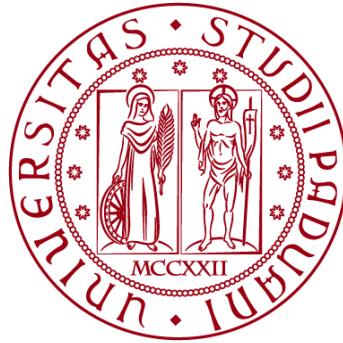


**UNIVERSITÀ DEGLI STUDI DI PADOVA**

**DIPARTIMENTO DI BIOLOGIA**

**Corso di Laurea magistrale in Environmental Sustainability and  
Education**



**TESI DI LAUREA**

**“Does traffic noise affect food delivery and nest attendance in Great Tits  
(*Parus major*)?”**

**Relatore:** Prof. Lucio Bonato

(Dipartimento di Biologia)

**Correlatore:** Dr.ssa Didone Frigerio

(Core facility KLF for Behaviour and Cognition)

**Laureando:** Edoardo Bonte

**ANNO ACCADEMICO 2023/2024**

## Summary

Plagiarism declaration.....	1
Abstract.....	2
1 Introduction.....	3
2 Materials and Methods.....	6
2.1 Study site.....	6
2.2 The nest boxes.....	8
2.3 The species.....	8
2.4 Experimental design.....	10
2.4.1 Traffic noise preparation.....	10
2.4.2 Noise playback experiment.....	11
2.4.3 Ambient noise measurements.....	12
3. Data analysis.....	12
4. Results.....	13
4.1 Feeding rate and traffic noise.....	13
4.2 Nest Attendance and traffic noise.....	15
5. Discussion.....	17
6. Conclusion.....	18
7. References.....	19
8. Acknowledgements.....	28
9. Appendix.....	28

## **Plagiarism declaration**

I hereby declare that I have written this thesis by myself and have only used the sources indicated. It is my own work, except where clearly acknowledged or referenced to the work of others.

## **Abstract**

Worldwide, half of the bird species are declining, largely as a consequence of increased human activities. Roads and traffic are one such form of disturbance and can affect reproductive behaviour in birds. Increasing knowledge about how human activities affect bird behavior is essential to implement conservation actions. This Master's thesis investigated if and how traffic noise affects parental care in Great Tits (*Parus major*) depending on the distance from a road. The study was conducted on 31 nest boxes located in the forests of Grünau im Almtal, Upper Austria. When chicks were 10–13 days old, I broadcast traffic noise near the nest for one hour and recorded (1) parental time spent at the nest, and (2) the number of parental food deliveries. I compared each of these behaviours to a one-hour control period without broadcast traffic noise. The treatment and control order was randomised at every nest to control for time-of-day effects. Parental behavior did not differ significantly between control and treatment periods, even after accounting for factors such as ambient noise and distance from a road. However, feeding rate increased with brood size. While this study shows and confirms the resilience and the adaptability of Great Tits to noisy environments, further studies are needed to investigate road mortality on fledglings. Moreover, it is recommended to work also on other species, considering possible interspecific differences in behavior.

## 1. Introduction

Biodiversity is declining around the globe at alarming rates (Pimm et al., 2014). This is mainly due to human activities, such as land use changes, pollution and climate change (Oliver & Morecroft, 2014). Land use changes, such as the conversion of natural habitats into urban and agricultural areas, significantly affect several ecological communities across taxa (Newbold et al., 2020). For instance, amphibian dispersal in urban and suburban areas is likely to be impeded (Hamer & McDonnell, 2008). In addition, fertilizers and heavy metals together with pesticides lower survivorship of amphibians living in urban areas (Sparling, 2003, Casey et al., 2005, Snodgrass & Massal, 2007, Boone et al., 2024). Moreover, pesticides deployed in agriculture damage aquatic (Hasenbein et al., 2016) and terrestrials (Gunstone et al., 2021) invertebrate communities.

Avian species that largely rely on invertebrates (e.g. songbirds) are also affected by these activities (Wilson et al., 1999). Indeed, BirdLife International report that one in eight species (1,409 species in total) are threatened with extinction (BirdLife International, 2024a) and 60% of global bird populations are now declining (IUCN Red List, 2024). Together with urbanization, road length and associated traffic will increase substantially in the near future (Meijer et al., 2018), leading to deleterious effects on bird populations (Kociolek et al., 2011).

Traffic has different components that can affect bird species, including noise, vibrations, light, and flue gases. Some studies have demonstrated that light pollution has substantial effects on the timing of reproductive behavior and on individual mating patterns (Kempnaers et al., 2010), while others focused on noise (Herrera-Montes & Aide, 2011). Noise has two major components: frequency (Hz) and amplitude (dB). Songbirds dealing with an increase of noise frequency try to mitigate the impairments on their communication caused by masking noise (Brumm et al., 2004). Birds that are forced to sing with higher amplitudes have to bear the increased energetic costs of singing, which can considerably affect the behavioral ecology of singing males (Brumm et al., 2004). Some case studies reported

that begging behavior is also influenced by noise. For instance, tree swallow (*Tachycineta bicolor*) nestlings consistently increase call amplitude in response to ambient noise (Leonard et al., 2005). Some studies indicate that noise can shape species richness and abundance (Summers et al., 2011). The presence of roads can decrease Pied Flycatcher (*Ficedula hypoleuca*) breeding success through adult mortality (Kuitunen et al., 2003), and in tree swallows can also directly affect chicks' development and health (Injaian et al., 2018). Therefore, roads are known to reduce bird density populations and shape species distribution and composition (McClure et al., 2017), acting as geographical barrier and masking bird songs (Slabbekoorn et al. 2008, Parris & Schneider 2009). Some studies highlighted that high traffic noise level may interfere with the detection of alarm calls, such as those signaling the presence of predator: this is the case in the Northern Cardinal (*Cardinalis cardinalis*), which relies on Tufted Titmouse (*Baeolophus bicolor*) alarm calls to escape predators (Grade & Sieving 2016).

Nevertheless, traffic effects vary between and within different species and the mechanisms that affect different species are still uncertain. One study reported a serious fitness decrease after noise exposure in secondary cavity-nesting birds breeding near natural gas fields in New Mexico, caused by glucocorticoid-signaling dysfunction (Kleist et al., 2018). In addition, it was shown that high noise levels could reduce nestling body size and feather growth (Kleist et al., 2018). Another study suggested that chronic traffic noise levels reduce fledgling mass, independently from clutch size (Halfwerk, et. al., 2011). Whether this was related to higher stress levels, reduced foraging, or decreased communication was difficult to disentangle, but it does suggest that noise interference could affect food provisioning to the chicks (Halfwerk, et. al., 2011).

Food delivery is not the only variable that may be affected by noise. Indeed, a recent study suggested that nest attendance may also be altered during the incubation period, and this could be due to differences in noise structures that lead to miscommunication between male and female (Viigipuu et al., 2023). Differences in nest attendance between older and younger parents during urban noise exposure have been reported in Great Tits, depending also on the personality of the individual (Grunst et al., 2021).

Twenty-four years of banding activity performed in four different habitats of the Austrian valley of Grünau im Almtal revealed a 50% species decline in bird species. Of these, 80% are insectivores and 30% are secondary cavity-nesting birds. The causes of this dramatic reduction in avian diversity are puzzling and important conservation actions have been taken to reverse the decline of secondary cavity-nesting birds (Vogel, 2022). Over the last 30 years, projects erecting new nest boxes, implementing the use of feeders, and improving the management of woods and agricultural fields have been developed, but no clear benefits have been recorded for the local avian diversity. One understudied hypothesis that could contribute to this local decline in bird species may be the presence of roads and associated traffic.

This study aims to measure the effect of traffic noise on parental food delivery rate and nest attendance in Great Tits (*Parus major*). This study examines the effect of experimentally broadcast traffic noise at nests located close (0–50 m) and further (100–150m) from a road in four different locations in the Grünau valley. I expect that parents will reduce their food delivery rate and nest attendance during exposure to traffic noise, with a stronger effect at nests that are located further from the road. Furthermore, I expect a lower response in parents nesting near natural ambient noise sources.

## 2. Materials and methods

### 2.1 Study site

The study area is located in the Grunau im Almtal valley, Upper Austria. It stretches for 130 ha, and it is dominated by mixed deciduous forest. A road (Österreichische Romantik Strasse) crosses the valley from north to south, ending in proximity to

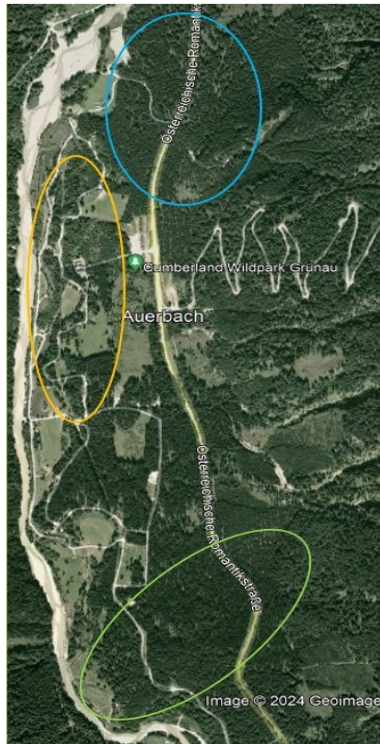
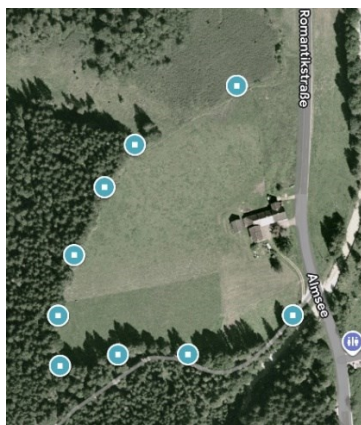


Figure 1(a) above: Four macro-areas into which our study site was divided. Figure 1(b) below: Meadow field, blue dots correspond to nest boxes.



the Almsee. The study area has been divided into four macro-areas: KLF Forest (blue), Cumberland Wild Park (yellow) Oberganslbach (OGB) (green) and Meadow, as shown in Figure 1. Since 2022, 190 nest boxes have been deployed to support cavity-nesting bird species, such as Great Tits, Blue Tits (*Cyanistes caeruleus*), Coal Tits (*Parus ater*), Marsh Tits (*Poecile palustris*), European Crested Tits (*Lophophanes cristatus*), Eurasian Nuthatches (*Sitta europaea*) and Collared Flycatchers (*Ficedula albicollis*). Once a week, each nest was checked to know which species occupied the nest box, the day of the first laid egg, and the number of eggs or chicks. These were necessary to estimate the hatching and ringing date. Hatching normally occurs after a 12–14 day incubation period (Haftorn & Svein 1981). Ringing the nestlings was necessary to understand the development stage of the nestling. Nestlings could be underdeveloped or overdeveloped with respect to their effective age, depending on the amount of food that they have received (Royama, T. R. 1966, Royama, T. 1970, Naef-Daenzer et al. 2000). Of the 190 nest boxes, 38 have been occupied by Great

Tits. To avoid differences in sound transmission due to different environments, I

only used nest boxes installed in the same habitat type (mixed forest). In this way, sound transmission did not differ from one location to another (Cook & van Haverbeke 1972, Bucur 2006, Gilricht et. al., 2003).

## **2.2 The nest boxes**

Great tits at our study site used two different types of nest box: wooden and concrete (Figure (A1) in the Appendix). The wooden nest boxes were quadrangular and made from spruce wood, with a lid that could be folded back to monitor the nest occupants. The external dimensions were  $25 \times 12.5 \times 16$  cm, with an internal chamber that was  $23 \times 8.8 \times 12$  cm. The concrete nest boxes were purchased from Schwegler Germany (model 1B) and were cylindrical and made from a mixture of cement and other materials (Lambrechts et al., 2016), with a removal frontal lid. The external dimensions were  $26 \times 17 \times 18$  cm, with an internal chamber of diameter 12 cm and height 17.5 cm. The entrance for both nest box types had a diameter of 32 mm (Vogel, 2022).

### 2.3 The species

The Great Tit is a passerine bird belonging to family Paridae. It is a common visitor to garden bird feeders (Tryjanowski et al., 2015). Outside urban areas, it is primarily a species of scrub and deciduous woodland (Calladine et al., 2019). The Great Tit, has a bluish-green back and a yellow breast divided by a central black stripe. The sexes are similar, but in males the black stripe is more pronounced (Figure 2)



*Figure 2: The difference between male (left) and female (right) Great Tits. Photo credit: Edoardo Bonte*

It is a vocal species with a wide range of songs and calls; its most familiar vocalization is its repeated ‘teacher-teacher-teacher’ song, which can be heard throughout woodlands in spring (Krebs et al., 1978). Great Tits nest in cavities. Some populations use nest boxes and others nest in tree cavities and other structures (Maziarz et al., 2016, Lambrechts et al., 2017)



*Figure 3: on the left Great Tits eggs, on the right Great Tit hatchlings, picture of Edoardo Bonte*

Its population number is stable, and it is listed from International Union for Conservation of Nature (IUCN) as “least concern”. Great Tits inhabit mostly deciduous and mixed forests but also conifer forests, parks, and gardens (BirdLife International, 2021a). They build nests out of moss, plant fibers and grass and a layer of wool, hair and feathers, and they are frequently found using nest boxes (Mänd et al., 2009). Great Tits usually lay from six to eleven eggs, and they start laying eggs between March and April (Amrhein et al., 2008). The female incubates the eggs for 12–14 days, during which the males support her with food. Nestlings are provisioned by both parents and leave the nest when they are three weeks old (Jongsomjit et al., 2007; Pietz et al., 2012). Great Tits sometimes lay second clutches, depending if the first one was laid early in the season (Verboven et al., 2001). Delayed first clutches are usually small and take longer to hatch than non-delayed ones (Barba et al., 1995).

This species was chosen for the experiment because it was the most abundant in the territory, and because the chances to find a nest were higher than other species. In addition, Great Tit was used as model species for studies on avian ecology (Dingemanse et al., 2012, Smallegange et al., 2010), including effects of

anthropogenic disturbance on avian behaviour (Caorsi et al., 2019, Dominoni et al., 2020).

## **2.4 Experimental design**

### **2.4.1 Traffic noise preparation**

For the traffic noise playbacks, we used four synthetic noise files with the frequency spectra of a vehicle passing by a recorder. In order to obtain reliable results, I took four vehicle passing events from recordings made by a passive recorder (Song Meter Mini, Wildlife Acoustics) deployed near a road around the Konrad Lorenz Forschungsstelle (KLF) (47.8349657, 13.9510416) and clipped 4-second files ( $\pm 2$  seconds from the peak amplitude). Then in R (v. 4.3.2), using the package `seewave` v. 2.2.3, I created mean frequency spectra for each event with the “`meanspec`” function (see Figure (A2) in the appendix). I used these mean frequency spectra to filter white noise created using the software Audacity v. 3.3.3 (all with the same amplitude -1 dB as appear in Figure (A3) in the appendix); for the filtering, I used the function “`ffilter`” from the R package `seewave`. The R script code is available as “traffic noise filtering code R” in the Appendix. For every synthetic noise file ( $N = 4$ ), two audio files of 2-hour duration were created using Audacity v. 3.3.3, in which silence was generated before and after traffic noise.

### **2.4.2 Noise playback experiment**

Of the 190 monitored nest boxes, 38 were occupied by Great Tits and 29 were selected and tested as described below. At first, nest boxes occupied by Great Tits were selected depending on: habitat type (Mixed Forest) and nestling age (on average 12 days) so that sound dispersion would remain the same across nest boxes and the feeding rate would not vary as a function of nestling age (Barba et al., 2009). Therefore, nestlings were aged the day before running the experiment, during ringing following Austrian Ornithological Centre (AOC) protocols. All the trials were made between 6<sup>th</sup> May and 23<sup>rd</sup> of June between 6 and 11am because according to some studies, this time of the day reaches the peak of feeding trips (Kluyver et al., 1950, Pagani-Núñez & Senar, 2013). Before starting the experiment, the speaker was calibrated with the help of a digital sound level meter (Voltcraft SL-100) so that the traffic noise could reach 80 dB at 2m (Halfwerk, et. al., 2011).

The speaker (JBL Clip 4 see Figure (d) in the appendix) was positioned at the base of the tree where the nest box was located (2m from the nest) and the behavior of the parents was recorded with a video camera (GoPro Hero7 or Hero9) set in high zoom mode placed on the ground and fixed on a small tripod approximately 4 m from the nest box to ensure good visibility, but slightly covered up with grass so that bird's behavior was not affected. Each nest box was observed for two hours: for one hour in the absence of noise playback (control period) and one hour during exposure to noise playback (treatment period). The order of the treatment and control periods was randomised so that the silence was sometimes after the traffic noise. Four different traffic noise tracks were alternated at different nests to avoid pseudoreplication.

The number of trips was recorded during control and treatment periods. Therefore, the feeding rate was expressed as the number of trips in one hour, while nest attendance was expressed as the total amount of time (s) that parents spent inside the nest. Nest attendance was calculated starting from the moment when the bird entered with its whole body until the moment in which the bird took off. Other

events, such as the bird perching at the nest box entrance, were counted separately and not included in data analysis.

### **2.4.3 Ambient noise measurements**

Ambient noise measurements were taken to understand if ambient noise could affect bird behavior during the playback experiment. To do so, a digital sound level meter (Voltcraft SL-100) was set on A-weighted decibel (dBA) and ambient noise was sampled twice at every cardinal point at 2 m from the nest, producing a total of eight measurements at every nest (each measurement lasted 1 min). Then measurements were mean-averaged in one single measurement. All the recordings were made in the same time span of the experiments (6–11 am). Measurements were averaged in one single measurement (see Table (A1) in the appendix). The distance of the nest from road was measured using Google Maps updated in year 2024 (10 m resolution).

### **3. Data analysis**

Data analysis was performed using R (v4.1.1; R Core Team 2024). Linear mixed models (LMMs) were conducted using the ‘lmer’ function in *lme4* package v. 1.1-32 (Bates et al., 2015) and the backward stepwise approach was used. Models initially included two-way interactions between all fixed effects with interactions removed if not statistically significant ( $P < 0.05$ ). The same procedure was adopted for both the response variable: food delivery (feeding rate) and nest attendance (time spent in the nest).

To test the relationship between food delivery and traffic noise, an LMM was used with feeding rate as response variable. This model included clutch size (number of nestlings), location (KLF Forest, Cumberland Wild Park, OGB, and Meadow) and playback type (control and treatment) as fixed effects and nest attempt as a random effect. We initially also included three interactions terms between playback type and distance from the road, ambient noise, and playback order, respectively, but these were not statistically significant and subsequently removed from the model. An identical LMM was performed with nest attendance (log-transformed) as response variable. Model fit was tested using “DHARMA” and the residual

distribution was tested using “Shapiro.test” for every model to ensure reliable results. More information on the R script is available in the Appendix section.

## 4. Results

### 4.1 Feeding rate and traffic noise

Table 1: Output from linear mixed models testing which factors influence feeding rate. Model (a) is a full model containing interaction variables with the treatment which revealed to be not significant ( Distance from the road:  $t$ -value = 0.125,  $P$ -value = 0.901, Ambient noise:  $t$ -value = -0.549,  $P$ -value = 0.588, Playback order:  $t$ -value = 1.669,  $P$ -value = 0.109) therefore removed together with not significant fixed effects.

	Estimate	Std. Error	t value	P value
<b>Fixed effects, N = 58</b>				
<b>observations</b>				
from 29 nest attempts				
a) Full model				
Distance_road	0.00	0.03	-0.11	0.915
Type[Treatment]	-11.20	19.40	-0.58	0.566
n_nestlings	3.20	0.97	3.31	<b>0.003 **</b>
Location[Meadow]	3.83	8.21	0.47	0.645
Location[OGB]	-11.19	8.33	-1.34	0.194
Location[Wildpark]	-10.06	6.29	-1.60	0.124
Ambient_noise	0.10	0.33	0.29	0.776
Playback_order	-7.90	4.35	-1.80	0.078
Distance_road:Type[Treatment]	0.00	0.03	0.13	0.901
Type[Treatment]:ambient_noise	-0.16	0.30	-0.55	0.588
Type[Treatment]:Playback_orde	11.61	6.95	1.67	0.109
r				

(b) Reduced model				
N_nestlings	3.41	0.90	3.86	<b>0.0007</b>
Location[Meadow]	4.07	7.72	0.53	0.603
Location[OGB]	-11.50	5.94	-1.94	0.064
Location[Wildpark]	-10.24	4.43	-2.31	<b>0.029 *</b>
Type[Treatment]	-3.80	2.52	-1.49	0.147

Feeding rate did not vary significantly between the control and treatment periods ( $t = -1.49, p = 0.147$ ) The feeding rate did not change significantly in OGB ( $t = -1.94, p = 0.194$ ) and Meadow ( $t = 0.53, p = 0.603$ ). but in the Wild Park, feeding rate was lower respect to other locations ( $t = -2.31, p = 0.029$ ). The distance of the nest box from the road did not affect the response to the treatment ( $t = -0.11, p = 0.915$ ). Ambient noise did not affect feeding rate ( $t = 0.29, p = 0.776$ ) as appear in table 1. On the other hand, the number of nestlings affects the feeding rate ( $t = 3.31, p = 0.003$ ).

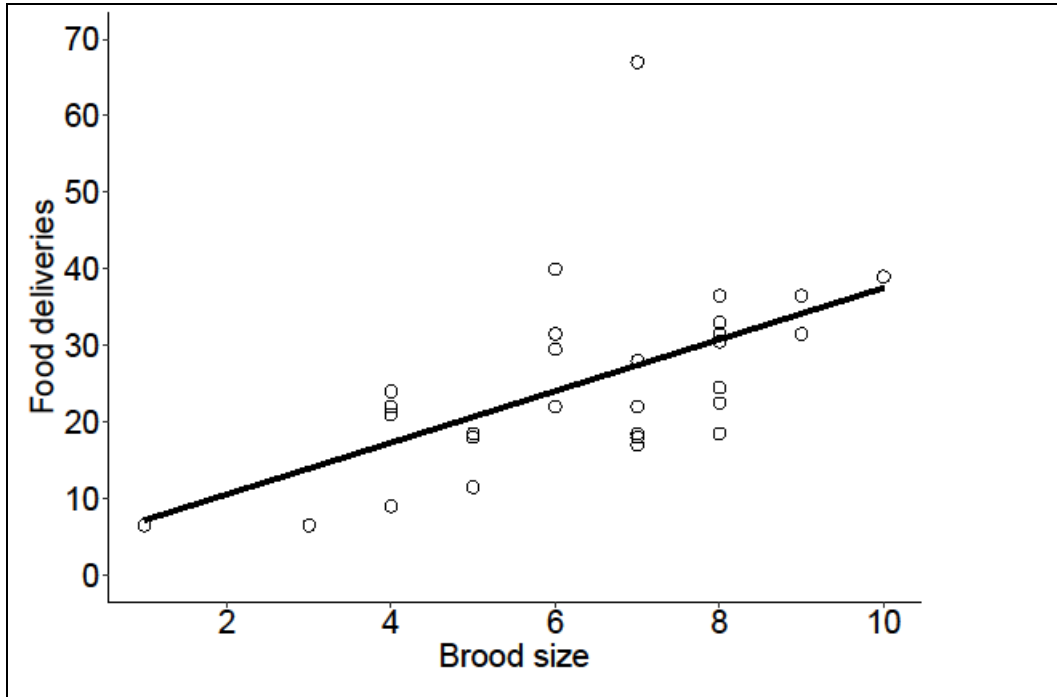


Figure 4: This graph represents mean food delivery rates (number of trips per hour) directly proportional to brood size (number of nestlings). Voids represent each nest attempt, while the thick line represents the regression line.

#### 4.2 Nest attendance and traffic noise

Table 2: This table illustrates the outputs of the models for nest attendance log-transformed. Model (a) is a full model containing interaction variables with the treatment which revealed to be not significant ( Distance from the road: t-value = 0.909, P-value = 0.372, Ambient noise: t-value = -0.752, P-value = 0.459, Playback order: t-value = -0.016, P-value = 0.988) therefore removed together with not significant fixed effects. In both Model(a) and (b) the treatment does not affect nest attendance (p-value = 0.582, p value = 0.527)

	Estimate	Std. Error	t value	P value
<b>Fixed effects, N = 58 observations</b>				
<b>from 29 nest attempts</b>				
(a) Full model				
Distance_road	0.00	0.00	0.44	0.661
Type[Treatment]	0.25	0.44	0.55	0.582
n_nestlings	-0.01	0.02	-0.60	0.577
Location[Meadow]	0.00	0.20	-0.02	0.988

Location[OGB]	-0.06	0.20	-0.33	0.743
Location[Wildpark]	-0.08	0.14	-0.56	0.582
Ambient_noise	0.00	0.00	-0.20	0.846
Playback_order	-0.12	0.10	-1.16	0.254
Distance_road:Type[Treatment]	0.00	0.00	0.91	0.372
Type[Treatment]:ambient_noise	0.00	0.01	-0.80	0.459
Type[Treatment]:Playback_order	0.00	0.16	-0.02	0.988
(b) Reduced model				
Type[Treatment]	0.00	0.00	0.64	0.527
Playback_order	-0.12	0.00	-2.06	<b>0.049</b>

Nest attendance did not differ significantly between control and treatment periods ( $t = 0.64, p = 0.527$ ) as depicted in table 2. The time spent by the parents inside the nest did not vary between locations (OGB:  $t = -0.33, p = 0.743$ , Wild Park:  $t = -0.56, p = 0.582$ , Meadow:  $t = -0.02, p = 0.988$ ) and the distance of the nest from the road did not predict parental response ( $t = 0.44, p = 0.661$ ). Furthermore, ambient noise did not influence the behavior of the parents during the treatment ( $t = -0.20, p = 0.846$ ) as appear in table 2. The number of nestlings did not influence the time spent in the nest by the parents ( $t = -0.60, p = 0.577$ )

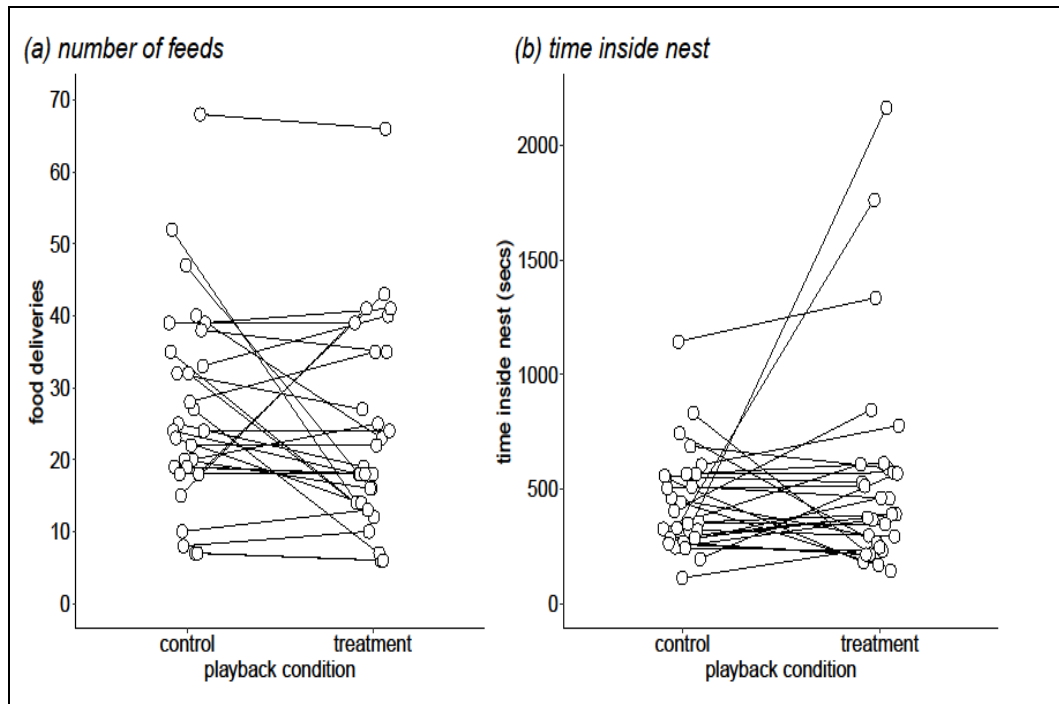


Figure 5: Food deliveries(a) and nest attendance(b) plotted for both control and treatment condition

In Figure 5(a), raw data points for each nest are plotted for the control and treatment periods. There was no substantial difference between control and treatment. Figure 5(b) outline a similar scenario, despite the presence of two outliers, nest attendance remained mostly unaltered between control and treatment.

## 5. Discussion

My results show that feeding rate increased with brood size (number of nestlings). Contrary to my predictions, feeding rate and nest attendance were not reduced during the experimental noise treatment. This may be because birds at the study site have already experienced traffic noise and adapted to the stimulus (Blas, 2015). This would explain why ambient noise did not affect their response during the treatment. It has been demonstrated that in Great Tits signal efficacy improved during noise exposure. In fact, birds counteract low frequency noise in urban environments by increasing the frequency of their song (Langemann et al., 1998). Another possible explanation for these results is that Great Tit nestlings increased

begging amplitude to overcome traffic noise masking. This would be in contrast with findings of impaired communication in Blue Tits (Lucass et al., 2016). Given that nestling begging can significantly affect food provisioning (Bengtsson et al., 1983), Great Tits may have increased their ability to discriminate begging calls over traffic noise (Pohl et al., 2012).

While previous research found that exposure to pre- and postnatal traffic noise cumulatively impaired nestling growth and physiology and aggravated telomere shortening across life stages until adulthood (Meillère et al., 2024), However, differently from what was hypothesised by Halfwerk et al. (2011), my results demonstrate that traffic noise does not have direct negative effects on parental care.

While this research improves our understanding of traffic noise and its effect on a breeding bird population, these results cannot necessarily be generalized to other species that share the same habitat and that may be affected by the presence of a road, such as Blue Tits, Coal Tits, Marsh Tits, European Crested Tits, Eurasian Nuthatches and Collared Flycatchers. Perhaps the urban-adaptability of a species is a more relevant predictor of its noise tolerance: urban-adapted birds may be more tolerant of noise compared to non-urban-adapted species. Australian Magpies (*Gymnorhina tibicen*) and European Starlings (*Sturnus vulgaris*) appear to be well adapted to urban noise (Linley et al., 2018, Walther et al., 2020), while others like the Goldcrest (*Regulus regulus*), and the declining European Turtle Dove (*Streptopelia turtur*) are not (Patón et al., 2012). Indeed, bird species that are generalists (i.e. having a large niche breadth), with large clutch size, are among the most urban-tolerant bird species. Conversely, specialized feeding strategies (i.e. insectivores and granivores) are negatively associated with urbanization (Callaghan et al., 2019).

Indeed, one study tested whether traffic noise reduced breeding success in Tree Swallows in urbanized areas and demonstrated that exposure to traffic noise altered growth rates and subsequent survival in chicks (Injaian et al., 2019). Another study on White-crowned Sparrows (*Zonotrichia leucophrys*) found that nestlings developed faster close to the road because paternal provisioning rates increased with road proximity (Crino et al., 2011). Whereas traffic noise effects on parental

care were still uncertain and varied between different species, this study provides new evidence on the resilience of this Great Tit population.

In this study, nests were experimentally exposed to continuous traffic noise source, but discontinuous traffic noise could lead to different results. Another aspect that limited this study was that all the nest boxes tested were in the same habitat. Different habitat types could influence traffic noise transmission and so generate different results. Unfortunately, it was not possible to create a sound map of the area because high-quality microphones were not available. The relationship between the proximity to a road and the breeding success was not investigated in this study and needs to be verified in further studies.

## **6. Conclusions**

My study showed that there was no effect of traffic noise exposure on feeding rate or nest attendance in Great Tits. The ambient noise around the nest box and the distance from the main road did not affect parents' response to the playback. This suggests that Great Tits are relatively tolerant of short-term noise near the nest. Future research might consider other factors (i.e. the effects of longer-term noise pollution) that may affect diverse species that share the same habitat.

In fact, other studies revealed deleterious effects of traffic on bird populations (Patón et al., 2012), one in particular highlights traffic noise as the major component that affects species presence along a road (McClure et al., 2013). In many cases, the reasons why traffic noise could be deleterious for some species remain unknown or unclear. This research contributed to fill the gap in knowledge, revealing that Great Tit parental care was not affected by traffic noise, in contrast with Halfwerk, et. al. (2011). Nonetheless, traffic noise persistence may still reduce breeding success. Further studies need to investigate whether these findings may be applied to other species, considering that different species may react differently to the same stimulus. To better understand the implications of these results, future studies could address long-term effects of traffic major components, such as noise, vibrations, and lights, on bird communities recruitment of the area. Further research is needed to determine the relationship between traffic and mortality rates to establish concrete conservation actions.

## 7. References

<https://www.birdlife.org/news/2022/09/28/state-of-the-worlds-birds-2022-paints-most-concerning-picture-for-nature-yet/>

Gilchrist, A., Allouche, E. N., & Cowan, D. (2003). Prediction and mitigation of construction noise in an urban environment. *Canadian Journal of Civil Engineering*, 30(4), 659-672. <https://doi.org/10.1139/103-019>

Slabbekoorn, H., & Ripmeester, E. A. P. (2008). Birdsong and anthropogenic noise: implications and applications for conservation. *Molecular Ecology*, 17(1), 72-83. <https://doi.org/10.1111/j.1365-294X.2007.03487.x>

Brumm, H. (2004). The impact of environmental noise on song amplitude in a territorial bird. *Journal of Animal Ecology*, 434-440. <https://doi.org/10.1111/j.0021-8790.2004.00814.x>.

Leonard, M. L., & Horn, A. G. (2005). Ambient noise and the design of begging signals. *Proceedings of the Royal Society B: Biological Sciences*, 272(1563), 651-656. <http://doi.org/10.1098/rspb.2004.3021>

Summers, P.D., Cunnington, G.M. and Fahrig, L. (2011), Are the negative effects of roads on breeding birds caused by traffic noise?. *Journal of Applied Ecology*, 48: 1527-1534. <https://doi.org/10.1111/j.1365-2664.2011.02041.x>

Kempenaers, B., Borgström, P., Loës, P., Schlicht, E., & Valcu, M. (2010). Artificial night lighting affects dawn song, extra-pair siring success, and lay date in songbirds. *Current Biology*, 20(19), 1735-1739.  
DOI: [10.1016/j.cub.2010.08.028](https://doi.org/10.1016/j.cub.2010.08.028)

Injaian, A. S., Taff, C. C., & Patricelli, G. L. (2018). Experimental anthropogenic noise impacts avian parental behaviour, nestling growth and nestling oxidative stress. *Animal behaviour*, 136, 31-39.  
<https://doi.org/10.1016/j.anbehav.2017.12.003>

Halfwerk, W., Holleman, L.J.M., Lessells, C.M. and Slabbekoorn, H. (2011), Negative impact of traffic noise on avian reproductive success. *Journal of Applied Ecology*, 48: 210-219. <https://doi.org/10.1111/j.1365-2664.2010.01914.x>

Barba, E., Atiénzar, F., Marín, M., Monrós, J. S., & Gil-Delgado, J. A. (2009), Patterns of nestling provisioning by a single-prey loader bird, Great Tit *Parus major*. *Bird Study*, 56(2), 187–197. <https://doi.org/10.1080/00063650902792049>

Blas J. (2015) Stress in Birds *Sturkie's Avian Physiology* (6) ,33 769-810  
<https://doi.org/10.1016/B978-0-12-407160-5.00033-6>

Kluijver, H. N. (1950), Daily routines of the Great Tit, *Parus m. major*  
*L. Ardea*, 55(1–2), 99-135. <https://doi.org/10.5253/arde.v38.p99>

Langemann U., Gauger B., Klump, G. M., (1998) Auditory sensitivity in the Great Tit: perception of signals in the presence and absence of noise. *Animal Behaviour*, 56,3, 763-769. <https://doi.org/10.1006/anbe.1998.0879>

Pohl, N. U., Leadbeater, E., Slabbekoorn, H., Klump, G. M., & Langemann, U. (2012). Great tits in urban noise benefit from high frequencies in song detection and discrimination. *Animal Behaviour*, 83(3), 711-721.

<https://doi.org/10.1016/j.anbehav.2011.12.019>

Bengtsson, H., & Rydén, O. (1983). Parental feeding rate in relation to begging behavior in asynchronously hatched broods of the great tit *Parus major*: an experimental study. *Behavioral Ecology and Sociobiology*, 12, 243-251.  
<https://doi.org/10.1007/BF00290777>

Naef-Daenzer, L., Naef-Daenzer, B. and Nager, R.G. (2000), Prey selection and foraging performance of breeding Great Tits *Parus major* in relation to food availability. *Journal of Avian Biology*, 31: 206-214. <https://doi.org/10.1034/j.1600-048X.2000.310212.x>

Lucass, C., Eens, M., & Müller, W. (2016). When ambient noise impairs parent-offspring communication. *Environmental Pollution*, 212, 592-597.

<https://doi.org/10.1016/j.envpol.2016.03.015>.

Mänd, R., Leivits, A., Leivits, M., & Rodenhouse, N. L. (2009). Provision of nestboxes raises the breeding density of Great Tits *Parus major* equally in coniferous and deciduous woodland. *Ibis*, *151*(3), 487-492.

<https://doi.org/10.1111/j.1474-919X.2009.00929.x>

Amrhein, V., Johannessen, L.E., Kristiansen, L. *et al.* Reproductive strategy and singing activity: Blue Tit and Great Tit compared. *Behav Ecol Sociobiol* **62**, 1633–1641 (2008). <https://doi.org/10.1007/s00265-008-0592-6>

Meijer, J. R., Huijbregts, M. A., Schotten, K. C., & Schipper, A. M. (2018). Global patterns of current and future road infrastructure. *Environmental Research Letters*, *13*(6), 064006. <https://doi.org/10.1088/1748-9326/aabd42>

Meillère A. , Buchanan K. L., Eastwood J. R., Mariette M. M., (2024) Pre- and postnatal noise directly impairs avian development, with fitness consequences. *Science*: 384,475-480 <https://doi.org/10.1126/science.ade5868>

Royama, T. R. (1966). Factors governing feeding rate, food requirement and brood size of nestling Great Tits *Parus major*. *Ibis*, *108*(3), 313-347.

<https://doi.org/10.1111/j.1474-919X.1966.tb07348.x>

Royama, T. (1970). Factors governing the hunting behaviour and selection of food by the Great Tit (*Parus major* L.). *The Journal of Animal Ecology*, 619-668.

<https://doi.org/10.2307/2858>

Haftorn, S. (1981). Incubation during the Egg-Laying Period in Relation to Clutch-Size and Other Aspects of Reproduction in the Great Tit *Parus major*. *Ornis Scandinavica (Scandinavian Journal of Ornithology)*, *12*(3), 169–185.

<https://doi.org/10.2307/3676074>

Jongsomjit, D., Jones, S. L., Gardali, T., Geupel, G. R., & Gouse, P. J. (2007). A guide to nestling development and aging in altricial passerines. *BTP-R6008-2007*, 1-66, <https://digitalcommons.unl.edu/usfwspubs/161/>

Lambrechts, M. M., Marrot, P., Fargevieille, A., Giovannini, P., Lucas, A., Demeyrier, V., ... & Doutrelant, C. (2016). Nest size is not closely related to

breeding success in Blue Tits: A long-term nest-box study in a Mediterranean oak habitat. *The Auk: Ornithological Advances*, 133(2), 198-204.  
<https://doi.org/10.1642/AUK-15-214.1>

Pietz, P. J., Granfors, D. A., & Grant, T. A. (2012). Hatching and fledging times from grassland passerine nests. *Studies in Avian Biology*, 43, 47-60.  
<https://doi.org/10.1525/9780520954090-007>

McClure, C. J., Ware, H. E., Carlisle, J., Kaltenecker, G., & Barber, J. R. (2013). An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. *Proceedings of the Royal Society B: Biological Sciences*, 280(1773), 20132290. <http://doi.org/10.1098/rspb.2013.2290>

Crino, O. L., Van Oorschot, B. K., Johnson, E. E., Malisch, J. L., & Breuner, C. W. (2011). Proximity to a high traffic road: glucocorticoid and life history consequences for nestling white-crowned sparrows. *General and Comparative Endocrinology*, 173(2), 323-332.

<https://doi.org/10.1016/j.ygcen.2011.06.001>.

Injaian, A. S., Gonzalez-Gomez, P. L., Taff, C. C., Bird, A. K., Ziur, A. D., Patricelli, G. L., ... & Wingfield, J. C. (2019). Traffic noise exposure alters nestling physiology and telomere attrition through direct, but not maternal, effects in a free-living bird. *General and Comparative Endocrinology*, 276, 14-21.  
<https://doi.org/10.1016/j.ygcen.2019.02.017>.

Parris, K. M., & Schneider, A. (2009). Impacts of traffic noise and traffic volume on birds of roadside habitats. *Ecology and society*, 14(1).  
<http://www.jstor.org/stable/26268029>

Grade, A. M., & Sieving, K. E. (2016). When the birds go unheard: highway noise disrupts information transfer between bird species. *Biology letters*, 12(4), 20160113. <http://doi.org/10.1098/rsbl.2016.0113>

Viigipuu, R., Mägi, M., & Tilgar, V. (2023). Great tits alter incubation behaviour in noisy environments. *Journal of Ethology*, 41(1), 39-46.

<https://doi.org/10.1007/s10164-022-00765-y>

Grunst, M. L., Grunst, A. S., Pinxten, R., & Eens, M. (2021). Little parental response to anthropogenic noise in an urban songbird, but evidence for individual differences in sensitivity. *Science of The Total Environment*, 769, 144554. <https://doi.org/10.1016/j.scitotenv.2020.144554>.

Pagani-Núñez, E., & Senar, J. C. (2013). One hour of sampling is enough: great tit *Parus major* parents feed their nestlings consistently across time. *Acta Ornithologica*, 48(2), 194-200. <https://doi.org/10.3161/000164513X678847>

Calladine, J., Jarrett, D., & Wilson, M. (2019). Breeding bird assemblages supported by developing upland shrub woodland are influenced by microclimate and habitat structure. *Bird Study*, 66(2), 178-186.

<https://doi.org/10.1080/00063657.2019.1635986>

Tryjanowski, P., Morelli, F., Skórka, P. (2015). Who started first? Bird species visiting novel birdfeeders. *Sci Rep* 5, 11858 <https://doi.org/10.1038/srep11858>

Krebs, J., Ashcroft, R., & Webber, M. (1978). Song repertoires and territory defence in the great tit. *Nature*, 271(5645), 539-542.

<https://doi.org/10.1038/271539a0>

Kociolek, A. V., Clevenger, A. P., St. Clair, C. C., & Proppe, D. S. (2011). Effects of road networks on bird populations. *Conservation Biology*, 25(2), 241-249. <https://doi.org/10.1111/j.1523-1739.2010.01635.x>

Pimm, S. L., Jenkins, C. N., Abell, R., Brooks, T. M., Gittleman, J. L., Joppa, L. N., ... & Sexton, J. O. (2014). The biodiversity of species and their rates of extinction, distribution, and protection. *science*, 344(6187), 1246752. DOI:[10.1126/science.1246752](https://doi.org/10.1126/science.1246752)

Oliver, T.H. and Morecroft, M.D. (2014), Interactions between climate change and land use change on biodiversity: attribution problems, risks, and opportunities. *WIREs Clim Change*, 5: 317-335. <https://doi.org/10.1002/wcc.271>

Verboven, N., Tinbergen, J. M., & Verhulst, S. (2001). Food, reproductive success and multiple breeding in the Great Tit *Parus major*. *Ardea*, 89(2), 387-406.

<https://research.rug.nl/en/publications/food-reproductive-success-and-multiple-breeding-in-the-great-tit>

Barba, E., Gil-Delgado, J. A., & Monrós, J. S. (1995). The Costs of Being Late: Consequences of Delaying Great Tit *Parus major* First Clutches. *Journal of Animal Ecology*, 64(5), 642–651. <https://doi.org/10.2307/5806>

Summers, P.D., Cunnington, G.M. and Fahrig, L. (2011), Are the negative effects of roads on breeding birds caused by traffic noise?. *Journal of Applied Ecology*, 48, 1527-1534. <https://doi.org/10.1111/j.1365-2664.2011.02041.x>

Kuitunen, M. T., Viljanen, J., Rossi, E., & Stenroos, A. (2003). Impact of busy roads on breeding success in pied flycatchers *Ficedula hypoleuca*. *Environmental Management*, 31, 0079-0085. <https://doi.org/10.1007/s00267-002-2694-7>

Kleist, N. J., Guralnick, R. P., Cruz, A., Lowry, C. A., & Francis, C. D. (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(4), E648-E657.

<https://doi.org/10.1073/pnas.1709200115>

Herrera-Montes, M. I., & Aide, T. M. (2011). Impacts of traffic noise on anuran and bird communities. *Urban Ecosystems*, 14, 415-427. <https://doi.org/10.1007/s11252-011-0158-7>

Hamer A. J., McDonnell M. J., (2008) Amphibian ecology and conservation in the urbanising world: A review, *Biological Conservation*, 141(10), 2432-2449, ISSN 0006-3207,

<https://doi.org/10.1016/j.biocon.2008.07.020>.

Sparling, D. W. (2003). A review of the role of contaminants in amphibian declines. *Handbook of ecotoxicology*, 2, 1099-1128.

<https://www.academia.edu/download/32938319/handbook.of.ecotoxicology.2nd.ed.2003.pdf#page=1124>.

Boone, M. D., Hua, J., Gabor, C. R., Gomez-Mestre, I., Katzenberger, M., McMahon, T. A., & Rumschlag, S. L. (2024). Ecotoxicology: amphibian

vulnerability to chemical contamination. *Amphibian Conservation Action Plan (ACAP): a status review and roadmap for global amphibian conservation*. IUCN Species Survival Commission (SSC), Amphibian Specialist Group, Gland, Switzerland, 89-113. <https://doi.org/10.2305/QWVH2717>

Casey, R., Shaw, A., Massal, L., & Snodgrass, J. (2005). Stormwater retention ponds in suburban Maryland, USA. *Bull. Environ. Contam. Toxicol*, 74, 273-280. <https://doi.org/10.1007/s00128-004-0580-0>

Snodgrass, J., Casey, R., & Massal, L. (2007). Nitrogen pollution of stormwater ponds: Potential for toxic effects on amphibian embryos and larvae. *Applied Herpetology*, 4(1), 19-29. <https://doi.org/10.1163/157075407779766714>

Hasenbein, S., Lawler, S.P., Geist, J. and Connon, R.E. (2016), A long-term assessment of pesticide mixture effects on aquatic invertebrate communities. *Environ Toxicol Chem*, 35, 218-232. <https://doi.org/10.1002/etc.3187>

Gunstone, T., Cornelisse, T., Klein, K., Dubey, A., & Donley, N. (2021). Pesticides and soil invertebrates: A hazard assessment. *Frontiers in Environmental Science*, 9, 643847.

<https://doi.org/10.3389/fenvs.2021.643847>

Wilson, J. D., Morris, A. J., Arroyo, B. E., Clark, S. C., & Bradbury, R. B. (1999). A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. *Agriculture, Ecosystems & Environment*, 75(1-2), 13-30.

[https://doi.org/10.1016/S0167-8809\(99\)00064-X](https://doi.org/10.1016/S0167-8809(99)00064-X)Get rights and content

Callaghan, C. T., Major, R. E., Wilshire, J. H., Martin, J. M., Kingsford, R. T., & Cornwell, W. K. (2019). Generalists are the most urban-tolerant of birds: a phylogenetically controlled analysis of ecological and life history traits using a novel continuous measure of bird responses to urbanization. *Oikos*, 128(6), 845-858. <https://doi.org/10.1111/oik.06158>

Linley, G. D., Kostoglou, K., Jit, R., & Weston, M. A. (2018). Australian magpies exhibit increased tolerance of aircraft noise on an airport, and are more responsive

to take-off than to landing noises. *Wildlife Research*, 45(3), 282-286.  
<https://doi.org/10.1071/WR18039>

Patón, D., Romero, F., Cuenca, J., & Escudero, J. C. (2012). Tolerance to noise in 91 bird species from 27 urban gardens of Iberian Peninsula. *Landscape and Urban Planning*, 104(1), 1-8.

<https://doi.org/10.1016/j.landurbplan.2011.09.002>

Maziarz, M., Wesołowski, T., Hebda, G., Cholewa, M., & Broughton, R. K. (2016). Breeding success of the Great Tit *Parus major* in relation to attributes of natural nest cavities in a primeval forest. *Journal of Ornithology*, 157, 343-354.  
<https://doi.org/10.1007/s10336-015-1294-2>

Lambrechts, M. M., Charmantier, A., Demeyrier, V., Lucas, A., Perret, S., Abouladzé, M., ... & Grégoire, A. (2017). Nest design in a changing world: Great tit *Parus major* nests from a Mediterranean city environment as a case study. *Urban Ecosystems*, 20, 1181-1190.

<https://doi.org/10.1007/s11252-017-0670-5>

Dingemanse, N. J., Bouwman, K. M., van de Pol, M., van Overveld, T., Patrick, S. C., Matthysen, E., & Quinn, J. L. (2012). Variation in personality and behavioural plasticity across four populations of the great tit *Parus major*. *Journal of Animal Ecology*, 81(1), 116-126.

<https://doi.org/10.1111/j.1365-2656.2011.01877.x>

Smallegange, I. M., Fiedler, W., Köppen, U., Geiter, O., & Bairlein, F. (2010). Tits on the move: exploring the impact of environmental change on blue tit and great tit migration distance. *Journal of Animal Ecology*, 79(2), 350-357.  
<https://doi.org/10.1111/j.1365-2656.2009.01643.x>

Caorsi, V., Sprau, P., Zollinger, S. A., & Brumm, H. (2019). Nocturnal resting behaviour in urban great tits and its relation to anthropogenic disturbance and microclimate. *Behavioral Ecology and Sociobiology*, 73, 1-9.  
<https://doi.org/10.1007/s00265-018-2624-1>

Dominoni, D., Smit, J. A., Visser, M. E., & Halfwerk, W. (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. <https://doi.org/10.1016/j.envpol.2019.113314>

R Core Team (2024). *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria. <<https://www.R-project.org/>>.

Bates D, Mächler M, Bolker B, Walker S (2015). “Fitting Linear Mixed-Effects Models Using lme4.” *Journal of Statistical Software*, 67(1), 1–48. <https://doi.org/10.18637/jss.v067.i01>

Newbold, T., Bentley, L. F., Hill, S. L., Edgar, M. J., Horton, M., Su, G., ... & Purvis, A. (2020). Global effects of land use on biodiversity differ among functional groups. *Functional Ecology*, 34(3), 684-693. <https://doi.org/10.1111/1365-2435.13500>

## 8. Acknowledgements

I would like to thank the University of Padova and the University of Vienna for giving me the possibility to do my traineeship at the Konrad Lorenz Research Center. A special thank you goes to Dr. Andrew Katsis, Dr. Didone Frigerio, Alper Yelimlieş, Francesca Castellazzi, Prof. Lucio Bonato and Dr. Sonia Kleindorfer, who helped me during the writing of my thesis and during fieldwork. A special thank you to Dr. Josef Hemetsberger who taught me how to ring nestlings. Last but not least I would like to say thank you to my girlfriend for supporting me during the writing of this thesis.

## 9. Appendix

## traffic noise filtering code R

```
library(seewave)
```

```
library(tuneR)
```

```
# read white noise
```

```
white_noise <- readWave("white_noise.wav")
```

```
#read vehicle noises
```

```
car_1 <- readWave("car1.wav")
```

```
car_2 <- readWave("car2.wav")
```

```
car_3 <- readWave("car3.wav")
```

```
car_4 <- readWave("car4.wav")
```

```
#create mean spectrum for each file
```

```
car1_meanspec <- meanspec(car_1)
```

```
car2_meanspec <- meanspec(car_2)
```

```
car3_meanspec <- meanspec(car_3)
```

```
car4_meanspec <- meanspec(car_4)
```

```
#filter white noise according to mean spectrum profile of each vehicle sound
```

```
white_noise_1 <- ffilter(white_noise, wl = 512, custom = car1_meanspec, output  
= "Wave")
```

```
meanspec(white_noise_1)
```

```
white_noise_2 <- ffilter(white_noise, wl = 512, custom = car2_meanspec, output  
= "Wave")
```

```
meanspec(white_noise_2)
```

```
white_noise_3 <- ffilter(white_noise, wl = 512, custom = car3_meanspec, output  
= "Wave")
```

```
meanspec(white_noise_3)
```

```
white_noise_4 <- ffilter(white_noise, wl = 512, custom = car4_meanspec, output  
= "Wave")
```

```
meanspec(white_noise_4)
```

```
#write wave files
```

```
writeWave(white_noise_1, filename = "continuous_car_noise_1.wav")
```

```
writeWave(white_noise_2, filename = "continuous_car_noise_2.wav")
```

```
writeWave(white_noise_3, filename = "continuous_car_noise_3.wav")
```

```
writeWave(white_noise_4, filename = "continuous_car_noise_4.wav")
```

```
#R code for nestbox playback experiment
```

# First install all the required packages using the following templates. You only need to do this once:

```
install.packages("effects")
```

```
install.packages("gridExtra")
```

```
install.packages("grid")
```

```
install.packages("ggpubr")
```

```
install.packages("lmtest")
```

```
install.packages("MuMIn")
```

```
install.packages("ggplot2")
```

```
install.packages("plyr")
```

```
install.packages("dplyr")
```

```
install.packages("plotrix")
```

```
install.packages("conflicted")
```

```
install.packages("ggbeeswarm")
```

```
install.packages("lme4")
```

```
install.packages("lmerTest")
```

```
install.packages("tidyverse")
```

```
install.packages("DHARMA")
```

# R script for conducting data analyses and producing graphs

# Packages to load: you need to load these every time you open R.

```
library(effects) #version 4.2-2
```

```
library(gridExtra) #version 2.3
```

```

library(grid) #base package

library(ggpubr) #version 0.6.0

library(lmtest) #version 0.9-40

library(MuMIn) #version 1.47.5

library(ggplot2) #version 3.4.1

library(plyr) #version 1.8.8

library(dplyr) #version 1.1.1

library(plotrix) #version 3.8-2

library(conflicted) #version 1.2.0

library(ggbeeswarm) #version 0.7.1

library(lme4) #version 1.1-32

library(lmerTest) #version 3.1-3

library(tidyverse) #version 2.0.0

library(DHARMA)

conflict_prefer("rename", "plyr")

conflict_prefer("select", "dplyr")

conflict_prefer("filter", "dplyr")

conflict_prefer("lmer", "lmerTest")

# Import supplementary data file (sheet: "Dataset"), naming the dataset
"NestData"

NestData <- readXL("C:/Users/Utente/Desktop/Data
analysis/FoodDelivery_parental care_data_2024-08-21.xlsx", rownames=FALSE,
header=TRUE, na="", sheet="Foglio1",

```

```

stringsAsFactors=TRUE)

# Check number of rows in dataset
nrow(NestData)

# Run linear mixed model testing which factors predict feeding rate, including
three interaction terms

model.1 <- lmer(Feeding_Rate ~ Distance_road*Type + n_nestlings + Location +
ambient_noise*Type + Type + Type*Playback_order + (1|NestAttemptID), data =
NestData)

summary(model.1)

rand(model.1)

plot(allEffects(model.1))

# Reduced model without any interactions

model.1<- lmer(Feeding_Rate ~ Distance_road + n_nestlings + Location +
ambient_noise + Type + (1|NestAttemptID), data = NestData)

summary(model.1)

rand(model.1)

plot(allEffects(model.1))

# Fully reduced model

model.1<- lmer(Feeding_Rate ~ n_nestlings + Location + Type +
(1|NestAttemptID), data = NestData)

summary(model.1)

```

```

rand(model.1)

plot(allEffects(model.1))

#Checking model fit (DHARMA)

res=simulateResiduals(model.1)

plot(res)

#Testing model fit

plot(resid(model.1)~fitted(model.1)) + abline(h=0)

hist(resid(model.1))

qqnorm(resid(model.1));qqline(resid(model.1))

normalityTest(~resid(model.1), test="shapiro.test", data=NestData)

# 'Time in nest' as response variable

# possible transformations

# square-root, cube-root, logarithmic (log10)

# Run linear mixed model testing which factors predict time in nest, including
three interaction terms

model.1<- lmer(log10(Time_in_nest) ~ Distance_road*Type + n_nestlings +
Location + ambient_noise*Type + Type + Playback_order*Type +
(1|NestAttemptID), data = NestData)

summary(model.1)

rand(model.1)

```

```

plot(allEffects(model.1))

# Reduced model without any interactions

model.1<- lmer(log10(Time_in_nest) ~ Distance_road + n_nestlings + Location +
ambient_noise + Type + Playback_order + (1|NestAttemptID), data = NestData)

summary(model.1)

rand(model.1)

plot(allEffects(model.1))

# Fully reduced model

model.1<- lmer(log10(Time_in_nest) ~ Type + Playback_order +
(1|NestAttemptID), data = NestData)

summary(model.1)

rand(model.1)

plot(allEffects(model.1))

#Checking model fit (DHARMA)

res=simulateResiduals(model.1)

plot(res)

#Testing model fit

plot(resid(model.1)~fitted(model.1)) + abline(h=0)

hist(resid(model.1))

qqnorm(resid(model.1));qqline(resid(model.1))

```

```
normalityTest(~resid(model.1), test="shapiro.test", data=NestData)
```

```
#####
```

```
## Figures ##
```

```
#####
```

```
#####
```

```
# Treatment vs Control: Number of feeds #
```

```
#####
```

```
#+++++
```

```
# Function to calculate the mean and the standard deviation
```

```
  for each group
```

```
#+++++
```

```
# data : a data frame
```

```
# varname : the name of a column containing the variable
```

```
  to be summarized
```

```
# groupnames : vector of column names to be used as
```

```
  grouping variables
```

```
data_summary <- function(data, varname, groupnames){
```

```
  require(dplyr)
```

```
  summary_func <- function(x, col){
```

```
    c(mean = mean(x[[col]], na.rm=TRUE),
```

```
      SEM = ((sd(x[[col]])/sqrt(length(x[[col]]))), na.rm=TRUE)
```

```

}

data_sum<-ddply(data, groupnames, .fun=summary_func,
               varname)

data_sum <- plyr::rename(data_sum, c("mean" = varname))

return(data_sum)
}

df3 <- data_summary(NestData, varname="Feeding_Rate",
                   groupnames=c("Type"))

df3$Type=as.factor(df3$Type)

head(df3)

mean_data <- group_by(NestData, Type) %>%

  dplyr::summarise(Feeding_Rate = mean(Feeding_Rate, na.rm = TRUE))

pd <- position_dodge(0.20)

# Create plot with data points

NumberOfFeeds <- ggplot(NestData, aes(x=Type, y=Feeding_Rate,
group=NestAttemptID)) + geom_line(position = pd) +

geom_point(position = pd, size=4, shape=21, fill = "white") +
scale_fill_manual(breaks=c("Control","Treatment"),
labels=c("control","treatment")) +

theme(panel.border = element_blank(), panel.background =
element_rect(fill="white"), panel.grid.major = element_blank(),

```

```

panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"),
axis.title.x = element_text(colour="black", size=16),
axis.title.y = element_text(colour="black", size=16)) +
labs(x="playback condition", y="food deliveries") + theme(axis.text.x=
element_text(colour="black", size=16),
axis.text.y= element_text(colour="black", size=16)) + coord_cartesian(ylim=c(0,
70)) +
  scale_y_continuous(breaks=seq(0, 70, 10)) + scale_x_discrete(labels=
c("control", "treatment")) + theme(legend.position = "none")

#####

# Treatment vs Control: Time in nest #

#####

#++++++

# Function to calculate the mean and the standard deviation

# for each group

#++++++

# data : a data frame

# varname : the name of a column containing the variable

#to be summarized

# groupnames : vector of column names to be used as

# grouping variables

data_summary <- function(data, varname, groupnames){
  require(dplyr)

```

```

summary_func <- function(x, col){
  c(mean = mean(x[[col]], na.rm=TRUE),
    SEM = ((sd(x[[col]])/sqrt(length(x[[col]]))), na.rm=TRUE)
  }
data_sum<-ddply(data, groupnames, .fun=summary_func,
  varname)
data_sum <- plyr::rename(data_sum, c("mean" = varname))
return(data_sum)
}

df3 <- data_summary(NestData, varname="Time_in_nest",
  groupnames=c("Type"))
df3$Type=as.factor(df3$Type)
head(df3)

mean_data <- group_by(NestData, Type) %>%
  dplyr::summarise(Time_in_nest = mean(Time_in_nest, na.rm = TRUE))

pd <- position_dodge(0.20)

# Create plot with data points
TimeAtNest <- ggplot(NestData, aes(x=Type, y=Time_in_nest,
group=NestAttemptID)) + geom_line(position = pd) +

```

```

geom_point(position = pd, size=4, shape=21, fill = "white") +
scale_fill_manual(breaks=c("Control","Treatment"),
labels=c("control","treatment")) +

theme(panel.border = element_blank(), panel.background =
element_rect(fill="white"), panel.grid.major = element_blank(),
panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"),
axis.title.x = element_text(colour="black", size=16),
axis.title.y = element_text(colour="black", size=16)) +
labs(x="playback condition", y="time inside nest (secs)") + theme(axis.text.x=
element_text(colour="black", size=16),
axis.text.y= element_text(colour="black", size=16)) + coord_cartesian(ylim=c(0,
2200)) +

scale_y_continuous(breaks=seq(0, 2000, 500)) + scale_x_discrete(labels=
c("control", "treatment")) + theme(legend.position = "none")

# -----
# Combine two figures into single panel
# -----

Panel1 <- ggarrange(NumberOfFeeds, TimeAtNest, nrow=1, ncol=2, widths =
c(1,1.1), align = c("h"))

Panel2<- annotate_figure(Panel1, top = textGrob("(a) number of feeds", x =
unit(0, "npc"), y = unit(0.6, "npc"), just=c("left"),

gp=gpar(col="black", font=3, fontsize=20)))

Panel3<- annotate_figure(Panel2, top = textGrob("(b) time inside nest", x =
unit(0.5, "npc"), y = unit(-0.4, "npc"), just=c("left"),

```

```

gp=gpar(col="black", font=3, fontsize=20)))

# save figure as pdf

ggsave(file="Nest_Figure1.pdf", dpi = 200, width =30, height = 17, units =
c("cm"))

#####

# Number of nestlings vs number of feeds #

#####

#-----#

#--- Create a scatterplot that separately plots both control and treatment feeding
rates ---#

#-----#

# plot the scatterplot, with separate lines-of-best-fit for the treatment and control
periods

ggplot(NestData, aes(x=n_nestlings, y=Feeding_Rate)) + geom_smooth(method =
"lm", se=FALSE, color="black", aes(linetype=Type), lwd=1.2) +

geom_beeswarm(aes(color=Type, shape=Type, fill=Type), color="black", size=3,
stroke=0.7, cex = 2.0) +

scale_shape_manual(breaks = c("Control", "Treatment"), values=c(21,21)) +

scale_fill_manual(breaks = c("Control", "Treatment"), values=c("white",
"grey75")) +

scale_color_manual(breaks = c("Control", "Treatment"), values=c("black",
"grey75")) +

```

```

scale_linetype_manual(breaks = c("Control", "Treatment"), values=c("solid",
"dashed")) +

theme(panel.border = element_blank(), panel.background =
element_rect(fill="white"), panel.grid.major = element_blank(),
panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"),
axis.title.x = element_text(colour="black", size=20),
axis.title.y = element_text(colour="black", size=20)) +

labs(x="Brood size", y="Food deliveries") +

theme(axis.text.x= element_text(colour="black", size=20),
axis.text.y= element_text(colour="black", size=20),
legend.text=element_text(size=16),

legend.key.width = unit(4,"line"), legend.key.height = unit(2,"line"), legend.key=
element_rect(fill = NA, color = "NA"), legend.box.background =
element_rect(colour = "black", linewidth=2.5), legend.margin = margin(-0.2, 0.2,
0, 0, "cm"), legend.title=element_blank()) +

coord_cartesian(xlim=c(0,10)) + scale_x_continuous(breaks=seq(0, 10, 2)) +
coord_cartesian(ylim=c(0, 70)) +

scale_y_continuous(breaks=seq(0, 70, 10)) + guides(color =
guide_legend(keyheight=0.5), default.unit="cm")

# save figure as pdf

ggsave(file="Nest_Figure2.pdf", dpi = 200, width =24, height = 15, units =
c("cm"))

#-----#

#--- Create a scatterplot that plots the mean feeding rate for each nesting attempt -
--#

```

```

#-----#

# calculate the mean feeding rate per nesting attempt

number_nestlings <- data_summary(NestData, varname="Feeding_Rate",
                                groupnames=c("NestAttemptID", "n_nestlings"))

# plot the scatterplot

ggplot(number_nestlings, aes(x=n_nestlings, y=Feeding_Rate)) +
geom_smooth(method = "lm", se=FALSE, color="black", lwd=1.2) +
geom_point(color="black", size=3, stroke=0.7, shape=21) +
theme(panel.border = element_blank(), panel.background =
element_rect(fill="white"), panel.grid.major = element_blank(),
panel.grid.minor = element_blank(), axis.line = element_line(colour = "black"),
axis.title.x = element_text(colour="black", size=20),
axis.title.y = element_text(colour="black", size=20)) +
labs(x="Brood size", y="Food deliveries") +
theme(axis.text.x= element_text(colour="black", size=20),
axis.text.y= element_text(colour="black", size=20),
legend.text=element_text(size=16)) +
coord_cartesian(xlim=c(0,10)) + scale_x_continuous(breaks=seq(0, 10, 2)) +
coord_cartesian(ylim=c(0, 70)) +
scale_y_continuous(breaks=seq(0, 70, 10))

# save figure as pdf

```

ggsave(file="Nest\_Figure2b.pdf", dpi = 200, width = 20, height = 15, units = c("cm"))

**Pictures:**



*Figure (A1): Examples of the concrete (left) and wooden (right) nestboxes used in this study. Photos: Edoardo Bonte*

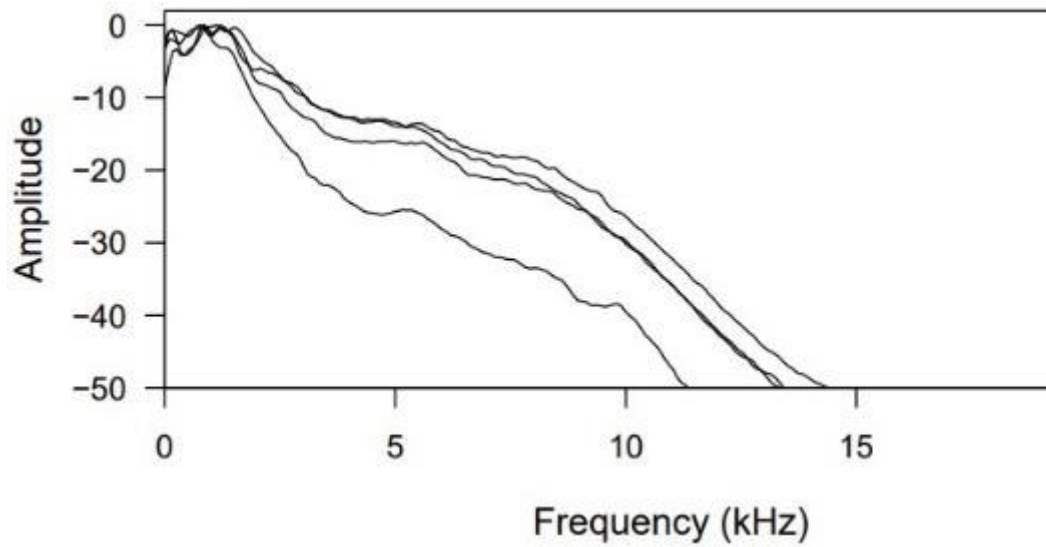


Figure (A2): graph representing mean frequency spectra used to filter white noise during traffic noise preparation, each line represents one vehicle passing along the road stimulus files.

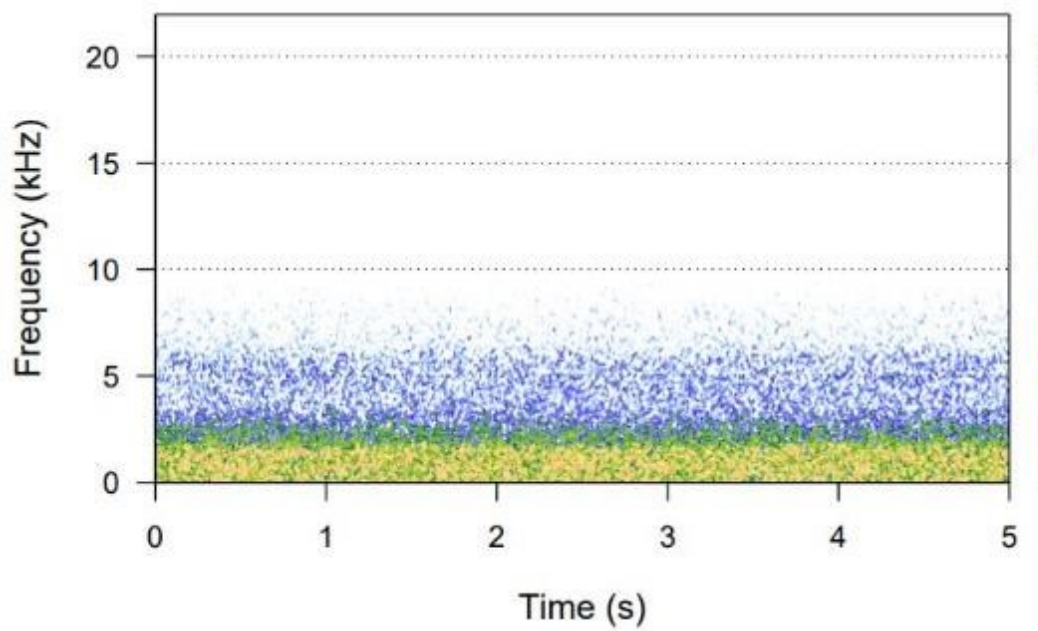


Figure (A3): graph representing the spectrogram of one filtered traffic noise files. As you can see, the frequency (y axes) and amplitude level (on the right) remain the same along the whole duration (x axes) of the stimulus.



*Figure (A4): on the left JBL speaker and Apple iPod, on the right decibelometer*

NB_ID	N	E	S	W	N'	E'	S'	W'	Average
53w	71,4	71,6	72,1	71,2	72,2	71,9	73,6	73,3	72,1625
1c	53	53	53,4	53,3	57	50	53,4	52,6	53,2125
4w	57	52,7	56	59,3	55,9	52,8	55,8	58,6	56,0125
23w	74,1	74,2	74,7	75,1	75,7	77,7	76,9	79,7	76,0125
20w	82,5	80,1	79,1	79,3	79,1	80,7	79,9	79,1	79,975
12c	72,4	69,8	69,8	69,7	69,9	69,9	69,1	69,7	70,0375
77w	63,5	63,9	58,6	66,6	67,1	66,4	66,4	71,7	65,525
17c	81,1	79,7	80,1	81,4	81,1	81,7	81,4	81,7	81,025
26m	46,1	50,2	49,3	56,4	53,9	66,5	57,3	43,6	52,9125
26w	78,5	78,3	78,9	78,8	78,6	77,9	78,9	79	78,6125
70w	61,4	54,1	67,2	60,3	60,9	59,8	64,7	69,8	62,275
49c	54,3	47,1	44,4	43,7	41,4	42	44,5	47,1	45,5625
29w	54,2	49,6	56,5	55,7	57,3	52,2	52,1	57,9	54,4375
72c	52	61,8	52,1	61,7	51	49	49,2	63,6	55,05
20m	50,4	47,3	60,9	55,3	56,3	51,6	50,8	49,8	52,8
10c	70,2	70,3	71,1	70,7	71,4	71,2	70,5	71,7	70,8875
11w	70,7	70,5	70	70,4	71,5	71,1	69,7	70,6	70,5625
13c	71,5	69,5	69,5	69,8	69,6	69,4	69,6	69	69,7375
68w	56,2	57,4	57	53,2	57,9	62,9	61,8	65,1	58,9375
21w	79,9	79	79,7	79,2	77,7	81,9	81,3	81,1	79,975
16w	80,7	79,7	79,7	80,1	79,3	77,3	77,9	77,1	78,975
31F	49,3	45,7	47,8	49,8	45,8	48,6	46,3	52,1	48,175
22w	77,2	76,7	77,2	78,8	77,3	77,7	77,4	77,7	77,5
30w	57,9	56,7	58,6	59	60,4	56,7	59,9	60,5	58,9625
25w	77,3	78,5	78,4	77,3	78,7	77,9	77,9	79	78,125
15w	81,2	81,9	81,4	81,8	81,7	81,5	81,3	82,1	81,6125
60c	46,8	52	48,6	45,5	45,7	47,5	46,6	55,5	48,525

Table (A1): Ambient noise recorded twice (e.g. N = first recording, N' = second recording) at every cardinal point and then mean-averaged (last column on the right).