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Effect of an ultrasonic device on the behaviour and the stress hormone corticosterone in feral pigeons

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Abstract The worldwide presence of feral pigeons *Columba livia domestica* in urban habitats presents potential public health hazards from pathogens and parasites, and droppings can lead to damage to buildings. A variety of lethal and non-lethal chemical repellents, visual, sonic or mechanic measures are available to deter pigeons, but they are not always applicable or effective. Ultrasonic devices are one of the available possibilities with the advantage of being inaudible to humans and more or less harmless to animals. However, their utility is questionable, because the upper limit of frequencies heard by pigeons reported is well below that of ultrasound. We tested whether a commercially used ultrasound deterrent system has an effect on the behaviour of free-living, as well as caged feral pigeons and assessed whether ultrasound has a physiological effect, i.e. whether it can activate the hypothalamo-pituitary-adrenal-axis (HPA-axis) known to trigger flight behaviour. Our experimental tests did neither show any effect on the behaviour and the HPA-axis of the caged pigeons nor any deterring effect on the free-living pigeons. A habituation effect could not be detected. We therefore, conclude that ultrasound does not deter feral pigeons.

Keywords Deterrent · Bird control · Feral pigeons · Ultrasound · Corticosterone

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Introduction

The worldwide presence of feral pigeons (*Columba livia domestica*) in urban habitats (Giunchi et al. 2012) and their high degree of interaction with human life can cause severe problems. Pigeon droppings present potential public health hazards from pathogens and parasites (Haag-Wackernagel and Moch 2004; Haag-Wackernagel and Bircher 2010) and can lead to damage to buildings. Fungi growing in the excrements release acids which corrode historic buildings constructed of limestone or calciferous sandstone (e.g., Bassi and Chiantante 1976). Health risks and high costs due to infrastructural damage raise a strong interest to prevent feral pigeons from roosting on and in buildings. A variety of lethal and non-lethal chemical repellents, such as visual, sonic or mechanic measures are available, but they are not always applicable or effective (for review see Mason 1997; Clark 1998) and rarely tested rigorously. Ultrasonic devices are offered as a measure to repel birds. In contrast to chemical repellents they most probably do not harm feral pigeons, but their utility is questionable. The upper limit of frequencies heard by pigeons is at 11.5 kHz (Bezzel and Prinzinger 1990), well below ultrasound which is defined as frequencies > 20 kHz (Hamershock 1992). The question arises how birds could perceive ultrasound if not by ear.

Tests of ultrasonic devices to repel different bird species are scarce and results often available only in unpublished reports that are hard to access. Two reviews and most reports clearly state that ultrasonic device fails to deter birds from the treated area (Bomford 1990; Hamershock 1992; Haag-Wackernagel 2000), but they also criticize that most studies lack experimental controls (Bomford and O'Brien 1990; Hamershock 1992). Some studies exist claiming the efficiency of ultrasonic devices (Krzysik 1987 cited in Woronecki 1988) and manufacturers still promise that ultrasound can deter pigeons. They claim that the pigeons can 'feel' ultrasound as 'an unpleasant sensation when it touches their feathers and subsequently avoid places protected by acoustic pressure' (Desostar Sytems GmBH 2013) or that 'they do feel the pressure of the high-frequency sound waves'(Bird-X).

The objective of our study was to test the effect of ultrasound on the behaviour and on the physiology in free-living and caged feral pigeons. First, the repelling effect of ultrasound was tested in free-ranging feral pigeons. For that purpose, we chose a place where pigeons roosted regularly, a platform in front of a dovecote in the roof of a historical building. This platform was treated repeatedly with ultrasound. To count the number of pigeons present on the platform, a digital camera was installed. Our hypothesis was that with ultrasound treatment fewer pigeons should sit/rest on the platform than during periods without treatment.

Up to now all tests reported in the literature are based on observations of the birds' behaviour. Therefore, we performed another test which might reveal whether pigeons 'perceive' or 'feel' ultrasound physiologically. We recorded the behaviour and measured the glucocorticoid hormone corticosterone in the plasma of caged feral pigeons after ultrasound treatment and compared them with non-treated control birds. Corticosterone is the main glucocorticoid (GC) in birds which is released in response to unpredictable events. When a stimulus is perceived as a threat or a disturbance, the HPA-axis mediates the secretion of GC hormones from the adrenal cortex into the blood (Sapolsky et al. 2000). The release of corticosterone can evoke an adaptive behavioural response (Monclús et al. 2005; Schulkin et al. 2005) or alteration in life-history strategy (Wingfield et al. 1998; Boonstra 2005). This reaction is crucial for coping with environmental threats in the life of all vertebrates. Our hypothesis was that corticosterone should increase, if the feral pigeons perceive ultrasound as disturbing.

Materials and methods

Experiment with free-living feral pigeons

We wanted to test the effect of ultrasound treatment at a place where feral pigeons can be observed regularly. For that purpose we chose a platform in front of a dovecote situated in the roof of the town hall of Lucerne, Switzerland. The dovecote has two rooflights each with a small wooden platform (17 × 70 cm) in front, which are used by feral pigeons to sit and rest. The dovecote in the loft was 4 × 6 m. The rooflights had an entrance of 75 × 37 cm and were 2.5 m apart. We used the ultrasonic device Citygard CG2 (Desostar Schutzsysteme GmbH www.desostar.com). According to the manufacturer the device operates in a range of 22–26 kHz and a sound pressure of 95–103 db. Ultrasound is emitted every 2–3 for 5 s. The optimal radius of action is within 1–15 m, and pigeons sitting within this range should react and avoid the place. The ultrasonic device and a digital camera (type Mobotix MX-M1 M) for surveillance of the platform were installed at the inner end of the eastern entrance, both pointing outwards at the platform (a distance of 1.6 m to the ledge of the platform; Fig. 1). The ultrasonic device was mounted by the manufacturer R. Weibel. The second platform was not directly attained by ultrasound and shielded by the walls between the two entrances. The metal plate at the backside of the ultrasonic loudspeaker ensured that the pigeons in the dovecote were in the shadow of the ultrasound. The western rooflight was left untouched to ensure that, in case of the expected deterrent effect of the ultrasound treatment, the pigeons could still enter the dovecote.

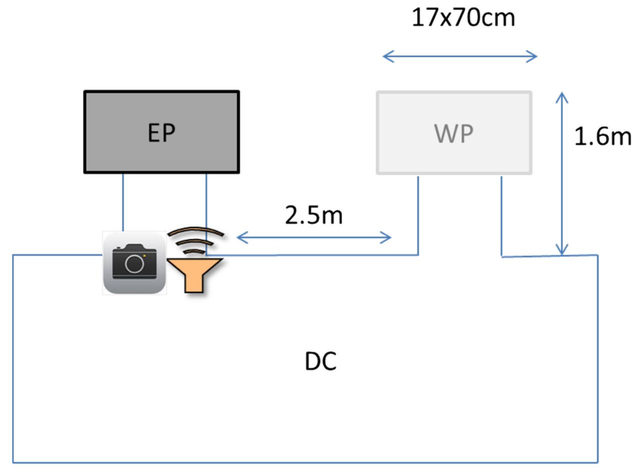

Fig. 1 Draft (not true to scale) of the Eastern (EP) and Western platform (WP), situated in front of the Western and Eastern entrance tunnel. At the Eastern entrance into the dovecote (DC) a digital camera and a Citygard ultrasonic device Type CG2 were installed pointing outwards through the tunnel at the Eastern platform (EP). The Western entrance was left untouched

From 29 March 2012 onwards the ultrasonic device was switched on (broadcasting day and night) and off in 1 week intervals until 21 May (with a technical break from 13 April to 2 May). Then, it was running for 8 weeks continuously to test for a possible adaptation effect. The ultrasonic device was finally switched off on 16 July. From 15 March to 31 July 2012 a photo was taken every 5 min during daylight (sunrise to sunset). The photos were sent via UMTS-router and mobile phone network directly to the FTP-server of our institute. From these stills, the number of feral pigeons present (sitting or resting, birds in flight were not included) on the platform was counted. The ultrasonic device and the camera were regularly checked to ensure that they were operating correctly.

Statistical analysis of counts of free-living feral pigeons

The number of the feral pigeons present on the platform was counted on a total of 16,474 stills. The details of stills not considered for analysis are given in Table 1. We used a first-order autoregressive Poisson regression model to analyse the number of pigeons on the stills. A model with an autoregressive structure was necessary, as stills were taken every 5 min and thus the number of pigeons on one still is likely to depend on the number of pigeons 5 min ago. Specifically, let the number of pigeons counted on still i at day d be $y_{i,t}$. Note that i indexes the stills within a day, where $i = 1$ for the first still taken at a day. Moreover, let $x_{i,\mathrm{d}}$ be an indicator variable denoting whether on still i at day d the ultrasonic device was switched off ($x_{i,\mathrm{d}} = 1$) or on ($x_{i,\mathrm{d}} = 2$) and z be a vector with the Julian date. The fitted model had the following structure:

$$y_{i,d} \sim \mathrm{Poisson}\left(\lambda_{i,d}\right)$$
$$\log\left(\lambda_{i,d}\right) = \alpha_{x_{i,d}} + \gamma z_d + w_{i,d}$$
$$w_{i,d} = \beta_{x_{i,d}} w_{i-1,d} + \varepsilon_{i,d}$$
$$\varepsilon_{i,d} \sim \mathrm{Normal}\left(0, \sigma^2_{x_{i,d}}\right)$$

where α_x are the mean numbers of pigeons for each treatment, γ is the date effect, $\beta_x$are the autoregressive parameters for each treatment and σ^2_x are normally distributed residual variances for each treatment. The model is coded in such a way that the first count of day d is independent from the last count of day $d - 1$.

Because this model is difficult to fit with maximum likelihood, we fitted this model in the Bayesian framework (Kéry 2010) using JAGS (Plummer 2003) that was run from R Core Team (2012) via package R2jags. We defined vague priors for all parameters ($\alpha_x \sim N(0, 1000)$,$\gamma \sim N(0, 1000)$, $\beta_x \sim U(-10, 10)$,$1/\sigma^2_x \sim \Gamma(0.001, 0.001)$). The posterior distribution was explored by Markov Chain Monte Carlos simulations. We created 25,000 samples, but only kept the last 5,000 to avoid any effects of initial conditions. The convergence of the chains was evaluated with the Brooks–Rubin–Gelman criterion and was satisfactory ($\hat{R} < 1.02$).

Experiment with caged feral pigeons

20 free-living feral pigeons were caught at 7 February 2012 in Basel (Switzerland) and transported to the Swiss Ornithological Institute, Sempach, Switzerland. The pigeons were kept in groups of five individuals in four aviaries (2 m × 0.8 m × 0.8 m) with water and food ad libitum (standard mixture for pigeons, Rust-Rain, Switzerland) located in four different rooms without any visual or acoustic contact between the rooms. In each room an ultrasonic device (Citygard Type CG2; Desostar Schutzsysteme GmbH, Switzerland) was installed by the manufacturer (R. Weibel). The swivelling devices were placed at a distance of 2 m by the manufacturer so that the entire aviary was sonicated. The birds were acclimatized for 14 days to the aviaries before the experiments started.

Table 1 Counted and analysed stills with and without treatment

Stills	Ultrasound treatment	No ultrasound treatment	Total
Total	9,530	7,677	17,207
No stills (camera failure)	241	223	464
Stills counted	9,289	7,454	16,743
Including other species	161	22	183
Hidden sight	54	32	86
Stills for analysis	9,074	7,400	16,474
Without pigeons	5,163	4,270	9,433
With pigeons	3,911	3,130	7,041

Experimental procedure

The general experimental design was to treat half of the pigeons with ultrasound and to investigate whether the treatment affected the pigeon's behaviour and/or glucocorticoid concentration.

After acclimatization to the aviaries and 5 days before the experiments started, a first blood sample was taken as baseline value for all individuals. Thereafter, aviaries 1 and 2 (ten pigeons) were treated with ultrasound for 10 min on three different occasions with at least 4 days in-between, while aviaries 3 and 4 (ten pigeons) served as controls (Table 2). For the last (fourth) ultrasound treatment, the treatment was exchanged, i.e. the experimental group 2 was treated with ultrasound, while the experimental group 1 served as control. This procedure allowed us to control for a possible effect of habituation or sensitization to the repeated handling and blood sampling. After each experiment the devices were tested for their function with a bat detector. The devices always emitted ultrasound in the range of 22–26 kHz.

At each of the four experimental ultrasound occasions, we filmed the pigeons in all 4 aviaries during the 10 min before and during the 10 min of the experiment, took blood samples immediately after the treatment and weighed the birds. In order to obtain baseline levels of corticosterone (Romero and Reed 2005) a group of four people sampled the five birds of an aviary within less than 3 min from entering the room until end of blood sampling. The wing vein was punctured with a needle and the blood drops collected with heparinized capillary tubes (100 µl). Blood was centrifuged within an hour after sampling, the plasma transferred into tubes and frozen at −20 °C until analysis.

Table 2 Experimental design with caged pigeons

Days in aviary	Day of treatment	Experimental group 1 Aviary 1 and 2	Experimental group 2 Aviary 3 and 4
15	1	Sampling 1	Sampling 1
20	2	10 min ultrasound treatment	Sampling 2
		Sampling 2	
24	3	10 min. ultrasound treatment	Sampling 3
		Sampling 3	
28	4	10 min ultrasound treatment	Sampling 4
		Sampling 4	
34	5	Sampling 5	10 min ultrasound treatment
			Sampling 5

The pigeons were put into the aviaries at day 1 (7 Feb. 2013, day of capture). Blood sampling 1 served to obtain baseline corticosterone before ultrasound treatment started

Corticosterone assay

Plasma corticosterone concentration was measured using an enzyme-immunoassay (EIA, Munro and Stabenfeldt 1984; Munro and Lasley 1988) in the laboratory of the Swiss Ornithological Institute in Sempach. Corticosterone in 20 µl plasma and 180 µl water (H_2O_{bidest}) was extracted with 4 ml dichlormethane, redissolved in phosphate buffer and measured in triplicates in the enzyme-immunoassay. The dilution of the corticosterone antibody (Chemicon; cross reactivity: 11-dehydrocorticosterone 0.35 %, progesterone 0.004 %, 18-OH-DOC 0.01 %, cortisol 0.12 %, 18-OH-B 0.02 %, and aldosterone 0.06 %) was 1:8,000. HRP (horseradish peroxidase, 1:400,000) linked to corticosterone served as enzyme label and 2,2′Azino-bis(3-ethylbenzo-thiazoline-6-sulfonic acid)diammonium salt (ABTS) as substrate. The concentration of corticosterone in plasma samples was calculated by using the standard curve run in duplicate on each plate. Plasma pool from chicken was included as internal control on each plate. Altogether ten plates were run on two different days. The detection limit of the assay was 0.1 ng ml^{-1}. If the concentration was below detection threshold, the value of the lowest detectable concentration (0.1 ng ml^{-1}) was assigned (20 samples out of 100). Intra-assay variation was 6.8 %, inter-assay variation 22.8 %.

Video recordings

All four aviaries were filmed before and during the 10 min of ultrasonic treatment of the two experimental groups. The videos were analysed as following: the film was stopped every minute and the behaviour of the five pigeons noted. Because the pigeons could not be distinguished individually, behaviour was analysed per aviary. Activities such as walking, sitting, self-preening, preening others, bathing, feeding, wing flapping, courting, and threatening were recorded. The behaviours were categorized and divided by the number of the observed animals, because not all five individuals could always be observed. The categories were (1) proportion 'sitting', (2) proportion 'active' (all activities except interactions with each other), (3) proportion 'interactions' (preening each other, courting, threatening) and (4) proportion 'all activities' (sum of categories 2 and 3).

Statistical analysis of corticosterone and behaviour of caged feral pigeons

Corticosterone concentrations were analysed in a linear mixed model with the dependent variable corticosterone, the fixed effects time span (time in seconds from entering the room until the end of blood sampling), treatment (ultrasonic treatment, no treatment), sampling occasion (number of sampling occasion), experimental group (1, 2), body mass (in g) and the random effect individual identity. However, pigeons that were kept in the same aviaries shared a common environment and were, therefore, not completely independent. To account for this nonindependence we nested the individual random effects within aviary.

Experimental group 1 comprised aviaries 1 and 2 which were treated three times (Table 2). Experimental group 2 comprised aviaries 3 and 4 which were treated only once (Table 2). Post-hoc tests were used to check whether there was any change in corticosterone between subsequent blood sampling occasions with/without treatment (i.e. blood sampling occasion 1–2 and 4–5 in experimental group 1, and 4–5 in experimental group 2).

Behaviour was analysed in a linear mixed model. The dependent variable was one of the four behavioural categories, fixed effects were video sequence (before, during experiment), treatment (ultrasonic treatment, no treatment) and number of experiment (1–4), random effect was aviary (1–4).

The statistical analyses for the caged pigeons were performed with SPSS release 18.

Results

Effect of ultrasonic device on the presence of free-ranging pigeons

For the analysis of the photos taken of the observed platform, stills showing other species than pigeons and stills

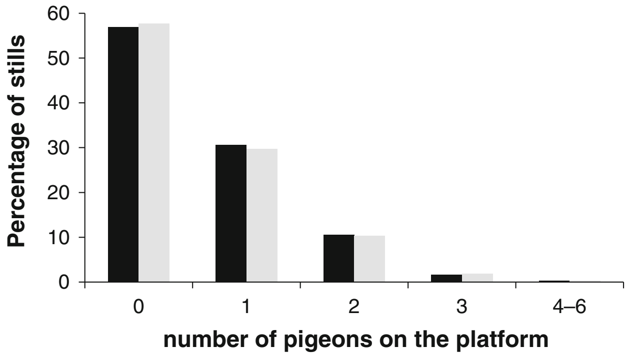

Fig. 2 Percentage of stills with no, 1, 2, 3 or 4–6 pigeons on the observed platform during ultrasound treatment (black columns, $N = 9{,}704$) and without ultrasound treatment (grey columns, $N = 7{,}400$)

with sight obstructed by a single pigeon sitting or moving very close to the camera were excluded (Table 1). Of the remaining 16,474 stills 9,074 stills were taken during ultrasonic treatment and 7,400 stills during phases without ultrasonic treatment.

The autoregressive parameters (β_x) were close to 1 indicating strong autocorrelation and similar for the two treatments (without ultrasonic treatment (mean 95 % credible interval): 0.974 (0.964–0.977); with ultrasonic treatment: 0.972 (0.963–0.975)). The date effect was not different to zero [mean (95 % credible interval): −0.023 (−0.111–0.065)], thus the mean number of pigeons did not change seasonally, and hence there was no evidence for a habituation effect. The model predicted that there were on average 0.44 pigeons per still (95 % credible interval 0.39–0.50) on the platform during ultrasonic treatment and 0.41 (0.36–0.47) without treatment. These numbers were very similar and the probability that ultrasonic treatment reduced the number of pigeons was only 0.20.

To illustrate that the ultrasonic treatment had no effect on the number of pigeons present on the platform, we also show the proportion of stills with 0, 1, 2, 3 and 4–6 present pigeons (Fig. 2). There were no stills showing more than six pigeons on the platform. Stills without pigeons present on the platform predominated (57 % of stills taken with treatment, 58 % without treatment). About one third (31 % of stills taken with treatment vs. 30 % of stills without treatment) of the stills showed a single pigeon, followed by stills with two pigeons (11 vs. 10 %), while stills showing three pigeons (2 % in both treatments) or 4–6 pigeons (0.3 % in both treatments) were rare.

Corticosterone and behaviour in laboratory experiments

The effect of the ultrasonic treatment on baseline plasma corticosterone concentration of pigeons was not significant (Table 3). Time span for blood sampling showed a weak

Table 3 Linear mixed model with corticosterone as dependent variable and the following fixed effects: time span between first disturbance and blood sampling, ultrasound treatment during 10 min before blood sampling, sampling occasion 1–5 (see Table 2), body mass and experimental group (see Table 2)

	D.F.	*F* value	*P* value
Constant	1	1.908	0.182
Time span	1	3.866	0.052
Ultrasound treatment	1	2.209	0.141
Sampling occasion	4	0.173	0.952
Body mass	1	0.094	0.762
Group	1	2.394	0.134

Random effects were individual identity nested in aviary

effect on corticosterone concentrations (Table 3), whereas sampling occasion, body mass and group had no significant effects. Post-hoc tests between the consecutive sampling occasions with changing treatment (sampling occasions 1 and 2 for experimental group 1 and sampling occasions 4 and 5 for both groups, Fig. 3), were not significant (experimental group 1, sampling occasion 1–2: F value = 0.006, $P = 0.940$; sampling occasion 4–5: F value = 0.036, $P = 0.853$; experimental group 2, sampling occasion 4–5: F value = 1.655, $P = 0.216$).

There was no significant effect of ultrasonic treatment on any of the four behaviour categories (Table 4).

Discussion

This study aimed at investigating the effect of ultrasound on pigeons from both the behavioural and physiological perspective. We also ensured to have an adequate control group, a shortcoming of many previous publications (reviewed in Bomford and O'Brien 1990), and to test for a possible habituation effect.

The results clearly showed that ultrasound treatment did not affect the behaviour of free-living and captive pigeons. Ultrasound treatment also had no effect on the HPA-axis of the caged birds. During the 16.5 weeks in free-living and the 5 weeks in caged pigeons, no change in behaviour over time could be observed.

Effect of ultrasound treatment in free-ranging feral pigeons

The feral pigeons used the photographically observed platform of the entrance to the dovecote regularly and independently of whether the ultrasonic device was running or not. Ultrasound treatment had no effect on the number of feral pigeons sitting on the platform, thus had no deterrent effect.

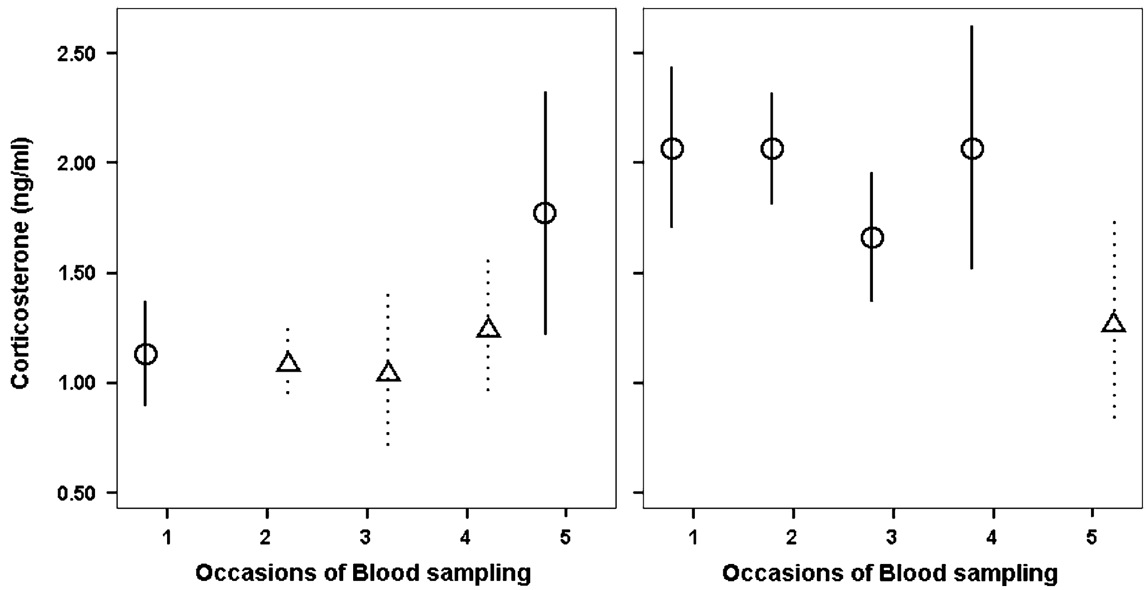

Fig. 3 Mean corticosterone concentration ± SD per sampling occasion and experimental group: *left side* experimental group 1, *right side* experimental group 2, *circles* no ultrasound treatment, *triangle* ultrasound treatment. $N = 100$ (ten per sampling occasion and group)

Table 4 Effect of ultrasound treatment on the behaviour of captive feral pigeons

	F value	*P* value
Active	0.015	0.903
Interaction	0.132	0.716
Sum of active and interactions	0.484	0.487
Sitting	1.047	0.307

The table summarizes four linear mixed models with one of the four behavioural categories as dependent variable, video sequence (before, during experiment), treatment (ultrasound treatment, no treatment) and sampling occasion (2–5) as fixed effects and aviary (1–4) as random effect. None of the effects was significant. Shown are the results for ultrasound treatment only

This result is not surprising, because pigeons, as the most other bird species, cannot hear ultrasound. The upper limit of hearing in pigeons was found to be 11.5–12.0 kHz, depending on the literature source (Bezzel and Prinzinger 1990; summarized in Hamershock 1992). There are some bird species which are able to hear frequencies above 20 kHz, such as the European Robin *Erithacus rubecula* (21 kHz), the chaffinch *Fringilla coelebs* (29 kHz) or the bullfinch P*yrrhula pyrrhula* (21–25 kHz). Since these species have not been tested so far, it remains unknown whether they could be deterred by ultrasound. The studies known to us tested the effect of ultrasound on feral pigeons (Woronecki 1988; Haag-Wackernagel 2010), European starlings *Sturnus vulgaris* (Beuter and Weiss 1986, Bomford 1990), house finches *Carpodacus mexicanus*, dark-eyed juncos *Junco hyemalis*, white breasted nuthatches *Sitta carolinensis*, tufted titmice *Baeolophus bicolor*, blue jays *Cyanocitta cristata* (Griffith 1987), cliff swallows *Petrochelidon pyrrhonota* (Kerns 1985 in Hamershock 1992) and gulls *Laridae* (Beuter and Weiss 1986) and none of them found any deterring effect. Hamershock (1992) lists two studies examining six different species (cormorant *Phalacrocorax carbo*, a gull species, feral pigeon, house sparrow *Passer domesticus*, tree sparrow *Passer montanus*, greenfinch *Carduelis chloris*) which found an effect, but the frequencies used (16.8 and 20 kHz, respectively) were below ultrasound. The effect can, therefore, not be explained by ultrasound. The upper limit of hearing for these species is not known except for the feral pigeon. It might be possible that greenfinches can hear ultrasound because the closely related chaffinches and bullfinches do so. But also for house finches no deterring effect of ultrasound could be detected. This is not surprising considering the fact that even in animal species hearing ultrasound, such as rats, the aversive effect is not straightforward (Shumake et al. 1982). The repelling effect on rats depends on frequency (20, 20–30, 40 kHz), food availability (abundant, restricted) and familiarity with the place. Because there was no effect of ultrasound at the observed platform, we have no indication that pigeons perceive ultrasound by any other sense.

One might argue that feral pigeons close to the dovecote have a strong urge to enter and that, therefore, no disturbing effect of ultrasound was found. A study testing a variety of pigeon repelling systems showed that the motivation to overcome a repelling system to get to the nest was very high for breeding birds. Breeding pigeons tolerated pain to return to their nests. In contrast, the pigeons using platforms for stopovers near the nests were easily repelled by different systems, but not by ultrasound (Haag-Wackernagel 2010). The platform in our study was used for stopovers and situated several metres away from the nesting place, outside of the building. If the pigeons would have been disturbed by the ultrasound, they could have avoided the platform and used the second entrance nearby which also had a platform but was not treated with ultrasound. Since there was no effect of ultrasound on the presence of the pigeons on the platform, it was not surprising to find no change over the 16.5 weeks of the experiment.

In summary, our results agree with other studies describing ultrasound treatment as an ineffective measure to deter birds from fields or buildings (Beuter and Weiss 1986; Griffiths 1987; Woronecki 1988; Bomford 1990; Hamershock 1992; Haag-Wackernagel 2010).

Effect of ultrasound treatment on caged feral pigeons

During the entire period of acclimatization to the aviaries (2 weeks) and the experiments in captivity (5 weeks) the pigeons remained healthy (normal feeding and droppings, no mortalities) and their body mass was stable. The baseline corticosterone concentration in the plasma of the non-treated feral pigeons of both groups corresponded to values in the literature (e.g. Haase et al. 1986; Rees and Harvey 1987; Viswanathan et al. 1987). We, therefore, concluded that after acclimatisation the pigeons were not physiologically stressed by the new surroundings and captivity.

Ultrasound treatment had no effect on baseline concentration and on the behaviour of the caged pigeons. This result corresponds to our expectations, since pigeons cannot hear ultrasound (e.g. Hamershock 1992) and it is not known whether ultrasound frequencies can be perceived by any other sense. If ultrasound would have been perceived as stressful, the HPA-axis would have been activated and plasma corticosterone should have increased. Stress-induced corticosterone levels are implicated in mediating physiological and behavioural changes which help to cope with such an event and trigger for instance a flight reaction (Cockrem and Silverin 2002). However, the corticosterone levels of the pigeons treated with ultrasound remained unchanged.

In summary, our study could not detect any aversive effect of ultrasound on the behaviour or physiology of pigeons. If ultrasonic devices are used to deter pigeons despite their questionable effect, it would be important to investigate their effect on other bird species which should not be deterred, such as jackdaw *Corvus monedula* and Alpine Swift *Apus melba*, both dependent on breeding in buildings and red-listed in Switzerland, or on bats which are well known to hear ultrasound up to a frequency of 140 kHz (Heldmaier and Neuweiler 2003).

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References

Bassi M, Chiantante D (1976) The role of pigeon excrement in stone biodeterioration. Intern Biodeterior Bull 12:3
Beuter KJ, Weiss R (1986) Properties of the auditory systems in birds and the effectiveness of acoustic scaring signals. Meet Bird Strike Comm Eur 8:60–73
Bezzel E, Prinzinger R (1990) Ornithologie. Ulmer, Stuttgart
Bird-X http://www.bird-x.com
Bomford M (1990) Ineffectiveness of a sonic device for deterring starlings. Wildl Soc Bull 18:151–156
Bomford M, O'Brien PH (1990) Sonic deterrents in animal damage control: a review of device tests and effectiveness. Wildl Soc Bull 18:411–422
Boonstra R (2005) Equipped for life: the adaptive role of the stress axis in male mammals. J Mamm 86:236–247
Clark L (1998) Review of bird repellents. Proceedings of the 18th Vertebrate Pest Conference 329–337, http://www.digitalcommons.unl.edu/vpc18/6
Cockrem JF, Silverin B (2002) Sight of a predator can stimulate a corticosterone response in the Great Tit (*Parus major*). Gen Comp Endocrinol 125:248–255
Desostar GmbH (2013) www.desostar.com
Giunchi D, Albores-Barajas YV, Baldaccini NE, Vanni L, Soldatini C (2012) Feral pigeons: problems, dynamics and control methods. In: Soloneski S (ed), Integrated pest management and pest control—current and future tactics, InTech, Europe, pp 215–240
Griffith RE (1987) Efficacy testing of an ultrasonic bird repeller. In: Shumake SS, Bullard RW (eds). Vertebrate pest control and management materials, 5th vol. ASTM Spec Tech Publ 974, Philadelphia, pp 56–63
Haag-Wackernagel D (2000) Behavioural responses of the feral pigeon (*Columbidae*) to deterring systems. Folia Zool 49:101–114
Haag-Wackernagel D (2010) Taubenabwehr, Tierschutz – Verhalten – Wirkung. Universität Basel, Verlag Medizinische Biologie
Haag-Wackernagel D, Bircher AJ (2010) Ectoparasites from feral pigeons affecting humans. Dermatol 220:82–92
Haag-Wackernagel D, Moch H (2004) Health hazards posed by feral pigeons. J Infect 48:307–313
Haase E, Rees A, Harvey S (1986) Flight stimulates adrenocortical activity in pigeons (*Columba livia*). Gen Comp Endocrinol 61:424–427
Hamershock DM (1992) Ultrasonics as a method of bird control. Report. Flight Dynamics Directorate, Wright Laboratory, Wright-Patterson Air Force Base
Heldmaier G, Neuweiler G (2003) Vergleichende tierphysiologie. Springer, Berlin Heidelberg New York

Kéry M (2010) Introduction to WinBUGS for ecologists. Academic Press, Burlington

Mason JR (1997) Overview of controls: why they work and how they function. Repellents. In: Nolte DL, Wagner KK (eds) Wildlife damage management for natural resource managers. Western Forestry and Conservation Association, Portland, pp 11–16

Monclús R, Rödel HG, Von Holst D, De Miguel J (2005) Behavioural and physiological responses of naive European rabbits to predator odour. Anim Behav 70:753–761

Munro CJ, Lasley BL (1988) Non-radiometric methods for immunoassay of steroid hormones. In: Albertson BD, Haseltine FP (eds) Non-radiometric assays: technology and application in polypeptide and steroid hormone detection. Liss, New York, pp 289–329

Munro CJ, Stabenfeldt G (1984) Development of a microtitre plate enzyme immunoassay for the determination of progesterone. J Endocrinol 101:41–49

Plummer M (2003) JAGS: A Program for analysis of Bayesian graphical models using gibbs sampling. Proceedings of the 3rd Internnational Workshop on Distributed Statistical Computing (DSC 2003)

R Core Team (2012): R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org

Rees A, Harvey S (1987) Adrenocortical responses of pigeons (*Columba livia*) to treadwheel exercise. Gen Comp Endocrinol 65:117–120

Romero LM, Reed JM (2005) Collecting baseline corticosterone samples in the field: Is under 3 min good enough? Comp Biochem Physiol 140:73–79

Sapolsky RM, Romero LM, Munck AU (2000) How do glucocorticoids influence stress responses? Integrating permissive, suppressive, stimulatory and preparative actions. Endocr Rev 21:55–89

Schulkin J, Morgan MA, Rosen JB (2005) A neuroendocrine mechanism for sustaining fear. Trends Neurosci 28:629–635

Shumake SA, Kolz AL, Crane KA, Johnson RE (1982) Variables affecting ultrasound repellency in Philippine rats. J Wildl Manage 46:148–155

Viswanathan M, John TM, George JC, Etches RJ (1987) Flight effects on plasma glucose, lactate, catecholamines and corticosterone in homing pigeons. Horm Metabol Res 19:400–402

Wingfield JC, Maney DL, Breuner C, Jacobs JD, Lynn S, Ramenofsky M, Richardson RD (1998) Ecological bases of hormone-behavior interactions: the "emergency life history stage". Integr Comp Biol 38:191–206

Woronecki PP (1988) Effect of ultrasonic, visual, and sonic devices on pigeon numbers in a vacant building. In: Crabb AC, Marsh RE (eds) Proceedings of the Vertebrate Pest Conference, vol 13, University of California, Davis, pp 266–272