great tits, CR values are nearly constant across the audible spectrum, ranging from 23.8 – 25.9 dB in the frequency range of most great tit songs [3]. Syllables for which the SNR were positive are bold, and SNRs that exceed the CR are green.

CITY NOISE TREATMENT								
Syllable	f_{min}, Hz	dB at f_{min}	Noise dB at f_{min},	SNR f_{min},	f_{peak}, Hz	dB at f_{peak}	Noise dB at f_{peak}	SNR f_{peak}
A1	3716	23.6	31.6	-8.0	3984	51.1	22.8	28.3
B1	3661	39.4	29.6	9.8	3901	56.7	24.8	31.9
C1	3623	41.3	29.4	11.9	3807	58.0	27.4	30.6
D1	3258	28.0	46.9	-18.9	4040	60.1	21.5	38.6
E2	3396	32.5	40.3	-7.8	3447	57.7	39.4	18.3
F3	2981	31.3	51.9	-20.6	3434	61.5	20.6	40.9
G2	2706	32.1	54.1	-22.0	2752	38.5	51.6	-13.1
H1	3637	22.5	29.4	-6.9	4393	61.5	17.8	43.7
I2	3616	25.2	29.4	-4.2	3775	53.5	27.7	25.8

CONTROL NOISE TREATMENT								
Syllable	f_{min}, Hz	dB at f_{min}	Noise dB at f_{min},	SNR f_{min},	f_{peak}, Hz	dB at f_{peak}	Noise dB at f_{peak}	SNR f_{peak}
A1	3716	23.6	47.7	-24.1	3984	51.1	45.1	6
B1	3661	39.4	45.2	-5.8	3901	56.7	48.6	8.1
C1	3623	41.3	47.8	-6.5	3807	58.0	42.8	15.2
D1	3258	28.0	60.0	-32.0	4040	60.1	51.3	8.8
E2	3396	32.5	58.0	-25.5	3447	57.7	54.8	2.9
F3	2981	31.3	51.9	-20.6	3434	61.5	58.5	3
G2	2706	32.1	50.9	-18.8	2752	38.5	47.4	-8.9
H1	3637	22.5	46.7	-24.2	4393	61.5	50.1	11.4
I2	3616	25.2	55.8	-30.6	3775	53.5	49.1	4.4

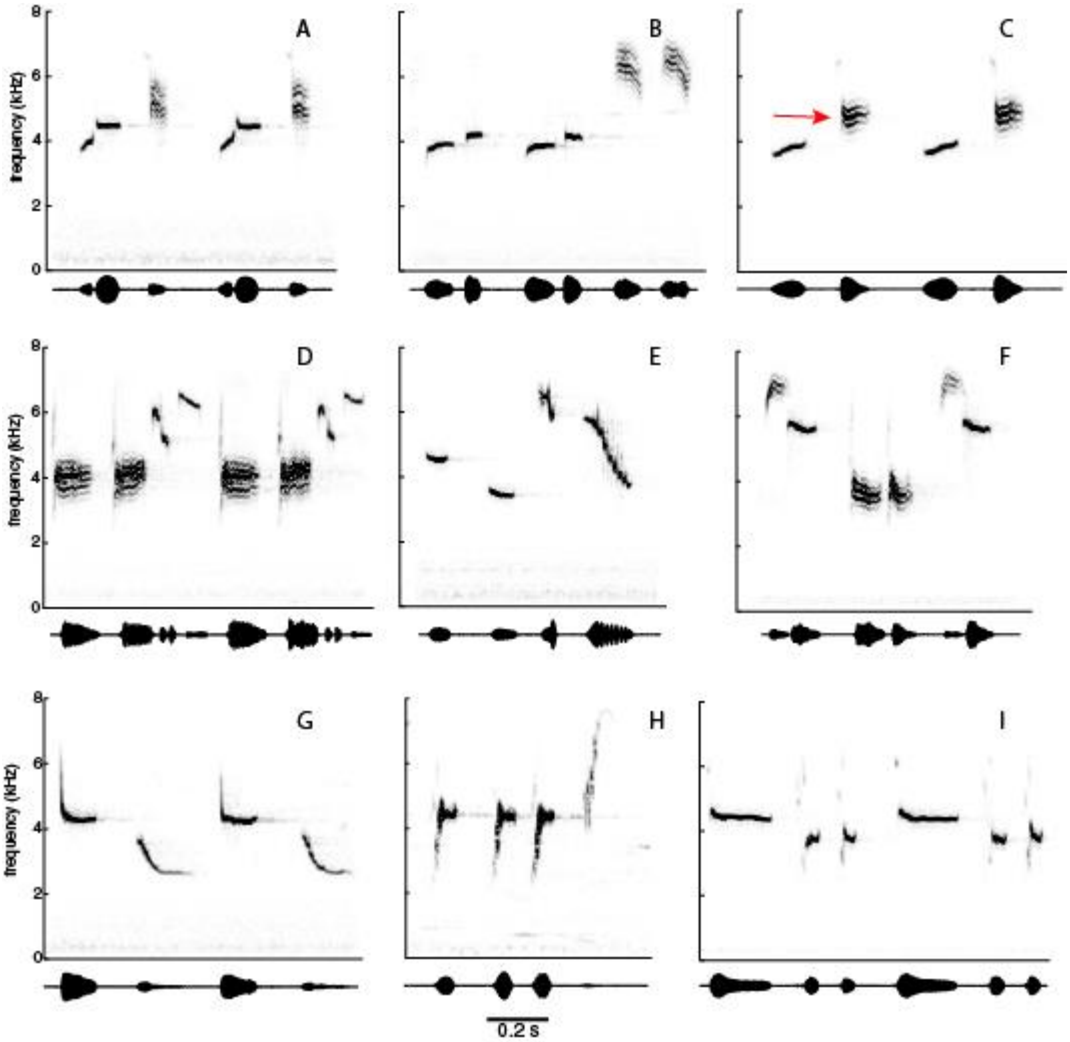

Figure S2. Spectrograms of each tutor song type that birds in the song ontogeny study were exposed to, with normalized waveforms beneath. Tutor songs were recorded from nine adult males in the quiet forested population of great tits from which the juveniles were collected. Each tutor song recording consisted of 11-14 different renditions of the song motif sung by the same bird. Songs were selected that included both frequency modulated, tonal syllables (e.g. song G), as well as songs that included syllables with rapid amplitude modulation (AM) and frequency modulation (songs A, B, C, D, F), which appears as sidebands in a narrowband spectrogram (e.g. arrow in C).

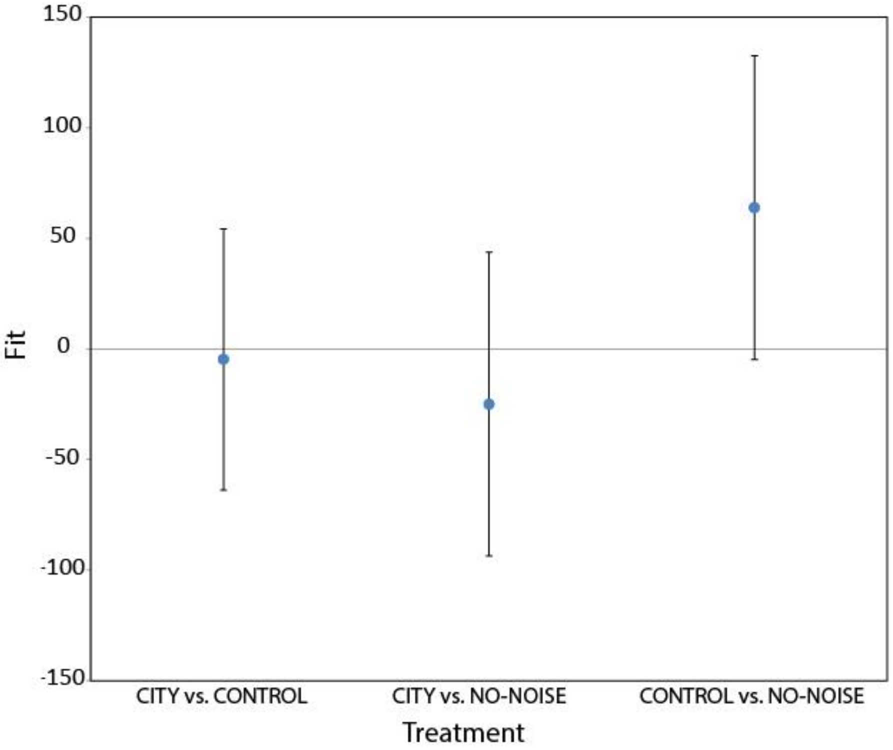

Figure S3. Effect sizes calculated for the model that tests for a difference in the minimum frequency within syllable type, and within individual in the three different noise treatments, in the Adult Plasticity study 1. The test is independent of noise presentation order. Error bars denote standard error.

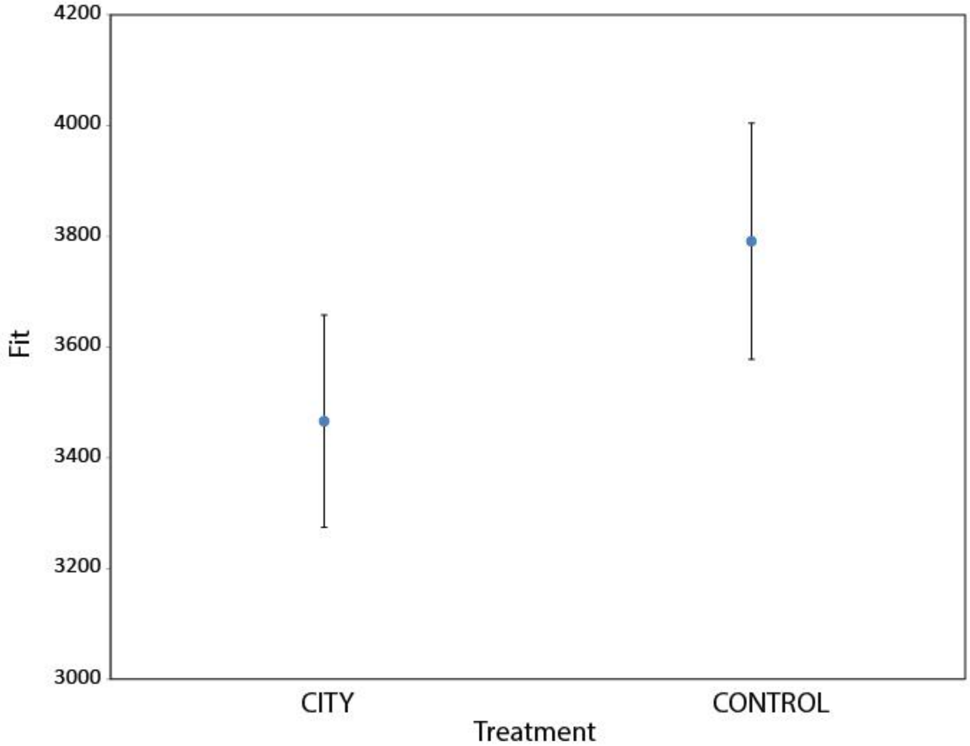

Figure S4. Effect sizes calculated for the model that tests for a difference in mean minimum frequency in 15 minutes of song, independent of syllable type, that individuals used in two different noise treatments (e.g. CITY-reared birds singing in CITY noise vs. CONTROL noise conditions, and vice versa) in the Adult Plasticity study 2.

Table S2. Minimum frequency of each tutor song, ordered from lowest to highest, and the number of birds in each treatment group that sang copies of that song type.

Tutor ID	Minimum frequency	CITY birds that copied	CONTROL birds that copied
G	2706	3	1
F	2981	1	2
D	3258	1	1
E	3396	1	2
I	3616	0	1
C	3623	3	1
H	3637	1	2
B	3661	1	2
A	3716	3	1

Supplementary References

1. Nemeth E, Brumm H. 2009 Blackbirds sing higher-pitched songs in cities: adaptation to habitat acoustics or side-effect of urbanization? *Anim. Behav.* **78**, 637-641. (doi:10.1016/j.anbehav.2009.06.016).
2. Halfwerk W, Slabbekoorn H. 2009 A behavioural mechanism explaining noise-dependent frequency use in urban birdsong. *Anim. Behav.* **78**, 1301-1307. (doi:10.1016/j.anbehav.2009.09.015).
3. Langemann U, Gauger B, Klump GM. 1998 Auditory sensitivity in the great tit: perception of signals in the presence and absence of noise. *Anim. Behav.* **56**, 763-769.