

Effects of severe anthropogenic disturbance on the heart rate and body temperature in free-living greylag geese (*Anser anser*)

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Abstract

Anthropogenic disturbances are a major concern for the welfare and conservation of wildlife. We recorded heart rate and body temperature of 20 free-living greylag geese in response to a major regularly re-occurring anthropogenic disturbance, New Year's Eve fireworks. Heart rate and body temperature were significantly higher in the first and second hour of the new year, compared to the same hour on the 31st of December, the average during December and the average during January. Heart rate and body temperature was not significantly affected by sex or age. From 0200-0300 onwards, 1st of January heart rates did not significantly differ from the other periods, however body temperatures were significantly increased until 0300-0400. From 0400-0500, heart rate was not affected by any of the investigated factors, whereas body temperature was significantly increased on the 1st of January compared 31st of December and the December average but not compared to the January average. To conclude, our results show that New Year's Eve fireworks cause a substantial physiological response, indicative of a stress response in greylag geese, which is costly in terms of energy expenditure.

Key words: animal welfare, anthropogenic disturbance, emotional arousal, greylag geese, heart rate, wildlife conservation.

Introduction

Anthropogenic disturbances, such as noise or light pollution, human presence or motor vehicles, are increasingly becoming a major concern for the welfare and conservation of wildlife (Marion et al. 2020, Corradini et al. 2021, Jerem and Mathews 2021).

Disturbances can result in short-term to long-term changes in the behaviour and physiology of individuals (Bejder et al. 2006, New et al. 2014). Globally, species increase their nocturnality in response to human disturbance (Gaynor et al. 2018). Physiological activation, for example, via the sympathetic branch of the automatic nervous system, causing an increase in heart rate and body temperature (Bartholomew et al. 1964, Cabanac and Guillemette 2001, Carere and Vanoers 2004), which helps organisms to cope with environmental challenges (*e.g.*, temperature stress (Bartholomew et al. 1964, Al-Haidary 2004, Alam et al. 2011); hunger (Mesteig et al. 2000, De Jong et al. 2002, Savory and Kostal 2006); agonistic encounters (Wascher 2021); predator exposure (Oulton et al. 2013)) and maintain homeostasis (von Holst 1998). However, this comes at the cost of increased energy expenditure (Weimerskirch et al. 2002, Wascher et al. 2018, Halsey et al. 2019). This is costly, as animals are limited in their actions by their energy throughput, the amount of energy they consume and use (McNab 2022). Increases in heart rate and body temperature can also be an indication of emotional arousal and poor welfare (von Borell et al. 2007, Wascher 2021). Chronic anthropogenic noise has been shown to decrease baseline corticosterone birds and, conversely, increasing acute stressor-induced corticosterone (Kleist et al. 2018). Bird nestlings in noisy areas had shorter telomere lengths (Grunst et al. 2021). Via such mechanisms, anthropogenic disturbances can negatively affect individuals' fitness (Daan et al. 1996, Fowler 1999) for example decrease hatching success or body condition (Kleist et al. 2018). Combined effects of anthropogenic noise and artificial light

affect activity patterns in birds (Dominoni et al. 2020), community structure (Willems et al. 2022) and chick development (Ferraro et al. 2020).

Biologging technologies to measure heart rate can be used to assess effects of anthropogenic disturbance on wildlife. This is especially relevant, as studies have shown that individuals can show pronounced activation of the physiological stress response in the absence of obvious behavioural changes. For example, American black bears, *Ursus americanus*, and bighorn sheep, *Ovis canadensis*, showed no behavioural responses but significantly increased heart rate in response to anthropogenic disturbances, such as drone overflights and vehicle traffic (MacArthur et al. 1979, Ditmer et al. 2015).

Anthropogenic noise causes elevated heart rates in farm animals (Talling et al. 1996), fish (Graham and Cooke 2008), and marine mammals (Hinde et al. submitted). Additionally, in response to a large-scale military manoeuvre moose, *Alces alces*, showed behavioural changes, *i.e.* decrease in flush distance, and physiological changes, *i.e.* higher maximum heart rates (Andersen et al. 1996). Direct human contact can activate the physiological stress response in wild animals; for example Brown bears, *Ursus arctos*, significantly increased heart rate in response to dog hunts and human encounters (Le Grand et al. 2019). Human approach towards nesting birds may not always lead to females leaving the nest, but activation of the physiological stress response can increase energy expenditure (Magellanic penguins, *Spheniscus magellanicus*: Fowler 1999; Yellow-eyed penguin, *Megadyptes antipodes*: Ellenberg et al. 2013; wandering albatrosses, *Diomedea exulans*: Weimerskirch et al. 2002). In contrast, other populations were described to be more resilient; for example nesting American oystercatchers, *Haematopus palliatus*, did not significantly increase heart

rate in response to a variety of human disturbances, including human approach, off-road vehicles, and aircraft overflights (Borneman et al. 2014), and greylag geese did not significantly increase heart rate in response to familiar humans approaching (Wascher et al. 2011). Whether or not a heart rate increase can be measured upon such events may be a matter of previous habituation.

A major regularly re-occurring world-wide anthropogenic disturbance are New Year's Eve firework celebrations, causing noise and light pollution and major anxiety in pet animals. Hence, it is a significant welfare concern (dogs, *Canis familiaris*: Levine and Mills 2008, Dale et al. 2010, Gates et al. 2019, Gähwiler et al. 2020, Riemer 2020; horses, *Equus caballus*: Gronqvist et al., 2016). A study on several species of captive zoo animals showed no changes in behaviour in response to fireworks in most species (Rodewald et al. 2014). However, birds have been shown to take flight shortly after midnight and move in the air for at least 45 minutes in response to fireworks on New Year's Eve in the Netherlands (Shamoun-Baranes et al. 2011). Besides these few studies, the effects of fireworks on wildlife are largely unknown.

In the present study, we investigate heart rate and body temperature responses of free-flying greylag geese in response to New Year's Eve celebrations. We expected a significant increase in both, heart rate and body temperature in response to the fireworks. Additionally, we investigated any effects of sex and age. Previously heart rate differences between the sexes have been described only during the reproductive season (Wascher et al. 2018) and specific behavioural contexts (Wascher et al. 2012), hence in this study we do not expect different responses between males and females. In respect to age, we were

interested whether older individuals, who have experienced multiple New Year's Eve celebrations, responded less strongly, as they might have habituated to fireworks previously or alternatively sensitized, meaning that response to fireworks would increase over time (Riemer 2019). Quantifying the impact of fireworks onto the short-term physiological stress response can help to understand the impact of anthropogenic disturbances for wild animals.

Methods

Study Site

The present study was conducted in a nonmigratory free-living flock of greylag geese in the Almtal, Upper Austria. At the time of data collection, the flock consisted of approximately 150 individuals, marked with coloured leg bands for individual identification. The geese are unrestrained and freely roam the valley from the lake Almsee, on which they usually roost at night (47.747793°, 13.956805°) to the Konrad Lorenz research station (47.814143°, 13.948519°). At the research station, the flock is supplemented with pellets and grain twice daily at 0800 and 1500 hours during the winter months and at 1700 hours during the summer months. Both hand-raised and goose-raised flock members are habituated to the close presence of humans and they neither show avoidance if approached up to 1 meter distance nor excrete elevated levels of corticosterone metabolites following such situations (Scheiber et al. 2005) or significantly change heart rate when familiar humans approach (Wascher et al. 2011). New Year's Eve celebrations and fireworks are held in several nearby villages, including Grünau im Almtal and directly at the Almsee, where the geese roost at night. Geese are subjected to visual as well as auditory stimuli from the fireworks. Most of the firework activity starts at 0000 on the first of January and lasts for several minutes. We did not collect behavioural data from the focal individuals in this study,

however from anecdotal observations we know that geese take flight during the fireworks and circle over the Almsee but remain on the roosting site.

Data Collection and Analysis

Twenty-five individuals (8 females/17 males) were fitted fully implanted transmitter packages (60 × 30 × 11 mm, ~60 g; for further technical details and implantation procedure see Wascher and Kotrschal 2013, Wascher et al. 2018). Both heart rate and body core temperature were stored as two-minute means in the implant over its lifetime and downloaded after electronic packages were surgically removed. Data were recorded during 2005 New Year's Eve from 20 individuals (6 females/14 males). One male individual was sampled twice during 2005 and 2006. Age of focal individuals ranged from 1 to 12 years (average ± standard deviation = 4.714 ± 2.813). Raw data were filtered with a moving average to remove biologically implausible outlier values. We calculated mean values per hour of the day. We compared daily heart rate pattern on the 31st of December compared to 1st of January, average values for the month of December and average values for the month of January. Additionally, we calculated mean value over one hour (*e.g.*, 00-01, 01-02, 02-03) on the 31st December, 1st of January and average over the entire month of December and January. Data was analysed using R version 4.0.3 (The R Foundation for Statistical Computing, Vienna, Austria, <http://www.r-project.org>). We calculated general linear mixed model using the function `lme` in the package `nlme` (Pinheiro et al. 2020) with gaussian error distribution and mean heart rate as well as body temperature as response variable. We calculated separate models for the hours 0000-0100, 0100-0200, 0200-0300, 0300-0400, 0400-0500 and 0500-0600, until no significant difference between different periods could be detected anymore. Period (31st December, 1st January, average December, average

January), sex and age were included as explanatory variables. Various model diagnostics were employed to confirm model validity (visual inspection of distribution of residuals, qq plots, residuals plotted against fitted values) none of which suggested violation of model assumptions. To assess multicollinearity between fixed factors, we calculated variance inflation factors (VIFs) using the `vif` function in the package `car` (Fox and Weisberg 2011). VIFs for all factors were below 1.5, indicating that there was no issue with multicollinearity (Zuur et al. 2009). For each model, we fitted individual identity as a random term to control for the potential dependence associated with multiple samples from the same individuals. To describe the variance explained by our models, we provide marginal and conditional R^2 values that range from 0 to 1 and describe the proportion of variance explained by the fixed and by the fixed and random effects combined, respectively (Nakagawa and Schielzeth 2013). We calculated marginal and conditional R^2 values using the `r.squaredGLMM` function in `MuMIn` (Bartoń 2019).

Results

Between 0000-0100, heart rate and body temperature were significantly higher in the first hour of the new year, compared to the same hour on the 31st of December, the average during December and the average during January (Table 1; Figure 1 and 2).

Compared to average values during the month December, heart rate increased by 96% and body temperature increased by 3% in the first hour of the new year. Heart rate and body temperature was not significantly associated with sex and age (Table 1). A similar pattern arose between 0100-0200, with heart rate and body temperature being significantly higher on the 1st of January compared to the other phases, but sex and age not having an effect (Table 1), reflecting a 31% increase in heart rate and 3% increase in body temperature compared to average December values. Between 0200-0300 and 0300-0400, heart rate was not significantly associated with any factors, however body temperature was still significantly higher on the 1st of January compared to other phases. Between 0400-0500, body temperature was significantly higher on the 1st of January compared to 31st of December and average December values but not average January values. None of the investigated factors significantly affected body temperature between 0500-0600 (Table 1).

Discussion

In the present study we describe a significant increase in heart rate and body temperature in response to a major regularly re-occurring anthropogenic disturbance, New Year's Eve firework celebrations. Heart rate was significantly increased from 0000-0200 compared to control periods. Similarly, also body temperature increased in response to the disturbance and only returned to baseline between 0500-0600 on the first of January. Although fireworks are well described as a major stressor in pets and domestic animals (Levine and Mills 2008, Dale et al. 2010, Gronqvist et al. 2016, Gates et al. 2019, Gähwiler et al. 2020), effects on wildlife remain largely unexplored (Shamoun-Baranes et al. 2011). We cannot conclusively tell whether the implanted geese were responding to the noise pollution or light pollution caused by the fireworks or to a combination of both. It has to be noted that the geese in our study were generally habituated to human presence and for example did not significantly increase heart rate while being approached by a familiar human (Wascher et al. 2011). We therefore need to consider the possibility that the observed changes in heart rate might not be representative of what would be observed in un-habituated wild animals, who might display even more pronounced responses or avoid areas in which fireworks occur altogether.

The physiological response we presently describe is likely associated with increased activity and a behavioural response. Anecdotally greylag geese from the studied population have been observed to take flight during the fireworks and circle over the lake Almsee, which is the roosting site (C.A.F. Wascher, personal observation). Hence, we suggest that the increase in heart rate in response to fireworks is likely to be caused by both, increased physical activity and psychological stress (Wascher 2021). Wild birds have been shown to

take flight for 45 minutes during New year's eve fireworks (Shamoun-Baranes et al. 2011), our results suggest an even longer response than this, heart rate only returned to baseline levels between 0200-0300, indicating geese to respond to the fireworks for 2 hours, which may also be due to the fact, that firework activity does not sharply end a few minutes after midnight, but may occur as single crackers or rockets 1-2 hours into the new year. As we do not have conducted behavioural observations, we cannot tell if geese took flight, for how long the geese were in the air and if all focal individuals did so, however in different contexts, heart rate has been described to return to baseline levels within seconds after a stressor (Wascher et al. 2008, Wascher et al. 2011, Wascher 2021).

We have previously, shown that heart rate and body temperature vary – indicative of energy expenditure – profoundly across annual and daily cycles, generally decreasing during winter as compared to summer and significantly increasing during the reproductive period (Wascher et al. 2018). Average daily heart rates in this previous study varied on average 22% between summer and winter, whereas body temperature was about 1° lower in winter compared to summer values. Here, we show heart rate increasing by 96% and body temperature increasing by 3% (about 1°) in the first hour of the new year, suggesting that New Year's Eve celebration present a major stressor affecting individuals energy expenditure. Further, social contexts have been shown to be strong modulators of heart rate (Wascher et al. 2008, Wascher et al. 2014) and of course, heart rate increases during locomotion and evidently stressful situations (i.e. a dog on the leash, the geese were not habituated to; Wascher et al., 2011; Wascher & Kotrschal, 2013). Disturbance in response to fireworks is not only very likely stressful, but presents an energetic cost to the geese (Butler and Woakes 1980, Wascher et al. 2018, Halsey et al. 2019), causes a disruption of their night

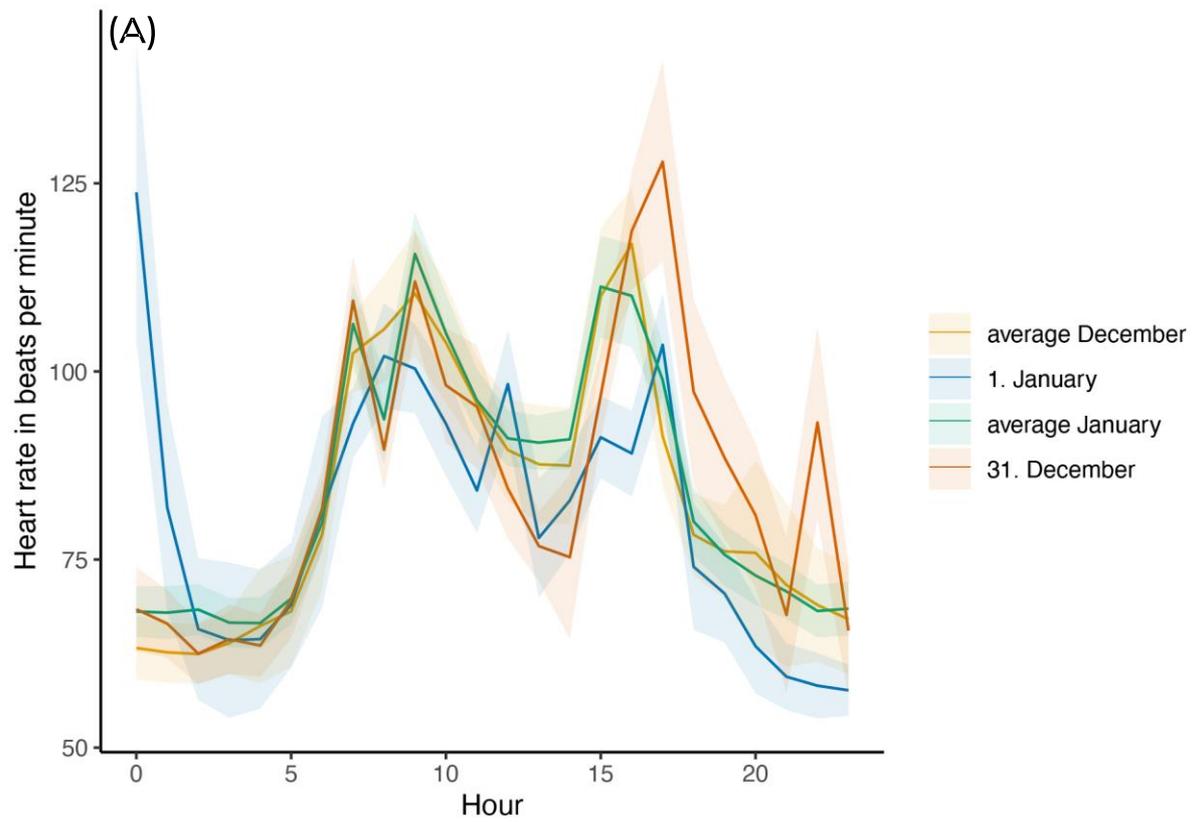
rest period (Raap et al. 2017, Aulsebrook et al. 2020, Grunst et al. 2021); in addition, birds are at risk of becoming disoriented (Van Doren et al. 2017).

Although there were pronounced individual differences in heart rate and body temperature responses, these were not significantly affected by sex and age. Differences in heart rate between the sexes have previously been described as depend on season and only apparent during the reproductive season (Wascher et al. 2018). Outside the reproductive season, differences between the sexes are context dependent, for example male individuals having a higher heart rate during agonistic encounters compared to females (Wascher et al. 2012). We did not describe an effect of age on the physiological response, showing no indication of the geese to either habituate or sensitize to the fireworks over time (Riemer 2020). Both, predictability and unpredictability as well as personality have been shown to affect behavioural and physiological stress response and depending on context can increase or decrease the response to stimuli (Bassett and Buchanan-Smith 2007). However it is questionable whether wild animals perceive New Year's Eve celebrations as predictable events, as they only occur one a year.

To conclude, our results show that New Year's Eve fireworks cause a substantial physiological response in greylag geese. A better understanding of the effects of anthropogenic disturbance onto wildlife can be useful for wildlife conservation attempts and our study is one of few showing negative effects of fireworks onto wildlife. A clear recommendation from our and other studies is to avoid fireworks in nature areas altogether.

Tables and Figures

Figure 1: Daily course of (A) heart rates and (B) body temperature. Solid lines are means, shaded areas indicate standard error between individuals.



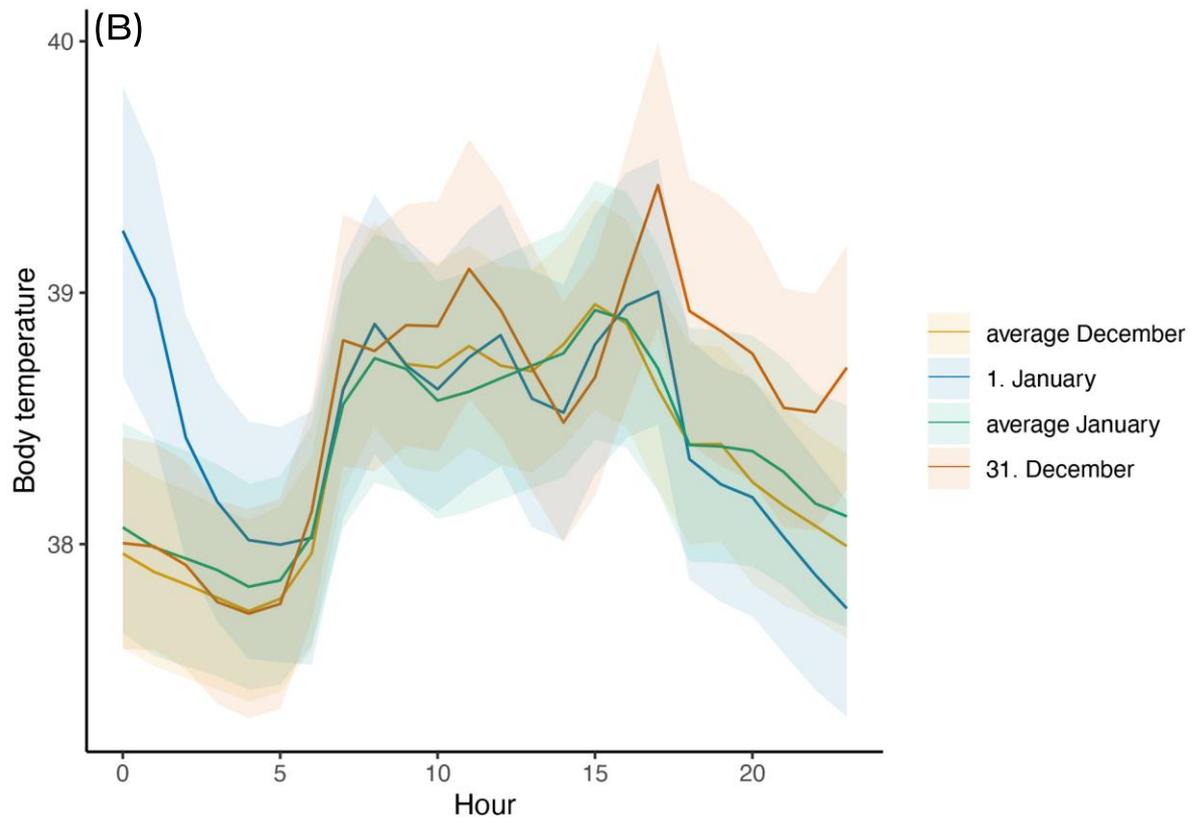
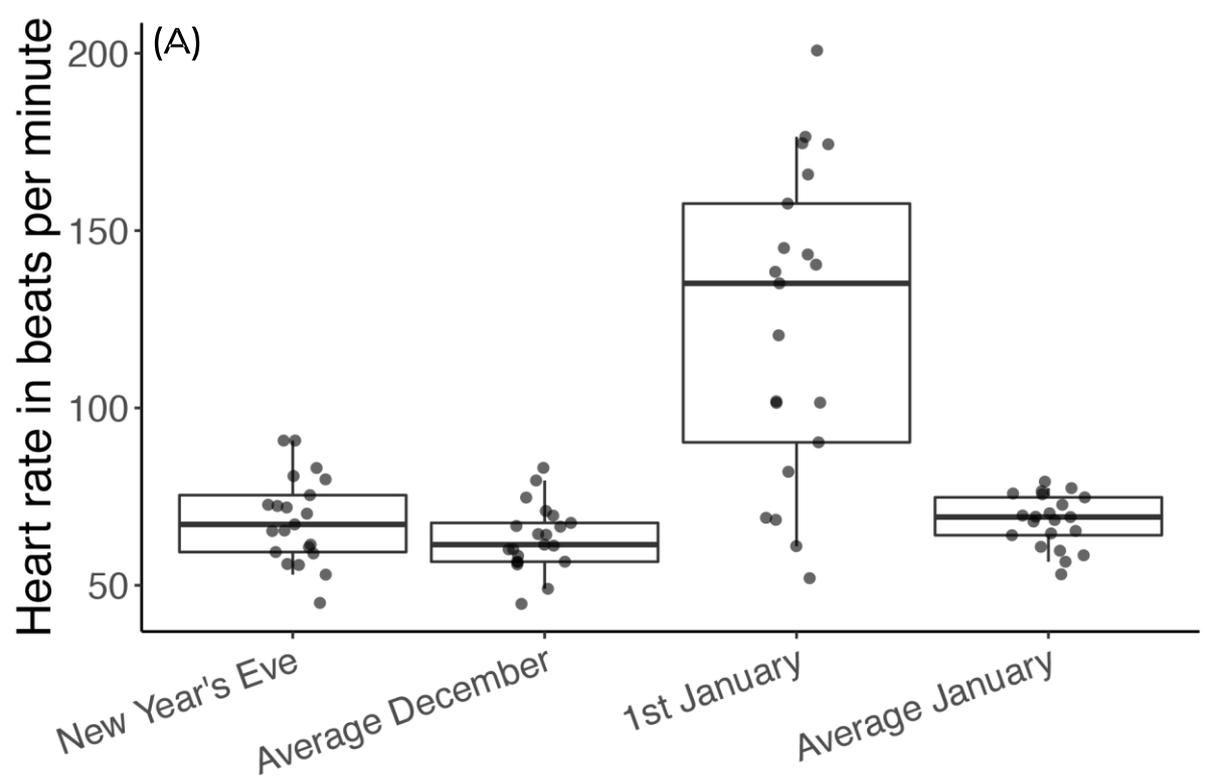


Figure 2: Mean heart rate (A) and body temperature (B) between 0000 and 0100. Box plots show the median and the interquartile range from the 25th to the 75th percentiles. Whiskers show the bottom 5% to the upper 95% confidence interval. Each data point is an individual's mean value.



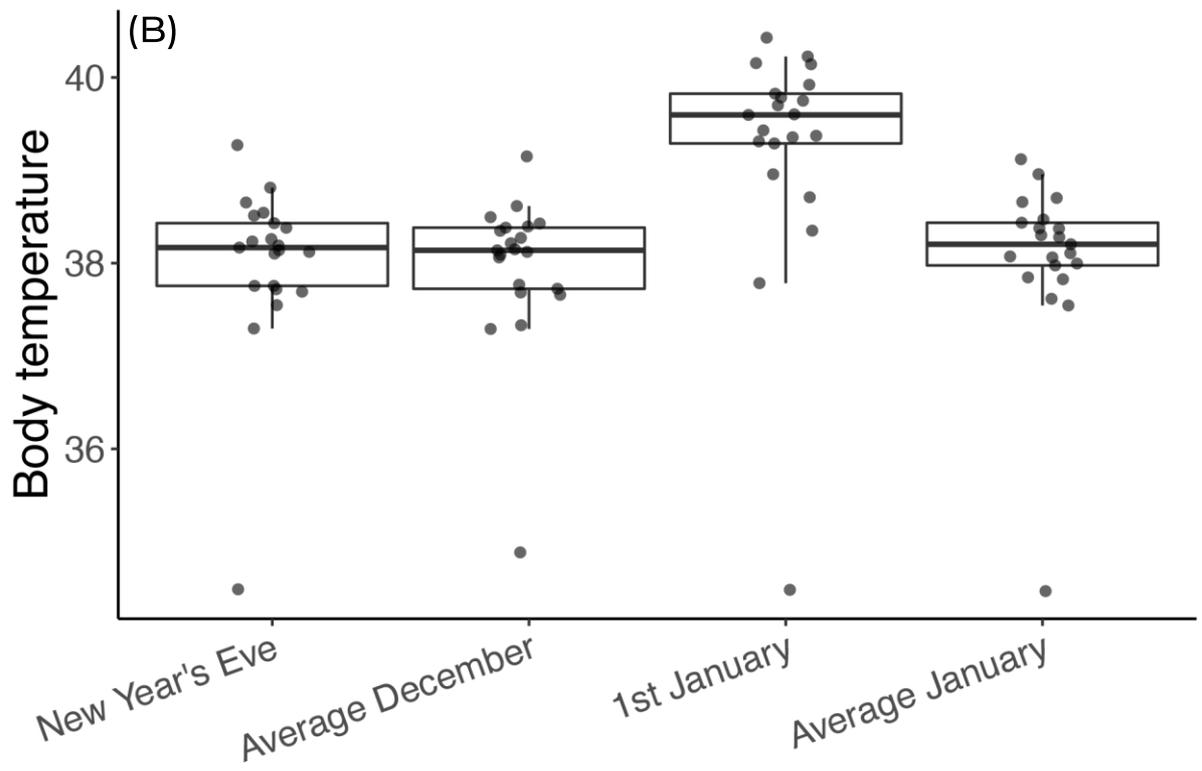


Table 1: Results of the general linear model investigating factors affecting heart rate (A) and body temperature (B) between 0000-0100, 0100-0200, 0200-0300, 0300-0400, 0400-0500 and 0500-0600. Significant factors are highlighted in bold. For each model, R^2 marginal value, describing the proportion of variance explained by the fixed and R^2 conditional value describing proportion of variance explained by the random effect (individual).

	Parameters	Estimate \pm SE	df	t-value	P
0000-0100					
(A) Heart rate R^2 marginal: 55%, R^2 conditional: 9%	(Intercept)	-3477.243 \pm 2379.94	61	-1.461	0.149
	Period (1. Jan relative to 31. Dec)	-55.424 \pm 6.465	61	-8.571	<0.001
	Period (1. Jan relative to Dec average)	-60.569 \pm 6.465	61	-9.367	<0.001
	Period (1. Jan relative to Jan average)	-55.721 \pm 6.46	61	-8.617	<0.001
	Sex	-8.933 \pm 7.171	17	-1.245	0.229
	Age	1.803 \pm 1.19	17	1.514	0.148
(B) Body temperature R^2 marginal: 24%, R^2 conditional: 64%	(Intercept)	70.924 \pm 161.338	61	0.439	0.661
	Period (1. Jan relative to 31. Dec)	-1.242 \pm 0.13	61	-9.505	<0.001
	Period (1. Jan relative to Dec average)	-1.284 \pm 0.13	61	-9.822	<0.001
	Period (1. Jan relative to Jan average)	-1.18 \pm 0.13	61	-9.026	<0.001
	Sex	-0.427 \pm 0.479	17	-0.892	0.384
	Age	-0.015 \pm 0.08	17	-0.194	0.848
0100-0200					
(A) Heart rate R^2 marginal: 21%, R^2 conditional: 22%	(Intercept)	-2568.699 \pm 1903.819	59	-1.349	0.182
	Period (1. Jan relative to 31. Dec)	-0.973 \pm 0.125	59	-7.728	<0.001
	Period (1. Jan relative to Dec average)	-1.074 \pm 0.125	59	-8.533	<0.001

	Period (1. Jan relative to Jan average)	-0.989 ± 0.126	59	-7.805	<0.001
	Sex	-0.328 ± 0.467	17	-0.7	0.492
	Age	-0.016 ± 0.078	17	-0.212	0.834
(B) Body temperature <i>R</i> ² marginal: 20%, <i>R</i> ² conditional: 66%	(Intercept)	72.663 ± 157.464	59	0.461	0.646
	Period (1. Jan relative to 31. Dec)	-0.973 ± 0.124	59.144	-7.83	<0.001
	Period (1. Jan relative to Dec average)	-1.074 ± 0.124	59.144	-8.645	<0.001
	Period (1. Jan relative to Jan average)	-0.989 ± 0.125	59.036	-7.908	<0.001
	Sex	-0.328 ± 0.488	17.04	-0.671	0.51
	Age	-0.016 ± 0.082	16.964	-0.203	0.841
0200-0300					
(A) Heart rate <i>R</i> ² marginal: 11%, <i>R</i> ² conditional: 36%	(Intercept)	-2330.824 ± 1529.329	59	-1.524	0.132
	Period (1. Jan relative to 31. Dec)	-2.872 ± 2.91	59	-0.987	0.327
	Period (1. Jan relative to Dec average)	-2.923 ± 2.91	59	-1.004	0.319
	Period (1. Jan relative to Jan average)	2.598 ± 2.934	59	0.885	0.379
	Sex	-3.294 ± 4.573	17	-0.72	0.481
	Age	1.199 ± 0.765	17	1.567	0.135
(B) Body temperature <i>R</i> ² marginal: 8%, <i>R</i> ² conditional: 80%	(Intercept)	52.334 ± 153.373	59	0.341	0.734
	Period (1. Jan relative to 31. Dec)	-0.496 ± 0.108	59	-4.592	<0.001
	Period (1. Jan relative to Dec average)	-0.572 ± 0.108	59	-5.299	<0.001
	Period (1. Jan relative to Jan average)	-0.48 ± 0.108	59	-4.42	<0.001
	Sex	-0.255 ± 0.455	17	-0.561	0.582
	Age	-0.006 ± 0.076	17	-0.089	0.929
0300-0400					
(A) Heart rate <i>R</i> ² marginal: 8%, <i>R</i> ² conditional: 35%	(Intercept)	-2688.979 ± 1630.469	59	-1.649	0.104
	Period (1. Jan relative to 31. Dec)	0.545 ± 3.178	59	0.171	0.864
	Period (1. Jan relative to Dec average)	0.033 ± 3.178	59	0.01	0.991

	Period (1. Jan relative to Jan average)	2.323 ± 3.205	59	0.724	0.471
	Sex	-2.869 ± 4.878	17	-0.588	0.564
	Age	1.377 ± 0.815	17	1.688	0.109
(B) Body temperature <i>R</i> ² marginal: 4%, <i>R</i> ² conditional: 83%	(Intercept)	47.319 ± 150.273	59	0.314	0.754
	Period (1. Jan relative to 31. Dec)	-0.399 ± 0.104	59	-3.811	<0.001
	Period (1. Jan relative to Dec average)	-0.382 ± 0.104	59	-3.65	<0.001
	Period (1. Jan relative to Jan average)	-0.271 ± 0.105	59	-2.576	0.012
	Sex	-0.189 ± 0.446	17	-0.424	0.676
	Age	-0.004 ± 0.075	17	-0.059	0.952
	0400-0500				
(A) Heart rate <i>R</i> ² marginal: 7%, <i>R</i> ² conditional: 26%	(Intercept)	-2235.595 ± 1617.503	59	-1.386	0.171
	Period (1. Jan relative to 31. Dec)	-0.453 ± 3.703	59	-0.122	0.903
	Period (1. Jan relative to Dec average)	2.139 ± 3.703	59	0.577	0.565
	Period (1. Jan relative to Jan average)	2.132 ± 3.738	59	0.57	0.57
	Sex	-5.934 ± 4.855	17	-1.222	0.238
	Age	1.154 ± 0.809	17	1.427	0.171
(B) Body temperature <i>R</i> ² marginal: 2%, <i>R</i> ² conditional: 81%	(Intercept)	51.501 ± 147.849	59	0.348	0.728
	Period (1. Jan relative to 31. Dec)	-0.295 ± 0.118	59	-2.491	0.015
	Period (1. Jan relative to Dec average)	-0.285 ± 0.118	59	-2.407	0.019
	Period (1. Jan relative to Jan average)	-0.185 ± 0.119	59	-1.551	0.126
	Sex	-0.097 ± 0.439	17	-0.22	0.827
	Age	-0.006 ± 0.073	17	-0.09	0.928
	0500-0600				
(A) Heart rate <i>R</i> ² marginal: 36%, <i>R</i> ² conditional: 38%	(Intercept)	-1558.818 ± 1747.148	59	-0.892	0.375
	Period (1. Jan relative to 31. Dec)	0.378 ± 3.336	59	0.113	0.91
	Period (1. Jan relative to Dec average)	0.08 ± 0.116	59	0.687	0.494

	Period (1. Jan relative to Jan average)	1.237 ± 3.336	59	0.37	0.712
	Sex	-4.315 ± 5.225	17	-0.825	0.42
	Age	0.814 ± 0.42	17	0.932	0.364
(B) Body temperature	(Intercept)	74.265 ± 149.291	59	0.497	0.62
<i>R</i> ² marginal: 15%, <i>R</i> ² conditional: 83%	Period (1. Jan relative to 31. Dec)	0.222 ± 0.116	59	1.906	0.061
	Period (1. Jan relative to Dec average)	0.08 ± 0.116	59	0.687	0.494
	Period (1. Jan relative to Jan average)	-0.02 ± 0.114	59	-0.176	0.86
	Sex	-0.016 ± 0.443	17	-0.038	0.97
	Age	-0.018 ± 0.074	17	-0.244	0.81

Declarations

Ethical Approval

This study was approved under an animal experiment license issued by the Austrian Ministry of Science GZ68.210/41-BrGT/2003. Before and after completion of the study, geese remained in the nonmigratory, free-roaming flock of greylag geese in the Almtal.

Consent for publication

Not applicable.

Availability of data and materials

The data and R code are provided via the platform Zenodo (10.5281/zenodo.6752634).
<https://zenodo.org/record/6752634#.YrhJvBPMLeo>

Competing interests

The authors declare that they have no competing interests.

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Author Contributions

CAFW conceptualized the study, curated, and analysed the data. CAFW, WA and KK write the original draft of the paper and contributed to reviewing and editing. All authors read and approved the final manuscript.

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References

- Alam, M. M., M. A. Hashem, M. M. Rahman, M. M. Hossain, M. R. Haque, Z. Sobhan, and M. S. Islam. 2011. Effect of heart stress on behavior, physiological and blood parameters of goat. *Progressive Agriculture* 22:37–45.
- Al-Haidary, A. A. 2004. Physiological responses of naimey sheep to heat stress challenge under semi-arid environments. *International Journal of Agriculture & Biology* 6:307–309.
- Andersen, R., J. D. C. Linnell, and R. Langvatn. 1996. Short term behavioural and physiological response of moose *Alces alces* to military disturbance in Norway. *Biological Conservation* 77:169–176.
- Aulsebrook, A. E., F. Connelly, R. D. Johnsson, T. M. Jones, R. A. Mulder, M. L. Hall, A. L. Vyssotski, and J. A. Lesku. 2020. White and Amber Light at Night Disrupt Sleep Physiology in Birds. *Current Biology* 30:3657-3663.e5.
- Bartholomew, G. A., P. Leitner, and J. E. Nelson. 1964. Body temperature, oxygen consumption, and heart rate in three species of Australian flying foxes. *Physiological Zoology* 37:179–198.
- Bartoń, K. 2019. MuMIn: Multi-Model Inference. <<https://CRAN.R-project.org/package=MuMIn>>.
- Bassett, L., and H. M. Buchanan-Smith. 2007. Effects of predictability on the welfare of captive animals. *Applied Animal Behaviour Science* 102:223–245.
- Bejder, L., A. Samuels, H. Whitehead, and N. Gales. 2006. Interpreting short-term behavioural responses to disturbance within a longitudinal perspective. *Animal Behaviour* 72:1149–1158.
- von Borell, E., J. Langbein, G. Després, S. Hansen, C. Leterrier, J. Marchant-Forde, R. Marchant-Forde, M. Minero, E. Mohr, A. Prunier, D. Valance, and I. Veissier. 2007. Heart rate variability as a measure of autonomic regulation of cardiac activity for assessing stress and welfare in farm animals — A review. *Physiology & Behavior* 92:293–316.
- Borneman, T. E., E. T. Rose, and T. R. Simons. 2014. Minimal changes in heart rate of incubating American Oystercatchers (*Haematopus palliatus*) in response to human activity. *The Condor* 116:493–503.
- Butler, P. J., and A. J. Woakes. 1980. Heart rate, respiratory frequency and wing beat frequency of free flying barnacle geese. *Journal of Experimental Biology* 213–226.
- Cabanac, A. J., and M. Guillemette. 2001. Temperature and heart rate as stress indicators of handled common eider. *Physiology & Behavior* 74:475–479.
- Carere, C., and K. Vanoers. 2004. Shy and bold great tits (*Parus major*): body temperature and breath rate in response to handling stress. *Physiology & Behavior* 82:905–912.
- Corradini, A., M. Randles, L. Pedrotti, E. van Loon, G. Passoni, V. Oberosler, F. Rovero, C. Tattoni, M. Ciolli, and F. Cagnacci. 2021. Effects of cumulated outdoor activity on wildlife habitat use. *Biological Conservation* 253:108818.
- Daan, S., C. Deerenberg, and C. Dijkstra. 1996. Increased daily work precipitates natural death in the kestrel. *The Journal of Animal Ecology* 65:539.
- Dale, A., J. Walker, M. Farnworth, S. Morrissey, and N. Waran. 2010. A survey of owners' perceptions of fear of fireworks in a sample of dogs and cats in New Zealand. *New Zealand Veterinary Journal* 58:286–291.
- De Jong, I. C., S. V. Voorst, D. A. Ehlhardt, and H. J. Blokhuis. 2002. Effects of restricted feeding on physiological stress parameters in growing broiler breeders. *British Poultry Science* 43:157–168.

- Ditmer, M. A., J. B. Vincent, L. K. Werden, J. C. Tanner, T. G. Laske, P. A. Iaizzo, D. L. Garshelis, and J. R. Fieberg. 2015. Bears show a physiological but limited behavioral response to unmanned aerial vehicles. *Current Biology* 25:2278–2283.
- Dominoni, D., J. A. H. Smit, M. E. Visser, and W. Halfwerk. 2020. Multisensory pollution: Artificial light at night and anthropogenic noise have interactive effects on activity patterns of great tits (*Parus major*). *Environmental Pollution* 256:113314.
- Ellenberg, U., T. Mattern, and P. J. Seddon. 2013. Heart rate responses provide an objective evaluation of human disturbance stimuli in breeding birds. *Conservation Physiology* 1:cot013–cot013.
- Ferraro, D. M., M.-L. T. Le, and C. D. Francis. 2020. Combined effect of anthropogenic noise and artificial night lighting negatively affect Western Bluebird chick development. *The Condor* 122:duaa037.
- Fowler, G. S. 1999. Behavioral and hormonal responses of Magellanic penguins (*Spheniscus magellanicus*) to tourism and nest site visitation. *Biological Conservation* 90:143–149.
- Fox, J., and S. Weisberg. 2011. *An {R} Companion to Applied Regression*. second. Sage Publications, California.
- Gähwiler, S., A. Bremhorst, K. Tóth, and S. Riemer. 2020. Fear expressions of dogs during New Year fireworks: a video analysis. *Scientific Reports* 10:16035.
- Gates, M., S. Zito, J. Walker, and A. Dale. 2019. Owner perceptions and management of the adverse behavioural effects of fireworks on companion animals: an update. *New Zealand Veterinary Journal* 67:323–328.
- Gaynor, K. M., C. E. Hojnowski, N. H. Carter, and J. S. Brashares. 2018. The influence of human disturbance on wildlife nocturnality. *Science* 360:1232–1235.
- Graham, A. L., and S. J. Cooke. 2008. The effects of noise disturbance from various recreational boating activities common to inland waters on the cardiac physiology of a freshwater fish, the largemouth bass (*Micropterus salmoides*). *Aquatic Conservation: Marine and Freshwater Ecosystems* 18:1315–1324.
- Gronqvist, G., C. Rogers, and E. Gee. 2016. The management of horses during fireworks in New Zealand. *Animals* 6:20.
- Grunst, M. L., A. S. Grunst, R. Pinxten, and M. Eens. 2021. Variable and consistent traffic noise negatively affect the sleep behavior of a free-living songbird. *Science of The Total Environment* 778:146338.
- Halsey, L. G., J. A. Green, S. D. Twiss, W. Arnold, S. J. Burthe, P. J. Butler, S. J. Cooke, D. Grémillet, T. Ruf, O. Hicks, K. J. Minta, T. S. Prystay, C. A. F. Wascher, and V. Careau. 2019. Flexibility, variability and constraint in energy management patterns across vertebrate taxa revealed by long-term heart rate measurements. D. Levesque, editor. *Functional Ecology* 33:260–272.
- Hinde, A., B. McDonald, H. Klinck, P. Ponganis, S. Hannah, L. Cooley, and C. Williams. submitted. Heart rate and temperature during at-sea disturbance in diving elephant seals Authors: Hindle A, McDonald B, Horning M, Klinck H, Ponganis P, Hannah S, Cooley L, Williams C. *Philosophical Transactions of the Royal Society B: Biological Sciences*.
- von Holst, D. 1998. The concept of stress and its relevance for animal behavior. Pages 1–131 *in*. *Advances in the Study of Behavior*. Volume 27. Academic Press.
- Jerem, P., and F. Mathews. 2021. Trends and knowledge gaps in field research investigating effects of anthropogenic noise. *Conservation Biology* 35:15.
- Kleist, N. J., R. P. Guralnick, A. Cruz, C. A. Lowry, and C. D. Francis. 2018. Chronic anthropogenic noise disrupts glucocorticoid signaling and has multiple effects on

- fitness in an avian community. *Proceedings of the National Academy of Sciences* 115. <<https://pnas.org/doi/full/10.1073/pnas.1709200115>>. Accessed 29 May 2022.
- Le Grand, L., N. H. Thorsen, B. Fuchs, A. L. Evans, T. G. Laske, J. M. Arnemo, S. Sæbø, and O.-G. Støen. 2019. Behavioral and physiological responses of Scandinavian brown bears (*Ursus arctos*) to dog hunts and human encounters. *Frontiers in Ecology and Evolution* 7:134.
- Levine, E. D., and D. S. Mills. 2008. Long-term follow-up of the efficacy of a behavioural treatment programme for dogs with firework fears. *Veterinary Record* 162:657–659.
- MacArthur, R. A., R. H. Johnston, and V. Geist. 1979. Factors influencing heart rate in free-ranging bighorn sheep: a physiological approach to the study of wildlife harassment. *Canadian Journal of Zoology* 57:2010–2021.
- Marion, S., A. Davies, U. Demšar, R. J. Irvine, P. A. Stephens, and J. Long. 2020. A systematic review of methods for studying the impacts of outdoor recreation on terrestrial wildlife. *Global Ecology and Conservation* 22:e00917.
- McNab, B. K. 2022. *The physiological ecology of vertebrates: A view from energetics*. Cornell University Press, Ithaca, NY.
- Mesteig, K., N. J. C. Tyler, and A. S. Blix. 2000. Seasonal changes in heart rate and food intake in reindeer (*Rangifer tarandus tarandus*): Heart rate and food intake. *Acta Physiologica Scandinavica* 170:145–151.
- Nakagawa, S., and H. Schielzeth. 2013. A general and simple method for obtaining R² from generalized linear mixed-effects models. R. B. O'Hara, editor. *Methods in Ecology and Evolution* 4:133–142.
- New, L., J. Clark, D. Costa, E. Fleishman, M. Hindell, T. Klanjšček, D. Lusseau, S. Kraus, C. McMahan, P. Robinson, R. Schick, L. Schwarz, S. Simmons, L. Thomas, P. Tyack, and J. Harwood. 2014. Using short-term measures of behaviour to estimate long-term fitness of southern elephant seals. *Marine Ecology Progress Series* 496:99–108.
- Oulton, L. J., V. Haviland, and C. Brown. 2013. Predator recognition in rainbowfish, *Melanotaenia duboulayi*, embryos. C. Fulton, editor. *PLoS ONE* 8:e76061.
- Pinheiro, J., D. Bates, S. DebRoy, and D. Sarkar. 2020. nlme: Linear and Nonlinear Mixed Effects Models. <<https://CRAN.R-project.org/package=nlme>>.
- Raap, T., J. Sun, R. Pinxten, and M. Eens. 2017. Disruptive effects of light pollution on sleep in free-living birds: Season and/or light intensity-dependent? *Behavioural Processes* 144:13–19.
- Riemer, S. 2020. Effectiveness of treatments for firework fears in dogs. *Journal of Veterinary Behavior* 37:61–70.
- Rodewald, A., U. Gansloßer, and T. Kölpin. 2014. Influence of fireworks on zoo animals: Studying different species at the zoopark Erfurt during the classic nights. *International Zoo News* 61:8.
- Santicchia, F., L. A. Wauters, B. Dantzer, S. E. Westrick, N. Ferrari, C. Romeo, R. Palme, D. G. Preatoni, and A. Martinoli. 2020. Relationships between personality traits and the physiological stress response in a wild mammal. J. Hare, editor. *Current Zoology* 66:197–204.
- Savory, C., and L. Kostal. 2006. Is expression of some behaviours associated with de-arousal in restricted-fed chickens? *Physiology & Behavior* 88:473–478.
- Scheiber, I. B. R., S. Kralj, and K. Kotrschal. 2005. Sampling effort/frequency necessary to infer individual acute stress responses from fecal analysis in greylag geese (*Anser anser*). *Annals of the New York Academy of Sciences* 1046:154–167.
- Shamoun-Baranes, J., A. M. Dokter, H. van Gasteren, E. E. van Loon, H. Leijnse, and W. Bouten. 2011. Birds flee en mass from New Year's Eve fireworks. *Behavioral Ecology* 22:1173–1177.

- Talling, J. C., N. K. Waran, C. M. Wathes, and J. A. Lines. 1996. Behavioural and physiological responses of pigs to sound. *Applied Animal Behaviour Science* 48:187–201.
- Van Doren, B. M., K. G. Horton, A. M. Dokter, H. Klinck, S. B. Elbin, and A. Farnsworth. 2017. High-intensity urban light installation dramatically alters nocturnal bird migration. *Proceedings of the National Academy of Sciences* 114:11175–11180.
- Wascher, C. A. F. 2021. Heart rate as a measure of emotional arousal in evolutionary biology. *Philosophical Transactions of the Royal Society B: Biological Sciences* 376:20200479.
- Wascher, Claudia A. F., W. Arnold, and K. Kotrschal. 2008. Heart rate modulation by social contexts in greylag geese (*Anser anser*). *Journal of Comparative Psychology* 122:100–107.
- Wascher, C. A. F., and K. Kotrschal. 2013. The costs of sociality measured through heart rate modulation. Pages 142–154 *in*. *The Social Life of Greylag Geese*. Cambridge University Press, Cambridge.
- Wascher, C. A. F., K. Kotrschal, and W. Arnold. 2018. Free-living greylag geese adjust their heart rates and body core temperatures to season and reproductive context. *Scientific Reports* 8:2142.
- Wascher, C. A. F., I. B. R. Scheiber, A. Braun, and K. Kotrschal. 2011. Heart rate responses to induced challenge situations in greylag geese (*Anser anser*). *Journal of Comparative Psychology* 125:116–119.
- Wascher, Claudia A.F, I. B. R. Scheiber, and K. Kotrschal. 2008. Heart rate modulation in bystanding geese watching social and non-social events. *Proceedings of the Royal Society B: Biological Sciences* 275:1653–1659.
- Wascher, C. A. F., J. W. Valdez, C. Núñez Cebrián, V. Baglione, and D. Canestrari. 2014. Social factors modulating attention patterns in carrion crows. *Behaviour* 151:555–572.
- Wascher, C. A. F., B. M. Weiß, W. Arnold, and K. Kotrschal. 2012. Physiological implications of pair-bond status in greylag geese. *Biology Letters* 8:347–350.
- Weimerskirch, H., S. A. Shaffer, G. Mabile, J. Martin, O. Boutard, and J. L. Rouanet. 2002. Heart rate and energy expenditure of wandering albatross. *Journal of Experimental Biology* 205:475–483.
- Willems, J. S., J. N. Phillips, and C. D. Francis. 2022. Artificial light at night and anthropogenic noise alter the foraging activity and structure of vertebrate communities. *Science of The Total Environment* 805:150223.
- Zuur, A. F., E. N. Ieno, N. J. Walker, A. A. Saveliev, and G. M. Smith. 2009. *Mixed Effects Models and Extension in Ecology With R*. Springer, New York.