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How aggressive personality shapes vigilance and foraging behavior in Greylag Geese

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1. Acknowledgment

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2. Abstract

In group living species, individuals must continuously balance the need to remain alert to potential threats with the necessity of acquiring sufficient food. This trade-off between vigilance and foraging may be influenced by consistent behavioral tendencies, commonly referred to as personality traits. Among these, aggressiveness may play a key role in shaping responses to a perceived danger. This study explores how aggressiveness affects anti-predator behavior and foraging in greylag geese (*Anser anser*) when exposed to an artificial predator. A semi-tame flock of greylag geese, located in the valley of Grünau im Almtal (Upper Austria), was observed to investigate behavioral responses, such as vigilance and foraging, of focal individuals (n=61) towards a predator-mimicking Robotfalcon.

Following the initial statistical analysis of the general behavioral response towards the falcon, individual aggressiveness score, derived from prior mirror test assessment, were incorporated to evaluate the role of personality in modulating these patterns. The exposure to the artificial predator led to an overall increase in vigilance duration and reduced feeding duration. Aggressiveness influenced individual responses towards the perceived threat, with more aggressive geese prioritizing vigilance over foraging. Given that aggressiveness is typically associated with higher dominance ranks in social hierarchies, this heightened vigilance may represent an adaptive strategy, enabled by greater access to resources, allowing them to afford the energetic costs of sustained alertness, while less aggressive, subordinate individuals may prioritize foraging to meet basic energy demands. This research adds to the growing evidence that individual differences in behavior are key to understanding variation in anti-predator responses in social animals.

Keywords: *greylag geese, trade-off, vigilance, foraging, aggressiveness, anti-predator behavior, Robotfalcon*

3. Zusammenfassung

In Gruppen lebende Tiere müssen laufend eine Balance zwischen der Wachsamkeit gegenüber potenziellen Gefahren und der ausreichenden Nahrungsaufnahme, zur Deckung ihres Energiebedarfs, abwägen. Dieser Kompromiss zwischen Wachsamkeit und Nahrungssuche kann durch konsistente Verhaltensweisen, sogenannte Persönlichkeitsmerkmale, beeinflusst werden. Insbesondere könnte Aggressivität eine zentrale Rolle bei der Reaktion auf wahrgenommene Bedrohung spielen. Diese Studie untersucht wie sich Aggressivität auf das Anti-Raubtierverhalt und die Nahrungssuche von Graugänsen (*Anser anser*) auswirkt, wenn sie einem künstlichen Raubtier ausgesetzt sind.

Eine halbzahme Graugansschar im oberösterreichischen Grünau im Almtal wurde beobachtet, um Verhaltensreaktionen einzelner Individuen (n=61), wie Wachsamkeit und Nahrungssuche, gegenüber eines Raubtier-imitierenden Robotfalcon zu beobachten.

Nach einer ersten Analyse des generellen Verhaltens gegenüber dem Falken wurden individuelle Aggressivitätswerte, basierend auf einem vorher durchgeführten Spiegeltest, integriert, um den Einfluss der Persönlichkeit auf diese Verhaltensmuster zu untersuchen. Die Konfrontation mit dem künstlichen Prädator führte zu einer insgesamt erhöhten Wachsamkeit und verringerter Nahrungsaufnahme. Aggressivität beeinflusste die individuelle Reaktion auf die wahrgenommene Bedrohung. Aggressivere Individuen priorisierten Wachsamkeit über Nahrungssuche. Da Aggressivität typischerweise mit höheren Dominanzrängen in sozialen Hierarchien assoziiert ist, könnte diese verstärkte Wachsamkeit eine adaptive Strategie darstellen, die durch besseren Zugang zu Ressourcen ermöglicht wird und es diesen Individuen erlaubt, die energetischen Kosten erhöhter Aufmerksamkeit zu tragen. Weniger aggressive, untergeordnete Tiere dagegen priorisieren Nahrungssuche über Wachsamkeit, um ihren eigenen Grundbedarf zu decken. Diese Forschungsarbeit liefert weitere Belege dafür, dass individuelle Unterschiede im Verhalten, der Schlüssel zum Verständnis von Unterschieden in anti-prädatorischen Reaktionen bei sozial lebenden Tieren sind.

Keywords: *Graugänse, Kompromiss, Wachsamkeit, Nahrungssuche, Aggressivität, Anti-Raubtierverhalten, Robotfalcon*

4. Introduction

In behavioral and cognitive biology, the term “animal personality” refers to differences in behavior among individuals of the same species that persist across time and context (Réale D. et.al., 2007). Understanding animal personality helps to explore how individual behavioral differences affect ecological dynamics, social structures and fitness (Gosling, 2001). Studies of animal personality most commonly use five axes describing certain behavioral traits including Aggressiveness/Agreeableness, Exploration/Avoidance, Boldness/Shyness, Sociability and Activity levels (Réale D. et.al., 2007). Several metrics were established to measure aggressiveness, for example the number of agonistic interactions towards a conspecific either in direct contact or via a so-called mirror test. These behavioral measurements in this context assess how individuals respond to their reflection in a mirror (Kleindorfer et. al., 2024). In species that do not have the capacity for self-recognition, the mirror test leads to a reaction towards another conspecific or rival, that is matching the testing individual in size and appearance (Gallup et.al., 2011; Balzarini et.al., 2014).

Aggressiveness, as a personality trait characterized by competitive and confrontational behavior, plays a crucial role in shaping social dynamics in group-living animals (Favati,2017). Functioning as a key personality dimension, aggressiveness is positively correlated with dominance in social hierarchies, improved resource acquisition and altered responses to perceived threats (Dingemanse & Réale,2005; Black & Owen, 1986). In birds such as ravens, this relationship is evident, with more aggressive individuals tend to win more agonistic interactions attaining higher dominance ranks, which in turn grants them better access to resources (Boucherie et.al., 2022). Understanding and quantifying aggressiveness can provide insights in how animals behave and navigate social structures and can reliably predict dominance rank (Kleindorfer et.al., 2024).

One’s role within a social flock also significantly shapes anti-predator behavior (Fuong, 2021). Individuals with an aggressive personality, often dominant in social hierarchies, tend to secure safer positions within a flock, benefiting from reduced predation risk and allocating less time to vigilance, whereas subordinate individuals, by contrast, are relegated to sites, where the risk of predation and vigilance demands are greater (Black et.al., 1992). This pattern has been demonstrated for instance in European starlings, where birds on the edge spend more time scanning for threats than individuals in the middle, as they are more vulnerable to a predator attack and bear greater responsibility for detecting danger (Keys &Dugatkin, 1990). Both position and social status impact vigilance levels and ultimately influencing the change to survive. This may reflect a so-called “dominance trade-off” as demonstrated in a mixed-species flock of Carolina Chickadees (*Poecile carolinensis*) and Tufted Titmice (*Baeolophis bicolor*), where dominant individuals exerted control over resources and social dynamics, relying on subordinates to take on the role of scanning for threat (Pravosudov &Grubb, 1999). This indicates that subordinates spend more time being vigilant, while dominants allocate more time to feeding and other activities.

Building upon the relationship of aggressiveness and spatial positioning, dominant individuals not only secure access to high quality food resources (Lathi, 1998), but also experience enhanced foraging opportunities (Hahn & Bauer, 2008). In addition to the advantage in foraging, dominant individuals gaining control over territories by winning agonistic interactions, allowing them to attract females, achieving greater reproductive success (Poisbleau et.al., 2006). This is exemplified in red junglefowls (*Gallus gallus*), were aggression and dominance, secure better mating opportunities (McDonald et.al, 2017).

To further investigate how individual personality traits influence individual key survival behaviors, such as vigilance and foraging, this study is focusing on aggressiveness in a flock of greylag geese from the Konrad- Lorenz research center, located in Grünau im Almtal, Austria. The semi-wild population of greylag geese provides a unique opportunity to study consistent individual differences(personality) in a setting that combines natural interactions with reliable observational access, possible because of the geese long-term habituation of human presence (Kralj-Fišer et.al., 2009).

To better grasp the role of aggressiveness in shaping this survival strategies, it is crucial to consider the underlying factors influencing this personality. A long-term study explored factors influencing aggressive behavior and dominance rank in greylag geese over a span of 15 years (Weiß et.al., 2011). This research provides a comprehensive overview of the interplay among genetic, environmental and social variables shaping these behaviors. The influences can be categorized into extrinsic and intrinsic factors. Seasonal variation**,** as an extrinsic factor, has an effect on aggression in greylag geese. During the mating season, the level of aggression tends to be higher due to the increased competition for resources and mating. The social tension decreases in winter reducing aggressiveness among the flock (Szipl, et.al, 2019a). According to extrinsic factors like flock composition and size, a significant influence for male-biased flock showing higher tendencies for aggression, had also been determined in the long-term study mentioned above (Weiß et.al., 2011). The environment in which geese are raised, whether they are hand raised or grow up in the wild, impacts their aggression levels. Hand-raised geese showed lower aggression tendencies during their early stages of life, but as they mature, those geese can adapt to higher social ranks and evolve more aggressive behavior (Scheiber et.al., 2013)**.** Parental influence is also a crucial intrinsic factor shaping dominance hierarchies and aggression levels in goslings. Raising offspring as a dominant parent influences the tendency to exhibit higher aggression and as they mature are more likely to occupy advanced social ranks (Black &Owen, 1986). Furthermore**,** Sex as another intrinsic factor also plays a significant role in this context. Females are exhibiting lower levels of aggression compared to males highly correlated with their dominance rank, shaping social interactions (Seibert & Crowell-Davis, 2001; Weiß et.al, 2011). This study emphasizes, that even though aggressiveness is considered to be consistent across time and context, this consistency pertains to the relative difference in behavior, rather than the absolute level of aggression expressed. In other words, individuals will adjust their behavior based on the social and environmental conditions, with their overall aggression tending to remain stable (Réale et.al., 2010).

When being threatened and exposed to a predator, individuals are typically more vigilant as they must balance their need to forage with the necessity with scanning for danger to mitigate the risk of attack (Lima & Dill, 1990). Aggressiveness, as a personality trait, may influence how greylag geese navigate this trade-off, with more aggressive individuals potentially prioritizing either vigilance or foraging based on their perceived risk.

Using these greylag geese as study subjects in the following experiment the focus will lay on the anti-predator response while being exposed to artificially build peregrine falcon (Robotfalcon) and how their aggressive personality might influence their vigilance behavior. The flock was habituated to a so called unmanned aerial vehicle drone (UAV) two weeks in advance before the actual start of the study, proceeding the standardize flight patterns performed subsequently in the experiment. The effect of a RobotFalcon has already been tested on bird flocks, such as gulls or starlings, to deter from certain areas (Storms et.al., 2022). Compared to these species, geese are much larger in size and therefore presumably don't experience the same threat towards the falcon. Geese might display more nuanced behaviors such as increased vigilance, temporary displacement or gathering in tighter flocks rather than fleeing completely. The chosen system could reveal a broader spectrum of anti-predator strategies that are influenced by the perceived threat level. Based on the preliminary data for aggressiveness score in greylag geese (Common, 2024), it remains uncertain to what extend personality traits influences the vigilance behavior and time spent foraging during the conducted experiment. Shifting the focus to an individual level cost rather than social roles, it can be suggested that more aggressive individuals display higher levels of vigilance. This may be explained by the notion that predator threats are more costly for less aggressive individuals, leading them to allocate more time foraging. The study aims to explore a relationship between aggressive personality traits, vigilance, and foraging behavior in response to a predator seeking to address gap in knowledge regarding the connection between these distinct factors.

Distinct hypotheses are aimed to be answered through this study:

H1: Vigilance and foraging behaviors are influenced by the presence of the Robotfalcon.

H2: The time the individuals spend feeding is influenced by the level of aggressiveness

H3: There is a link between personality and the vigilance behavior, influenced by the level of aggressiveness, determining the duration of vigilance exhibited by the individuals.

The study is predicting the following, based on the stated hypothesis:

P1: The exposure to the artificial predator will decrease the time the individual spent feeding while increasing vigilance behavioral duration.

P2: Individuals, which have a lower level of aggressiveness spend more time feeding, depending on the experimental phase

P3: Aggressiveness as a personality type has an impact on the behavioral duration of vigilance, with more aggressive individuals spending more time being vigilant.

5. Material und Methods

5.1 study site and subject

The flock of the greylag geese in valley Grünau im Almtal has been established in the 1973 through Konrad Lorenz, who relocated these individuals from Seewiesen in Germany to this Austria (Kleindorfer,2024). Researchers recorded life history traits, behavior and social structure throughout the years within the long studied free-ranging flock in the valley. The monitoring of the population has been conducted by the researcher of the Konrad Lorenz research centre which is part of the university of Vienna. The non-migratory flock is partially habituated to human presence, since regular interaction with researcher and students occur. The feeding of the geese with grain pellets takes place twice a day early in the morning and later in the afternoon (Scheiber et.al. 2007). Almost every individual (98%) has an aluminium leg band with a certain colour combination to enable identification of the birds (Kleindorfer et.al., 2024). The flock consists of approximately 121 individuals, including male or female, across juveniles, subadults and adult, as identified in a list provided by the researchers of the KLF. The list of the geese contains information about the ring combination of the legs for each individual for identification, sex, year of birth and if they have one or multiple partners.

5.2 experimental design

The experiment was conducted over a two-week period from 29.07 - 11.08 2024 in the valley of Grünau im Almtal, at the old Konrad- Lorenz research centre (KLF), also known as the so-called Auringerhof (47°48'49.0"N, 13°56'52.6"E). A very short time period was chosen to ensure that aggression levels were not noticeably affected by seasonal variation or changes in internal states across the experiment.

Flights using a UAV drone and/or the Robotfalcon were scheduled based on the weather conditions. In the initial days, a baseline was established by exposing the geese mainly to the UAV drone, without the Robotfalcon, to allow the geese to habituate the monitoring drone. The geese were fed early in the morning at 8.am and during this feeding session, the researchers positioned themselves around the feeding trays and maintained their positions, initially filming just the atomic clock view given by the coordinator. The recordings of the Geese ID videos commenced, initiated by a signal, to identify individual geese for tracking purposes. Every goose in the video frame was pointed out with an extended arm or index finger and each participant pronounced the leg band/ring combination of each individual from the left leg/pause/right leg. In response to an instruction, a focal goose was assigned to each one of us and everybody separately filmed again the atomic clock view, starting a recording lasting approximately 15-20 min. In case the focal has a partner, it was also important to mention this in the video and additionally keep track of this individual as well. Following four days of baseline, both the UAV drone and the Robotfalcon were introduced, for each trial the same procedure commenced as described, including Geese ID videos and the following focal videos with separate recordings and atomic clock view frames. The experiment was divided in multiple phases, although participants were not aware of these divisions during the practical part of the experiment. The time frames and durations of each phase were very crucial for later statistical analysis. After each researcher has identified their assigned focal goose, a visual cue (hat wave) was included and the monitoring UAV drone launched over the flock at an altitude of about 20 meters within the baseline period in the pre-exposure phase of the experiment lasting roughly five minutes. The exposure phase of the Robotfalcon launch commenced after a baseline period of five minutes first off heading towards the old KLF and the river without being a threat yet. Subsequently the falcon was randomly performing stooping manoeuvres on distinct days of the experiment, flying over the flock for about ten minutes at angles over the centre of 30-45 degrees. The randomized order was important to avoid biases in the individual responses towards the potential predator. In the so-called post- exposure phase or after landing phase the falcon commenced landing and withdrawal within five minutes and the recordings ended with an acoustic cue from the coordinator. In total the experiment spanned a total of eight days, including two distinct phases. Phase one involved data collection through focal observations and Geese ID videos, with the Robotfalcon performing no stooping manoeuvres at a medium risk level and an altitude of up to 80 meters. On the fourth day there were no focal observation, only Geese ID videos, introducing just the falcon to the flock. After a three-day break to prevent habituation, the second phase of the experiment commenced, which involved three days of focal recordings and Geese ID videos. The risk was now elevated to a higher level and the falcon was performing in total six stooping manoeuvres during the exposure phase. The final day (day 8) consisted solely of Geese ID videos without focal observation, only the falcon hovering above the flock.

5.3 video coding and behavioral analysis

The video coding, focused exclusively on the focal videos, was conducted using the software BORIS and distributed among the master's students Sara Lehner, Marion Lehner and Marc Surlemont. The behavioral evaluation was divided into two main aspects: coding focal videos for vigilance and for movement with the behavioral types being distinct and exclusive. For each video data was collected separately for movement and vigilance, ensuring that the analysis of these behaviors remained independent.

Greylag geese show specific head and neck positions when being vigilant. According to original ethogram of Konrad Lorenz (Lorenz, 1988), researchers at KLF managed to categorize and adapt the vigilance types in order to facilitate the following analysis (Barnas et.al.). If they are spending their time foraging, resting or just walking with their beak down this means that they show zero vigilance (V0). This behavior is called non-feeding (Supplementary. Fig 2). When their beak is straight and their neck is short, vigilance is at a higher level (V1 short-neck). If the beak is pointing upwards extending their neck the so-called long neck vigilance takes place (V2). The highest state of vigilance occurs when an individual tilts his head and makes a one-eye-up movement (V3). If the individual is currently not in focus or blocked by something, the observer will count this as an out-of-view (OOV) state. Movement types are categorized in standing, walking, lying, running, swimming or flying. The age, sex and pair status of the individuals have already been recorded by KLF researchers in advance through the life history of the geese, as well as the personality scores for aggressiveness, boldness and exploration have already been examined (Common, 2024). According to the experiment the length of the exposure elements varied across each day. For our analysis, only the days with focal recordings were considered for our later analysis, totally six days across both phases (Day 1: 98 sec, Day 2: 138 sec, Day 3: 99 sec, Day 4: 100 sec, Day 5: 138 sec, Day 6: 119 sec). In the subsequent statistical analysis, it was crucial to extract time budgets from the phases (before launch, exposure, after landing) to achieve that all the three timepoints have the same length and facilitate the comparison. The length of each exposure days was extracted and aligned to the corresponding phases of each individual day.

5.4 statistical analysis

The statistical analysis was performed using the RStudio software (Giorgi et.al., 2022), an open-source platform (Version 4.4.1.) freely available for download online. Thorough data exploration is an essential step before selecting and fitting an appropriate model.

Prior to model fitting, the analysis was restricted to a subset of data focusing on a behavioral type, for instance V0 feeding, which was filtered and pivoted to facilitate subsequent visualization. A function was applied using this subset, conducting a series of diagnostic tests. Potential outliers of the behavioral duration were identified with the Outlier Test as part of the preprocessing of the analysis using standardized z-scores. Behavioral durations (in ms) with standardized z-scores beyond ± 3 were considered as potential outliers due to substantial deviation from the mean (Priya, 2021). Outliers were examined and retained in the dataset, as they were not significant (p value >0.005).

Subsequent methods to determine which distribution our dataset has, is conducted for example with the statistical Anderson-Darling test, fitted for normal distribution. The expected distribution is supposed to match the cumulative distribution of the data, with smaller values indicating a better fit. The Anderson-Darling- test is an enhancement of the so-called Kolmogorov-Smirnov (K-S) test, with increased sensitivity to deviations in tails of the distribution (Anderson, 2010). The KS-test is used when parameters are already known, and the distribution is distinct (Kwam &Vidakovic, 2007). A logarithmic transformation and retesting's are necessary if the data is not following a normal distribution, may help to stabilize the variances and improve the normality. Checking for homogeneity of the variances examines whether or not the variances are equal across groups and serves as a key assumption for subsequent testing (f.e. ANOVA), with a p-value threshold of above 0.05 indicating homogeneity (Midway, 2022). Evaluating potential collinearity among predictor, through multicollinearity assessment, the Variance Inflation Factor (VIF) calculated from a linear model is being used. A high VIF indicates a strong correlation between predictors, effecting the model, making it more difficult to determine the individual impact. Reducing the number of predictors can solve as a solution for this problem (Tareen et.al., 2019; Kutner et.al., 2004). After the data exploration the model is fitted. The dataset from this experiment turned out to be not normally distributed. Instead, a Generalized Linear Mixed Model (GLMM, Verbeke & Molenberg, 2013) with a log link function is fitted using the glmmTMB (Brooks et.al., 2017) package in R Studio. The GLMM incorporates various variables, like response variable (duration), predictors (phase, aggressiveness), explanatory variables (e.g Age, Sex, pairing status, Handraised) and additionally random effects (BirdID, CoderID, Exposure.Day), which allows for modelling variability at different levels (Bolker et.al.,2009). Variables such as the starting quadrant/sector (quadrant A, B and C, river and aviary) of the focal individuals are derived from the areas within the feeding section and adjacent zones and were included as a random factor in the model (Supplementary Fig. 3). Diagnostics are performed after fitting the gamma distributed model such as the residual Analysis via Q-Q plot to assess randomness and inspect the assumption. Furthermore, the so-called DHARMA Diagnostic is used for advanced residual diagnostic including Dispersion test of the residuals, zero inflation test, uniformity and outlier test (Hartig, 2022). The standard deviation (=SD) is included in the final model, represented for each value and estimate. The statistical outputs like deviance and residual degrees of freedom (df.resid) are extracted to assess the goodness of the model fitting (Hartig,2022).

5.5 aggressiveness score and dominance rank

The Pearson and Spearman coefficients were calculated to examine the relationship between the two key variables latency and minimum distance derived from provided existing data from the KLF researchers (Common, 2024). The Pearson correlation ($r= 0.872$) demonstrates a strong linear relationship, closely similar to the Spearman coefficient ($r=0.814$) confirming the robustness of the association (Sheskin, 2000). This justifies further analysis subsequently using a linear regression model integrating the dependent variable latency and minimum distance as the independent variable. Residuals from the linear regression model were extracted and used to classify observations into quartiles based on their distribution. The quartiles, representing 25% intervals of the average residual values, were assigned to each individual, incorporating the Bird identifier (=BirdID). Furthermore, the individuals from the greylag geese flock ($n=43$) were categorized into four Quartiles based on the aggressiveness score. Quartile 1 (Q1) comprises geese with the highest level of aggressiveness, whereas Quartile 4 (Q4) include those with the lowest levels. Quartile 2 (Q2) and Quartile 3 (Q3) reflect intermediate levels, with Quartile 2 (Q2) representing moderately high and Quartile 3 (Q3) moderately low levels. The Quartiles 1,3 and 4 each consist of 12 individuals (n=12), while Quartile 2 includes seven greylag geese (n=7).

Subsequently, the interaction between the experimental phases and the aggressiveness quartiles (Q1-Q4) has been evaluated preforming a method called post-hoc pairwise comparison of estimated marginal means using an emmeans package in R studio (Lenth, 2023). Furthermore, a pairwise contrast has been conducted using a Bonferroni adjustment controlling for multiple comparison (Abdi, 2007). Additionally, a comparison of the lowest(Q1) and highest(Q4) levels of aggressiveness was conducted by calculating the mean duration of each Quartile (Q1-Q4) across the experimental phases. To determine whether there was a difference between the means of the respective Quartiles within each phase, a two-samples t-test was performed using a significance threshold of $p < 0.05$ (Ruxton, 2006).

6. Results

6.1 general results

The impact of the Robotfalcon experiment on flock-level vigilance and behavioral duration was examined across various categories including V1-V3 vigilance, V0 feeding and V0 non-feeding, as well as moment behaviors walking and standing (Supplementary Figures 4-10).

These findings are in line with the results obtained by my colleague who conducted parallel analyses on the same general results of the Robotfalcon experiment (Surlemont, 2025).

55 birds out of the 61 focals were included to conduct general results, excluding aggressiveness personality data (Common, 2024). The number of males (n=34, 62%) is exceeding the females (n=21, 38%) present in the greylag geese flock. The individual's range between 2 to 21 years of age. Paired individuals (n=43) occur more frequently than unpaired individuals (n=12).

Considering the duration for each behavior, feeding appeared to be longer during the before launch phase with a total of 17.51% within this period (Estimate=0.39 ±0.15, p= 0.001) relative to the after landing phase (15.99 %, Estimate =0.82 ± 0.12, p-value = <0.001) and the exposure phase (7,27%), serving as the reference. Both comparisons are statistically significant.

Short-neck vigilance (V1) is elevated during the Robotfalcon exposure (10.75%) compared to both before launch (6.9%, Estimate = -0.18 ± 0.09, p-value = 0.047) and the after landing period (4.7%, Estimate = -0.17 ±0.10, p-value = 0.085) period, with the former showing statistical significance.

Long neck vigilance (V2) also increased during exposure (3.4%) in contrast to before launch (1,32%, Estimate =-0.79 ±0.48, p = 0.109) and after landing phase (0.78%, Estimate = -0.26 ±0.31, p-value = 0.402), though neither difference is statistically significant.

Similarly, the duration of one-eye-up vigilance (V3) was higher during exposure (10.09%) than before launch phase (0.5%, Estimate =-0.54 ± 0.16, p-value = 0.033) and after landing (0.41%, Estimate = 0.26 ± 0.30, p-value = 0.383) with only the pre-exposure comparison reaching statistical significance.

Regarding movement-related behaviors, the individuals tended to stand more during the pre-exposure period (29.44%, Estimate -0.34 ±0.01, p-value = <0.001) compared to the exposure (23.00%) and post exposure phase (19.56%, Estimate =-0.24 ±0.04, p-value = <0.001).

Similarly, walking behavior was increased before launch (6.56%, Estimate = 0.17 ±0.03, p-value = <0.001) as opposed to exposure (5.98%) and after landing (4.76%, Estimate = 0.16 ± 0.04, p-value = <0.001).

6.2 analysis of behavioral categories including personality

The aggressiveness datasheet contains 159 entries of greylag geese, with 27 individuals having multiple data recordings across different dates. In total the data contains 104 unique individuals. The number of recorded focal individuals during the experimental period was 61 (n=61). For the subsequent analysis, 43 individuals (n=43) are included, based on their presence in the flock and the availability of aggressiveness personality data.

A total of 33 paired (n= 33, 76%) and 10 unpaired (n=8, 23%) individuals, with age ranging from 2 to 21 were incorporated in the study. The number of males (n= 25, 58%) exceeded the number of females (n=18, 41%). As already described above, the individuals are categorized into Quartiles ranging from high (Q1) to low (Q4) level of aggressiveness.

Each behavioral category was modeled using a generalized linear mixed model, with detailed output tables provided in a corresponding table (see Table 1-2, Appendix Table (TA) 5-8).

The feeding duration in seconds by the experimental phase in respect to the aggressiveness Quartiles (Q1-Q4) shows multiple significant effects (Fig. 1). There is a significant higher feeding duration in the before launch phase (Tab.1) compared to the reference phase, which is always the exposure phase (Estimate = 0.16 ± 0.03, p-value = <0.001). A positive estimate being significant indicating an increase in a behavioral duration in the pre-exposure phase compared to the exposure phase. The after-landing phase in this case also shows a significant difference compared to the reference phase (Estimate = 0.39 ± 0.04, p-value = <0.001) with foraging time being overall higher before and after the Robotfalcon attack. Male individuals spent less time feeding (Estimate =-0.16 ±0.06, p-value = 0.006). Individuals included in the second Quartile (Q2) have significantly lower feeding time compared to Quartile 1 (Estimate= -0.23 ± 0.10, p-value= 0.020). Within the before launch phase the Quartile 2 is higher in exhibiting this behavior in comparison to Quartile 1 and the exposure phase (Estimate = 0.63 ± 0.08, p-value = <0.001).

Regarding the included ANOVA values in the result table (Tab.1) it can be stated that the vigilance duration varies significantly across the experimental phase (Chi =222.67, Df =2, p-value = <0.001). The interaction of phase and quartiles as well has a significant influence on the feeding duration (Chi= 104.81, Df= 6, p-value = <0.001).

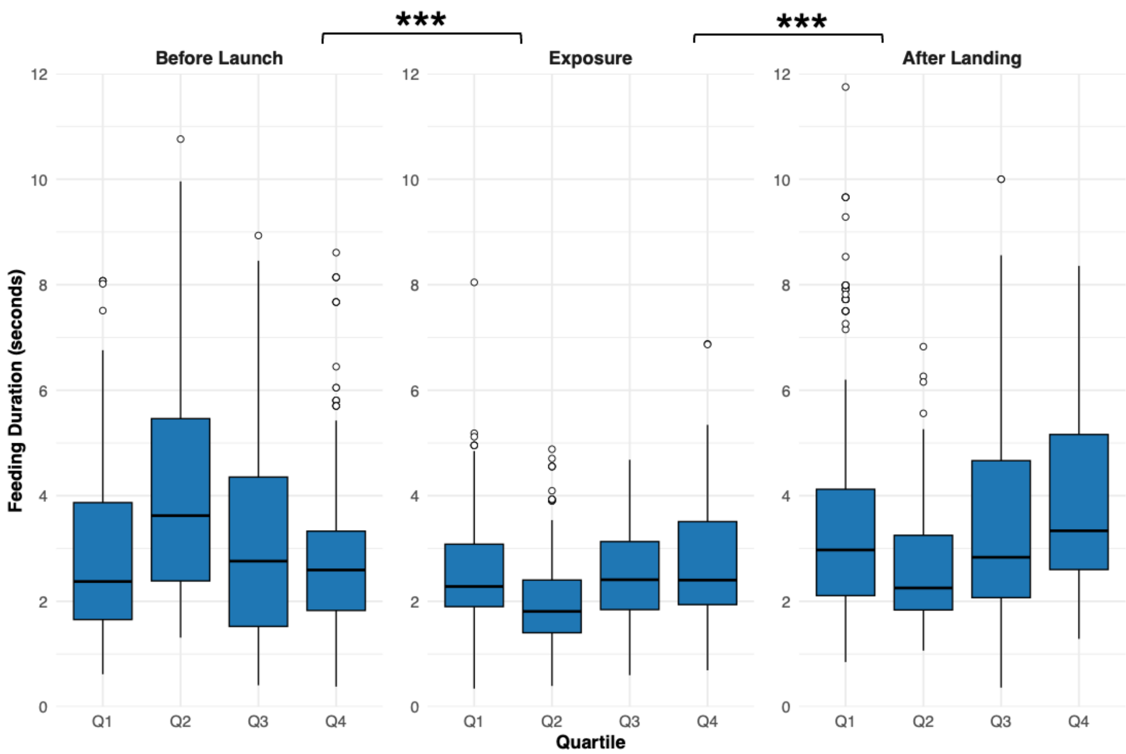

*Figure 1: V0 feeding duration across experimental phase and aggressiveness quartiles (Q1-Q4, Quartile 1 indicating the highest score of aggressiveness, while Q4 being the lowest level of aggressiveness) , Before Launch phase: time period before the artificial predator (Robotfalcon) launches, Exposure phase: period where the flock of greylag geese (n=42) is exposed to the Robotfalcon, After landing phase: period including the landing of the Robotfalcon A subset has been used to extract phase boundaries and include the exact exposure time length for the pre and post exposure phase according to each experimental day (Exposure Day 1: 98s, Exposure Day 2: 138 s, Exposure Day 3: 99s, Exposure Day 4: 100s, Exposure Day 5: 138s. Exposure Day 6:119s) before launch phase is significantly lower in vigilance duration compared to the reference phase exposure (Estimate = -0.16 ± 0.03, , p-value = <0.001***)as well as the after landing phase (Estimate = 0.39± 0.04, , p-value = <0.001***)*

*Table 1 Output from the generalized mixed model result GLMM analyzing **V0 feeding** vigilance duration for a flock of greylag geese (n=43) for three experimental phases. **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon The response variable is the behavioral duration of V0 feeding (square root in second) fitted in the model in correlation to the aggressiveness Quartile (Q1-Q4) and random factors like BirdID (variance 0.02± 0.14) or sector (n=6,variance=0.0005±0.02)) of the area the experiment is conducted Signif = Statistically significant values are marked with asterisks p-value = significant values under p< 0.05, highly significant p<0.001, Estimate = estimated coefficients, , SE = Standard Error, Chisq = Chi-squared statistic, df = degree of freedom, z value = z statistics, ^{AN} values derived from the ANOVA analysis*

	Estimate	SE	z value	p value	Chisq	Df	Signif
(Intercept)	0.88	0.12	7.21	**<0.001**			***
phasebefore_launch_duration	0.16	0.03	4.31	**<0.001**			***
phaseafter_landing_duration	0.39	0.04	8.91	**<0.001**			***
QuartileQ2	-0.23	0.10	-2.31	**0.020**			*
QuartileQ3	-0.01	0.08	-0.21	0.828			
QuartileQ4	-0.14	0.08	-1.69	0.089			.
Sex.yM^{AN}	-0.16	0.06	-2.71	**0.006**	7.56	1	**
Pairing.yunpaired^{AN}	-0.01	0.10	-0.11	0.907	0.33	1	
sqrt(Age.y) ^{AN}	0.05	0.03	1.61	0.105	2.62	1	
phasebefore_launch_duration:QuartileQ2	0.63	0.08	7.77	**<0.001**			***
phaseafter_landing_duration:QuartileQ2	-0.14	0.07	-1.90	0.056			
phasebefore_launch_duration:QuartileQ3	0.06	0.06	1.07	0.283			
phaseafter_landing_duration:QuartileQ3	-0.003	0.06	-0.04	0.964			
phasebefore_launch_duration:QuartileQ4	0.04	0.06	0.75	0.451			
phaseafter_landing_duration:QuartileQ4	0.05	0.07	0.75	0.447			
Sex.yM:Pairing.yunpaired^{AN}	0.08	0.13	0.61	0.537	0.37	1	
phase^{AN}				**<0.001**	222.67	2	***
Quartile^{AN}				0.345	3.31	3	
Phase:Quartile^{AN}				**<0.001**	104.81	6	***

The same analysis has been assessed for the overall vigilance duration (Tab.2), and for each phase in regard to the four aggressiveness quartiles (Q1-Q4).

Compared to the exposure phase, both the before launch phase (Estimate= -0.35 ± 0.01, p value = <0.001) and the after-landing phase (Estimate= -0.13 ±,0.01 p-value = <0.001) have significantly lower vigilance durations (Tab. 2), indicated by a negative estimate. Individuals from the flock, which were handraised by humans, showed a marginally significant effect on the vigilance duration (Estimate = 0.22±0.12, p-value = 0.057). Each Quartile (Q2-Q4) showed significant differences among each other and in reference to the exposure phase. The time the individuals spent in states of alertness is significantly varying across the experimental phases (Chi=1537.63, Df= 2, p-value = < 0.001) and Quartiles in correlation to the phase (Chi= 153.84, Df= 6., p-value =< 0.001).

*Table 2 Output from the generalized mixed model result GLMM analyzing **overall vigilance** duration (including V1 short neck, V2 long- neck, V3 one-eye-up) for a flock of greylag geese (n=43) for three experimental phases. **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon The response variable is the behavioral duration overall vigilance (square root in second) fitted in the model in correlation to the aggressiveness Quartile (Q1-Q4) and random factors like BirdID (variance= 0.02 ±0.14), Coder.ID (variance =0.001 ±0.04) and Exposure Day (variance=0.01 ±0.01) ,Handraised individuals are included as a fixed factor with Y indicating yes for being handraised, Signif = Statistically significant values are marked with asterisks), p-value = significant values under p< 0.05, highly significant p<0.001, Estimate = estimated coefficients, , SE = Standard Error, Chisq = Chi-squared statistic, df = degree of freedom, z value = z statistics, ^{AN} values derived from the ANOVA analysis*

	Estimate	SE	z value	p value	Chisq	Df	Signif
(Intercept)	1.00	0.11	8.81	**<0.001**			***
phasebefore_launch_duration	-0.35	0.01	-24.83	**<0.001**			***
phaseafter_landing_duration	-0.13	0.01	-7.95	**<0.001**			***
QuartileQ2	0.04	0.07	0.59	0.551			
QuartileQ3	0.04	0.06	0.62	0.533			
QuartileQ4	-0.05	0.06	-0.79	0.428			
HandraisedY^{AN}	0.22	0.12	1.90	0.057	3.61	1	.
Sex.yM^{AN}	-0.03	0.05	-0.74	0.456	0.55	1	
Pairing.yunpaired^{AN}	-0.01	0.05	-0.33	0.740	0.11	1	
sqrt(Age.y) ^{AN}	-0.02	0.03	-0.78	0.431	0.61	1	
phasebefore_launch_duration:QuartileQ2	0.04	0.02	1.90	0.056			.
phaseafter_landing_duration:QuartileQ2	-0.23	0.02	-8.04	**<0.001**			***
phasebefore_launch_duration:QuartileQ3	0.08	0.02	3.80	**<0.001**			***
phaseafter_landing_duration:QuartileQ3	-0.20	0.02	-7.95	**<0.001**			***
phasebefore_launch_duration:QuartileQ4	0.08	0.02	3.51	**<0.001**			***
phaseafter_landing_duration:QuartileQ4	-0.14	0.02	-4.75	**<0.001**			***
Phase ^{AN}				**<0.001**	1537.63	2	***
Quartile ^{AN}				0.687	1.47	3	
Phase:Quartile^{AN}				**<0.001**	153.84	6	***

6.4 Quartile comparison within experimental phases

A quartile comparison, including a post-hoc pairwise comparison with a Bonferroni adjustment, was conducted for each behavioral category (Tab. 3-4, TA. 9-12).

The comparison reveals differences within the phases regarding the feeding time budget in correlation to the four different quartiles (Tab.3). Within the before launch phase, Quartile 1 and 2 (Estimate: -1.41 ± 0.19, p-value = < 0.001), Quartile 1 and 3 (Estimate: -0.38 ± 0.12, p-value = 0.019), Quartile 2 and 3 (Estimate: 1.03 ± 0.2,p-value: < 0.001) , Quartile 2 and 4 (Estimate: 1.45 ± 0.2, p-value = < 0.001) and Quartile 3 and 4 (Estimate: 0.41 ± 0.14, p-value = 0.024) showed significant differences. During the exposure phase significance was shown within Quartile 1 and 2 (Estimate: 0.48 ± 0.18, p-value = 0.046), Quartile 2 and 3 (Estimate: -0.53 ± 0.19, p-value = 0.034) with an increase in duration, while Quartile 2 compared to 4 has a lower amount of time spend feeding(Estimate: -0.65 ± 0.19, p-value = 0.003). Within the after-landing phase Quartiles 1 foraged more than Quartile 2 (Estimate: 0.95 ± 0.18, p-value = <0.001). Quartile 2 had a lower feeding time compared to Quartile 3 foraging less (Estimate: -0.77 ± 0.17, p-value = <0.001). The same effect is given for Quartile 2 compared against Quartile 4 (Estimate: -1.34 ± 0.21, p-value = < 0.001) and Quartile 3 against 4 (Estimate: -0.57 ± 0.17, p-value = 0.0065). Further analysis using post-hoc pairwise t-test comparing the Quartile separately against each experimental phase revealing multiple significant effects (TA.13-14). The Quartile 1 with the highest level of aggressiveness is significantly lower in feeding duration (TA.13) during the exposure phase compared to the pre-exposure phase (Estimate = -0.43 ± 0.13, p-value = 0.002), post-exposure phase (Estimate= -1.17 ±0.14, p-value = <0.001) and for the latter against the pre-exposure phase (Estimate= -0.74 ±0.12, p-value = <0.001). During the exposure phase the individuals are feeding less in contrast to the other periods (exposure/before launch: Estimate =-2.34 ±0.23, p-value=<0.001, exposure/after landing: Estimate = -0.66 ±0.21, p-value = 0.005). The feeding duration for Quartile 3 is also lower during the exposure compared to pre and post-launch of the Robotfalcon (exposure/before launch: Estimate= -0.74 ±0.17, p-value=<0.001, exposure/after landing: Estimate = -1.01 ±0.16, p value = <0.001). Individuals with the lowest score of aggressiveness (Q4) feed less during exposure compared to the after landing phase (Estimate= -1.35 ±0.19, p-value = <0.001) and within the before launch phase compared post exposure period (Estimate = -1.11 ±0.18, p-value = <0.001).

*Table 3 post hoc comparison using a Bonferroni method of **V0 feeding duration** within each experimental phase, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

phase = before launch					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
Q1- Q2	-1.41	0.19	2634	-7.29	**<.0001**
Q1- Q3	-0.3801	0.129	2634	-2.951	**0.019**
Q2- Q3	1.03	0.20	2634	4.95	**<.0001**
Q2- Q4	1.45	0.20	2634	7.06	**<.0001**
Q3- Q4	0.41	0.14	2634	2.87	**0.024**
phase = exposure phase					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
Q1- Q2	0.48	0.18	2634	2.66	**0.046**
Q2- Q3	-0.53	0.19	2634	-2.76	**0.034**
Q2- Q4	-0.65	0.19	2634	-3.44	**0.003**
phase = after landing duration					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
Q1- Q2	0.95	0.18	2634	5.22	**<.0001**
Q2- Q3	-0.77	0.17	2634	-4.35	**<.0001**
Q2- Q4	-1.34	0.21	2634	-6.26	**<.0001**
Q3- Q4	-0.57	0.17	2634	-3.27	**0.006**

The quartile comparison with the post-hoc pairwise comparison using a Bonferroni adjustment concerning the overall vigilance duration within the quartiles specifically during the exposure phase has been conducted (Tab.4) and further visualized using Boxplots (Fig.2).

In the exposure phase Quartile 1 and 3 (Estimate: 0.15 ± 0.05, p-value = 0.026), Quartile 1 and 4 (Estimate: 0.29 ± 0.05, p-value = < 0.001), Quartile 2 and 3 (Estimate: 0.30 ± 0.06, p-value = <0.001) and Quartile 2 and 4 (Estimate: 0.44 ± 0.06, p-value = < 0.0001) showed significances. This result indicates that during the Robotfalcon exposure the lower Quartiles (Q1, Q2), which have a higher tendency to be aggressive, have a greater tendency to be vigilant compared to the upper Quartiles (Q3, Q4).

*Table 4: comparison of **vigilance duration**(V1 short-neck, V2 long neck, V3 one-eye-up) among aggressiveness Quartiles (Q1 -Q4, Quartile 1 indicating the highest score of aggressiveness, while Q4 being the lowest level of aggressiveness) across experimental phases with a post-hoc test using a Bonferroni comparison, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

phase = exposure phase

contrast	estimate	SE	df	t.ratio	p.value
Q1- Q2	-0.15	0.06	6834	-2.45	0.084
Q1- Q3	0.15	0.05	6834	2.84	**0.026**
Q1- Q4	0.29	0.05	6834	5.28	**<.0001**
Q2- Q3	0.30	0.06	6834	4.86	**<.0001**
Q2- Q4	0.44	0.06	6834	6.90	**<.0001**
Q3- Q4	0.14	0.05	6834	2.58	0.058

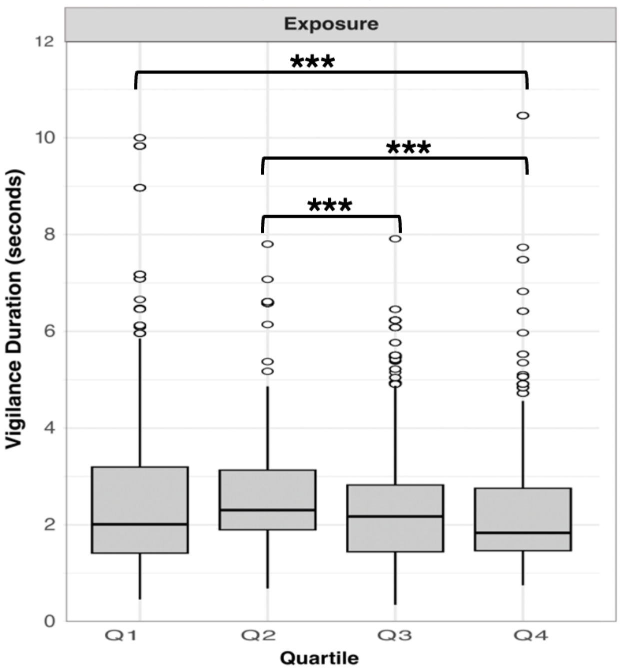

*Figure 2:overall vigilance duration (including V1 short-neck, V2 long neck + V3 one-eye-up)during Robotfalcon exposure across aggressiveness quartiles (Q1-Q4, Quartile 1 indicating the highest score of aggressiveness, while Q4 being the lowest level of aggressiveness), **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, , A subset has been used to extract phase boundaries and include the exact exposure time length for the pre and post exposure phase according to each experimental day (Exposure Day 1: 98s, Exposure Day 2: 138 s, Exposure Day 3: 99s, Exposure Day 4: 100s, Exposure Day 5: 138s. Exposure Day 6:119s), *** asterisk indicating a significance level of p-value <0.001 meaning highly significant.*

The comparison of the vigilance duration between the lowest Quartile (Q1) and the highest Quartile (Q4) across different phases was conducted by using a two sampled t-test (TA.15.) reveals key findings and additionally visualized with boxplots (Figure 3). If t- statistic value is positive it indicates that the difference between the groups (Q1 and Q4) goes in the direction of Q1 > Q4, meaning that the mean vigilance duration for Q1 is greater than for Q4. There is no significant difference between the vigilance duration of the two quartiles in the before launch phase (p-value = 0.447, t-stat = -0.76). This lack of significance suggests that aggressiveness could play a relatively minor role during this phase, as illustrated in Figure 3. In contrast, the exposure phase showed a highly significant difference (p-value = < 0.001, t-stat = 4.34) demonstrating that individuals included in Q1 exhibiting longer durations of vigilance compared to Q4. Similarly, in the after-landing phase, a high significance for Q1 showing longer durations compared to Q4 has been revealed by the analysis (p-value = <0.001, t-stat = 8.05). These findings suggest that highly aggressive geese (Q1) tend to be more vigilant than less aggressive individuals (Q4) during both exposure and after-landing phases (Figure 3).

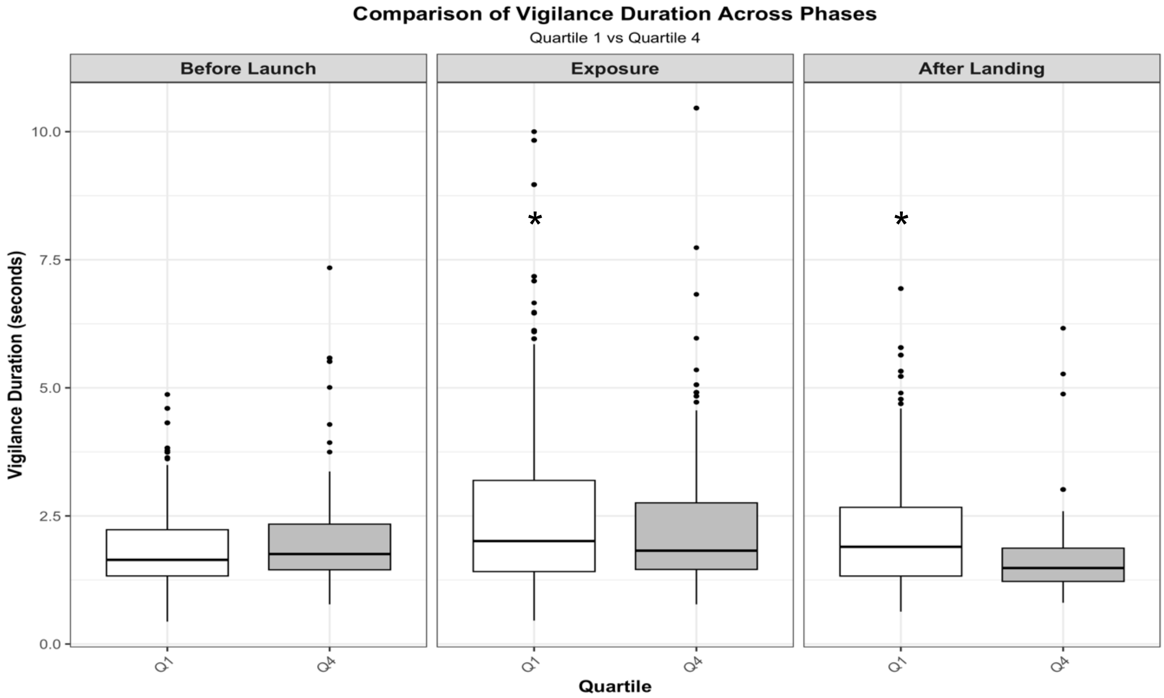

Figure 3: Comparison of the lowest Quartile 1 (high level of aggressiveness) and the highest Quartile 4 (lowest level of aggressiveness) across experimental phases statistically calculated by two-sampled t-test (before launch, exposure, after landing phase) statistical analysis revealed no significant difference between Q1 and Q4 in the before launch phase (p = 0.477, t statistic = -0.76), the exposure phase revealed a highly significant difference between the two Quartiles, with Q1 exhibiting more vigilance (p <0.001, t statistic = 4.34), after landing phase is also highly significant with Q1 > Q4 vigilance duration (p <0.001, t statistic = 8.05)

6.3 vigilance vs. foraging

The graph (Fig.4) below shows the normailzed vigilance duration (in percentage)versus the time spendt foraging for greylag geese (TA.16), categorized in quartiles and behavioral status (foraging vs. vigilance.) The vigilance category is further divided into the three types called V1 short neck (grey), V2 long neck (green) and V3 one eye up (red).

A general focus on feeding activity can be observed in the pre-exposure phase. Within the before launch phase Q4 individuals exhibit the highest percentage of foraging (Q4 = 0.53%) compared to the other Quartiles (Q2 = 45%, Q3: = 43%, Q1= 50%). Regarding the vigilance categories V1 short neck prevails in this phase, ranging from 39 to approximatly 44%, whereas V2 long neck and V3 one- eye up are very little in percentage in comparison. (V2 long neck: range norm-duration: 5-15%, V3 one eye up: range norm-duration: 2-8%). Quartile 3 is exhibiting the highest percentage of V2 long neck duration within this phase (Q3= 15%) followed by Quartile 1 (Q1 = 7%), Quartile 4 (Q4= 5%) and lastly Quartile 2 (Q2= 1%). One eye up vigilance behavior peaked highest in the second Quartile (Q2 = 8 %), subsequently seen in Quartile 1 (Q1= 4%), Quartile 3 (Q3= 3%) and Quartile 4 (Q4=2%).

In the exposure phase the foraging activity droped notable across all quartiles. (Q1 = 0.20%,Q2 = 0.15%, Q3 = 18%, Q4 = 29%). In contrast to that, the vigilance behaviors increase, particulaty V2 long neck (Q1 =16%, Q2 =20%, Q3 =14%, Q4 =8%) and V3 one-eye-up (Q1=32%, Q2=24%, Q3=31%, Q4=30%) in each quartile, whith V2 peaking highest in Q2 and V3 one eye up in Q1. The V1 short neck duration had the highest normalized duration in Quartile 2 (Q2=40%). The other quartiles ranged between 31-35% in this vigilance categoy.

Within the after landing phase, foraging resumes strongly, specifically in Quartile 3 (Q3=62%) and Quartile 4(Q4 =58%), while Q1 and Q2 show lower percentages (Q1= 50%, Q2= 46%).V1 short neck continues to dominate, specifically high in Quartile 2 (Q2=38%) and Quartile 1 (Q1= 37%). V3 one-eye-up is least expressed in the post-exposure phase (range 1-15%), with V2 long neck as well remaining low (range 1-8%), suggesting a return to baseline vigilance pattern, after the stressor subsides.

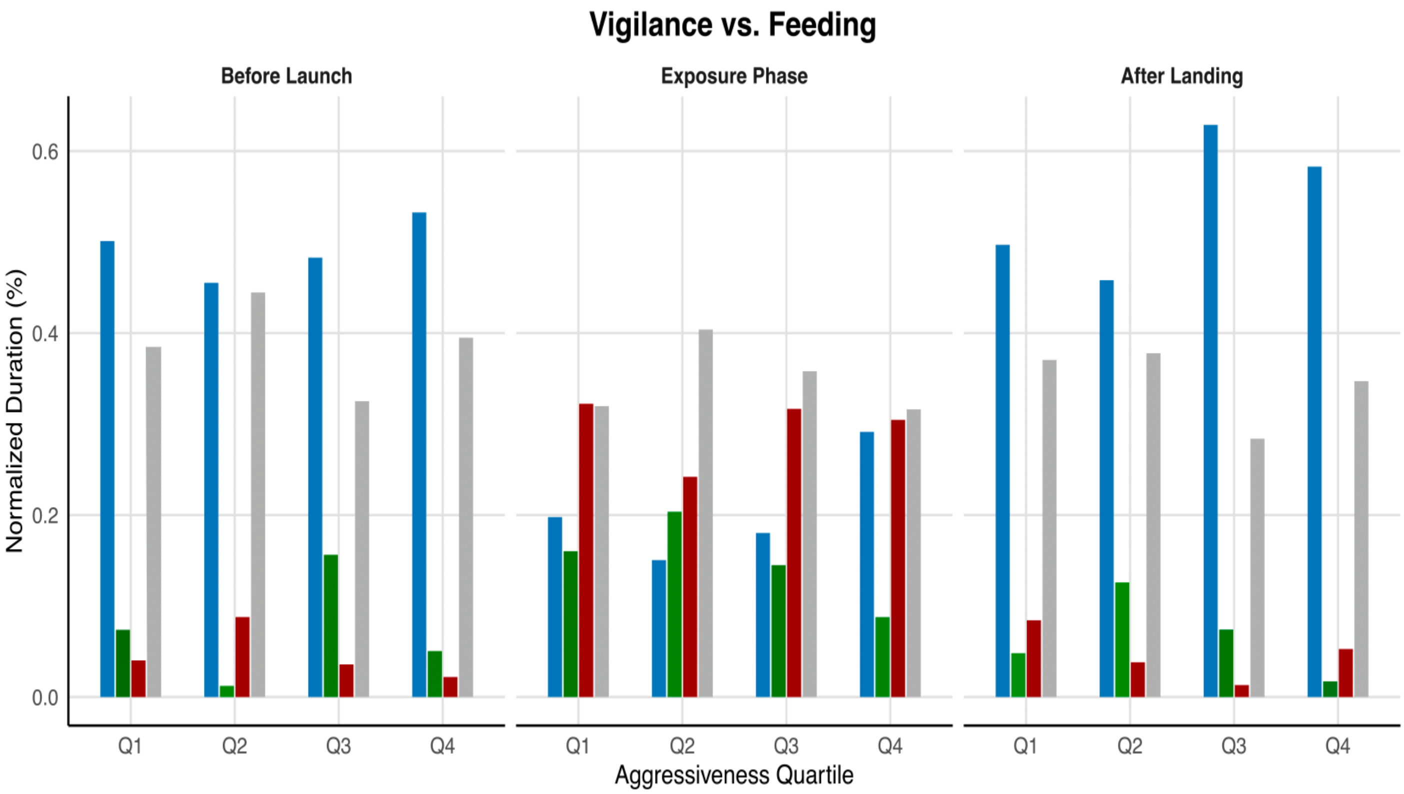

Figure 4: Comparison of vigilance and foraging normalized duration within the three phases of the experiment, x axis = aggressiveness quartiles ranking from Q1 -Q4 (high to low score), y axis = normalized duration in % of foraging against vigilance (categorized in V1 short neck(grey), V2 long neck(green) and V3 one eye up (red) , V0 feeding/foraging (blue), ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon,*

7. Discussion

This study explored the vigilance-foraging trade-off in a flock of non-migratory greylag geese (*Anser anser)* in Grünau im Almtal, with a twofold approach: first by assessing the immediate impact of a simulated aerial predator (Robotfalcon) on a group-level vigilance and foraging behavior, and second, by examining how individual variation in aggressiveness- a personality trait- modulates this trade-off.

In line with predictions, exposure to the artificial predator led to increased vigilance and reduced feeding time at the group level. However, incorporating individual aggressiveness revealed more nuanced patterns. Less aggressive geese spent more time feeding, especially during and after exposure, suggesting a stronger prioritization of energy intake. When addressing the final research question, it became evident, that during the Robotfalcon exposure more aggressive geese displayed higher vigilance and significantly reduced feeding time during the exposure phase. These findings indicate that personality traits such as aggressiveness shape individual responses to perceived threats and mediate the balance between vigilance and feeding. Vigilance and foraging behavior were significantly influenced by aggressiveness levels and its interaction with the experiment across phases.

7.1 Study comparison

Confronted with a fundamental trade-off between vigilance and foraging – individuals must balance the need to forage with the necessity to remain vigilant. An increase in vigilance can reduce predation risk but may lead to a decrease in foraging efficiency (Brown, 1999; Lima & Dill, 1990; Beauchamp & Roxton, 2016; Beauchamp, 2020). This trade-off is not fixed and can shift according to various ecological and social factors (Lima & Dill, 1990).

In my study, vigilance levels increased significantly during the exposure to an artificial predator, aligning with previous findings conducted in Grünau im Almtal in the early 1990s examining the impact of various natural predators, such as white-tailed eagle and golden eagle, on the flock of greylag geese (Kotrschal, 1992). Observations showed heightened vigilance among individuals in response to natural predator attacks. In contrast to my research, this study is based on observations of natural birds of prey visits, rather than an artificial predator. Vigilance was measured using mean values for days with high and low frequencies of predator exposure (Kotrschal, 1992). Given that natural predation still occurs in this region, their presence could have influenced the behavior of the individuals in my study flock, even in the absence of a direct predation event and furthermore contribute to baseline vigilance levels.

Additional factors shaping anti-predator behavior comes from research on other bird species such as the American coot (*Fulica americana),* which examined the time devoted to scanning for threats while considering flock size, comparing alertness on land and water. The findings suggest that vigilance declines as flock size rises, particularly for individuals on land (Lam et.al., 2020), a trend similarly observed in Black necked cranes (*Grus nigricollis*, Xu et.al., 2013; Michelena & Deneubourg, 2011). Habitat structure also plays a crucial role shaping vigilance, as highlighted in studies on grey partridges (*Perdix perdix*), which showed that both perceived threat levels and habitat characteristic can ultimately influence survival outcome (Watson et.al., 2007). Group size effects are also evident in an African ungulate community, where individuals in larger groups are often less alerted, due to dilution effects and collective detection (Cree et.al., 2014). This phenomenon is commonly referred to as the *"many-eyes-theory*", proposing that individuals can reduce their vigilance levels, but collectively enhance predator detection by allocating alertness among group members (Scheib et.al., 2003). Together these findings underscore the importance of ecological and social factors shaping vigilance and that animals can dynamically adjust their behavior in response to altered predation risk.

Greylag geese form dominance hierarchies, where each individual has a certain social rank within a goose society (Scheiber et.al., 2013). The social status can influence alertness, as previously stated for dominant male greylag geese (=ganders) being more sensitive towards predator threats (Kotrschal, 1992). Assuming that the more aggressive individuals tend to occupy higher dominance ranks within the observed goose flock in this study, vigilance behavior is likely being influenced by one's social rank. Subordinate individuals may prioritize foraging to fulfill their energy demands, potentially to avoid depleting valuable resource when being vigilant (Stahl et.al., 2001). In contrast, dominant individuals may be less constrained in energy limitation, have better access to resources, and can bear the costs of allocating more time to monitoring potential threats (Tibbets et.al., 2022; Milewski et.al., 2022; Natterson-

Horowitz & Cho, 2021). Dominant individuals may also exhibit higher vigilance due to their role in group defense and territory maintenance (Hahn & Bauer, 2008)

Intriguingly, the relationship between dominance and vigilance is never straight-forward. For example, subordinates may demonstrate higher vigilance as a certain trade-off of their lower social status, compensating for their limited access to resources and avoiding conflict with dominant individuals, increasing their chances of survival. The phenomenon is referred to as "socially mediated interference", which describes the influence of dominant individuals affecting subordinates foraging behavior (Rands et.al., 2006). These contrasting perspectives highlight the importance of a context dependent approach in behavioral studies, as vigilance may be influenced by multiple ecological and social factors (Monti et.al., 2024; Monclús, & Rödel, 2008).

Additionally, not only social rank, but also an individual's position within a flock, dwelling either at the center or edge of the group, can ultimately influence alertness. Proctor and colleagues (2005) used modeling to examine how a predator affects vigilance behavior depending on a bird's position, highlighting a completely different angle of this variable, which was not directly assed in this study. Findings revealed the birds on the edge tended to be more vigilant than those in the center, likely due to greater predator exposure. The study suggested that spatial position may also be shaped by social hierarchy, with dominant individuals occupying safer positions (Proctor et.al., 2005).

Building on the social structure within an animal society, findings emphasizing impacts not only on individual behavior, but also on the establishing dominance hierarchies (Withee, 2016; Tibbets et.al., 2022). Across a wide range of species, aggressiveness is a fundamental factor in shaping and establishing dominance hierarchies, as demonstrated in various taxa, including fish (e.g. *Melanotaenia duboulayi*, Colleter & Brown, 2011), birds (e.g. *Anser Anser*, Kleindorfer et.al., 2024) and mammals (e.g. *Rattus norwegicus*, Schweinfurth, 2020) as well as broader theoretical frameworks (Chase et.al.,2002; Drews, 1993).

Personality traits, such as aggressiveness**,** boldness and exploration, have been shown to shape animals responds towards environmental stimuli, including predator threats. Variation in predator responses have been observed in birds like great tits (*Parus major*) depending on the personality type, suggesting that these traits play a key role in shaping individual behaviors (Exnerová et.al., 2009). These findings are further supported by previous research on superb fairy-wrens (*Malurus cyaneus*), which showed that individuals displaying higher aggressiveness towards conspecific, assessed through a mirror test, exhibited stronger anti predator responses, including for example increased alarm calling during predator playback experiment and faster approaches to the perceived threat (Bilby et.al., 2022). Comparing my research to previous studies, no direct correlation between aggressiveness and the term vigilance has been explicitly assessed. Existing research typically investigates these behaviors in different contexts, such as predator responsiveness or social interaction, rather than exploring a direct link (Roth & Sterck, 2020). Kralj-Fišer and colleagues (2009) studied male greylag geese (ganders) exploring various factors influencing the aggressive personality traits, including vigilance, receiving agonistic interactions, sociability, boldness and proximity to the mates. All variables, except sociability, were found to contribute to aggressiveness (Kralj-Fišer et. al., 2009). While no direct correlation was identified for vigilance and personality, a positive link between aggressiveness and dominance was observed, suggesting that higher dominance rank is associated with higher alertness. This finding aligns with the early findings from Kotrschal et.al. (1992), already mentioned above, who reported that more dominant males tend to be more vigilant. Including the parameter sex in my study, revealed that male feeding duration was significantly lower throughout the experiment. A potential reason for this could be that males allocated more time to vigilance due to their role within goose society (Scheiber et.al., 2013; Kralj-Fišer et. al., 2007).

Importantly, personality traits such as aggressiveness, boldness and exploration often do not operate independently. Instead they are components of a so-called "behavioral syndrome", where multiple personality traits interconnect, influencing one another (Réale et.al., 2007; Sih et.al., 2004). While no significant collinearity was found between personality traits in this study (aggressiveness, boldness, exploration, $p>0.05$), the concept of behavioral syndromes remains relevant for understanding and predicting animal responses to changing environments. While a behavioral syndrome may shape a personality under normal conditions, its influence may shift under high-stress conditions, such as the predator exposure, leading to an alteration in behavioral responses *(Gryllus texenis*, Adamo et.al., 2013). Research on the three spined stickleback (*Gasterosteus aculeatus*) provides insight into this phenomenon, demonstrating that the exposure to a predator, strengthens the correlation between aggressiveness and boldness (Bell & Sih, 2007). Specifically, after the exposure, these traits become correlated, with increased aggression being associated with greater boldness. Prior to exposure no such link has been observed. The predator threat is acting as an environmental stressor, further shapes behavioral responses, modifying the correlation between the two personality traits. Additionally, the concept of rank is crucial, as more aggressive before the exposure did not necessary maintained the same level of aggressiveness after exposure. The likelihood of surviving predator encounters increased with higher levels of aggression, likely due to enhanced attentiveness or vigilance to both conspecifics and predator threat. This highlights the significance of aggressiveness, not only in direct combats but also in terms of natural selection (Smith & Blumstein, 2008; Bell & Sih, 2007). More recent work on another fish species (*Poecilia Formosa*) supports this pattern, revealed that early-life exposure to a predator lead to more consistent behavioral profiles over time. This suggest that predator induced stress can not only modify individual behavior but also reinforce behavioral patterns across contexts - characteristics central to behavioral syndromes (Scherer et.al., 2024).

Grasping the far-reaching impact of personality traits on behaviors, especially as they vary under ecological stressors, can have important implications for conservation in the context of species reintroduction or predator management within a given area (Powell & Gartner, 2011).

7.2 Future research & limitations

The experiment was restricted to a certain period lasting two weeks. While this short timeframe provides preliminary insights into vigilance responses, it restricts our understanding of long-term behavioral adaptation and habituation. One critical limitation is the potential for habituation, where repeated exposure may lead to a diminished perception of the Robotfalcon as a threat after only a few encounters (Dong & Clayton, 2009). To address this, future research should investigate the long- term impacts of an artificial predator to the non-migratory flock of greylag geese. By implementing prolonged exposure days with integrated scheduled breaks, studies can assess whether vigilance responses remain stable, gradually decline due to habituation or re-intensify following rest periods. A more detailed understanding of the adaptivity and consistency of the experimental effects, as well as general anti- predator responses, would be further analyzed. Additionally, researchers could compare exposure days and non-exposure days and analyze the impact of human presence as an external factor. The presence of multiple human observers can also have an influence on the individual's behavior diverting the attention away from the predator. The gathering around the flock may therefore disrupt natural behavior. This can also lead to a decrease of threat perception due to the safeguarding of humans during the simulated attack or on the other hand sensitize the geese making them more aware of the threat. Therefore, human presence must be controlled in future experimental designs, as it can act as a cofounding factor, serving either as a "*safety buffer*" or a stressor (Blumstein, 2016; Sadoul et.al., 2021).

Greylag geese have the ability to transit from an individual identity to a group identity, particularly in high-risk situations. During so-called "phase-transition" the goose temporarily loses its social position within the flock and suppressing their usual personality traits in favor of coordinated group action. The entire group is acting simultaneously, enhancing the change to survive when assembling during a risky situation (Kleindorfer, 2024). However, a key limitation of this study is the lack of data that allows to disentangle individual vigilance from group level conformity. When the geese act in unison, it becomes unclear whether observed vigilance reflects a group response or individual decision making. The relationship between vigilance and aggressiveness could have been obscured in this research, due to a shared level of vigilance during high-risk situations. Future research controlling for group dynamic may help determine whether this effect occurred, allowing for a clearer understanding of how aggressiveness influences individual behavior.

To further expand the research, valuable insight could be gained by incorporating the dominance hierarchy and social status of the existing flock members. The classification of the individuals from the greylag geese flock at the KLF based on their dominance rank can be integrated in the study to evaluate how rank position influences vigilance (Common, 2024.). Building on existing findings from this study, future research could test whether dominant individuals maintain higher vigilance due to their aggressive tendencies or lower alertness as a result of their secure social position. Kleindorfer et.al. (2024) demonstrated that aggressiveness serves as a strong predictor for dominance hierarchy and specifically older, paired birds and males holding onto higher social positions. Comparing the anti-predator response of these distinct individuals to those of unpaired geese and younger ones may reveal how social structure modulates vigilance behavior.

In accordance with the behavioral classification used in this study, I propose that agonistic interaction should be categorized separately, rather than subsumed under V1 short-neck vigilance. This distinction may provide a more precise understanding of whether vigilance is primarily driven predator presence or arises as a consequence of dyadic interactions**.** Previous research has demonstrated that vigilance duration increased with conflict intensity and elevated heart rates, indicating that alertness is not solely a response to a predation risk, but also reflects a reaction to a social stressor (Wascher et.al. ,2008).

One important limitation of the study is the exclusion of families and gosling in this study, which prevents the generalization of vigilance patterns to parental geese. Research has showed that alertness is heightened in geese with offspring compared to non-parental geese, and that age, season and number of goslings contribute to the level of exhibited vigilance in parental geese (Loth et al., 2017; Black & Owen, 1989). The vigilance of a parent can increase with brood size, suggesting that individuals with more offspring tend to be more watchful (Shimada & Shimada, 2004). Goslings' survival is strongly shaped by parental behavior, with increased aggression and vigilance playing a crucial role in enhancing their chances of survival (Szipl et.al., 2019b; Zhao et.al., 2007). To address this gap, future research should incorporate parent-offspring dynamics, investigating how vigilance patterns vary with brood size and offspring age and how dominant families, subordinate individuals, and solitary geese differ in their response to predator threats. Including family units in future studies could reveal broader ecological valid perspective on anti-predator behavior in greylag geese.

The lack of seasonal and environmental variation in the current study represents another key limitation, as it restricts the ability to assess context-dependent changes in vigilance behavior**.** Henceforth, the inconsistency of environmental factors plays a crucial role in shaping anti-predator response of aggressive individuals. Changes in external conditions, such as habitat structure or human-use patterns, influence risk assessment in a long-term experiment, possibly revealing behavioral plasticity (Li et.al., 2017). Additionally, future research should examine seasonal differences – such as comparison between breeding versus non-breeding season, to better understand how reproductive and environmental pressure shapes anti-predator responses (Dutour et.al., 2019).

Future studies could furthermore integrate physiological metrics or spatial tracking to deepen our understanding of the proximate mechanism behind vigilance responses (Kröschel et.al.,2017). Integrating the bird's spatial positioning using UAV tracking data within the experiment could enhance understanding of how vigilance behavior is influenced by flock position, as already conducted in the broader Robotfalcon experiment (Ossola, 2024). Comparative work across species could also test whether the behavioral patterns observed in greylag geese hold in taxa with differing social systems or ecological constraints and furthermore highlight species-specific strategies in terms of predator avoidance strategies and social behavior. Comparative studies of this nature can deepen our understanding of evolutionary underpinnings of aggression and vigilance (Hohmann & Woog, 2024).

7.3 Conclusion

The study adds to growing body of literature examining the role of consistent individual differences in shaping adaptive responses to environmental threats. By linking personality traits like aggressiveness to anti-predator vigilance, the study supports the idea that within group variation can influence overall group function and survival (Wolf & Weissing, 2012).

Understanding how individual variation in behavior shapes responses to perceived threats has implications for managing human-wildlife interactions in increasingly anthropogenic landscapes. In systems where artificial predators or deterrents are used, accounting for personality driven vigilance patterns, may improve the efficacy and ethical application of such tools (Gruber et.al., 2019).

Taken together this research lays the foundation for a more nuanced understanding of vigilance as a dynamic context-dependent behavior, shaped not only by ecological risk but also by social structure, individual variation and environmental change.

8. References

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9. Appendix

9.1 table outputs for behavioral categories

*TA.5: Output from the generalized mixed model result GLMM analyzing **V1 short-neck** vigilance duration for a flock of greylag geese (n=43) for three experimental phases. **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon The response variable is the behavioral duration of V1 short neck behavior (square root in second) fitted in the model in correlation to the aggressiveness Quartile (Q1-Q4) and random factors like BirdID (variance 0.02±0.16) or sector (n=6, variance=0.01±0.12) where the geese are located. Signif = Statistically significant values are marked with asterisks, p-value = significant values under p< 0.05, highly significant p<0.001, Estimate = estimated, Estimate = estimated coefficients, , SE = Standard Error, Chisq = Chi-squared statistic, df = degree of freedom, z value = z statistics, ^{AN} values derived from the ANOVA analysis*

	Estimate	SE	z value	p value	Chisq	Df	Signif
(Intercept)	0.69	0.12	5.49	**<0.001**			***
phasebefore_launch_duration	-0.20	0.02	-7.10	**<0.001**			***
phaseafter_landing_duration	0.04	0.03	1.25	0.211			
QuartileQ2	0.19	0.09	2.15	**0.031**			*
QuartileQ3	0.03	0.07	0.49	0.621			
QuartileQ4	-0.14	0.07	-1.88	0.059			.
Sex.yM^{AN}	-0.02	0.06	-0.45	0.650	0.39	3	
Pairing.yunpaired^{AN}	-0.01	0.10	-0.13	0.895	0.26	1	
sqrt(Age.y)^{AN}	0.05	0.03	1.51	0.130	2.28	1	
phasebefore_launch_duration:QuartileQ2	-0.12	0.05	-2.35	**0.018**			*
phaseafter_landing_duration:QuartileQ2	-0.57	0.05	-10.04	**<0.001**			***
phasebefore_launch_duration:QuartileQ3	0.08	0.04	1.961	**0.049**			*
phaseafter_landing_duration:QuartileQ3	-0.16	0.04	-3.478	**0.0005**			***
phasebefore_launch_duration:QuartileQ4	0.21	0.04	5.155	**<0.001**			***
phaseafter_landing_duration:QuartileQ4	-0.13	0.05	-2.726	**0.006**			**
Sex.yM:Pairing.yunpaired^{AN}	-0.03	0.13	-0.222	0.824	0.04	1	
Phase ^{AN}				**<0.001**	93.50	2	***
Quartile ^{AN}				0.368	3.93	3	
Phase:Quartile ^{AN}				**<0.001**	162.02	6	***

*TA.6: Output from the generalized mixed model result GLMM analyzing **V2 long neck** vigilance duration for a flock of greylag geese (n=43) for three experimental phases. **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon The response variable is the behavioral duration of V1 short neck behavior (square root in second) fitted in the model in correlation to the aggressiveness Quartile (Q1-Q4) and random factors like surveyor (variance 0.03± 0.19), Signif = Statistically significant values are marked with asterisks , p-value = significant values under p< 0.05, highly significant p<0.001, Estimate = estimated, Estimate = estimated coefficients, , SE = Standard Error, Chisq = Chi-squared statistic, df = degree of freedom, z value = z statistics, ^{AN} values derived from the ANOVA analysis*

	Estimate	SE	z value	p value	Chisq	Df	Signif
(Intercept)	0.88	0.07	11.99	**<0.001**			***
phasebefore_launch_duration	0.24	0.02	10.94	**< 0.001**			***
phaseafter_landing_duration	0.02	0.02	1.23	0.216			
QuartileQ2	0.03	0.02	1.41	0.155			
QuartileQ3	-0.04	0.01	-2.82	**0.004**			**
QuartileQ4	0.05	0.02	2.19	**0.028**			*
sqrt(Age.y) ^{AN}	0.001	0.01	0.07	0.940	0.001	1	
phasebefore_launch_duration:QuartileQ2	-0.47	0.03	-12.97	**< 0.001**			***
phaseafter_landing_duration:QuartileQ2	-0.08	0.05	-1.55	0.119			
phasebefore_launch_duration:QuartileQ3	0.14	0.02	5.18	**<0.001**			***
phaseafter_landing_duration:QuartileQ3	-0.01	0.03	-0.55	0.577			
phasebefore_launch_duration:QuartileQ4	-0.60	0.03	-16.50	**<0.001**			***
phaseafter_landing_duration:QuartileQ4	-0.64	0.05	-11.27	**<0.001**			***
Phase ^{AN}				**<0.001**	116.44	2	***
Quartile ^{AN}				**<0.001**	101.005	3	***
Phase:Quartile ^{AN}							

*TA.7: Output from the generalized mixed model result GLMM analyzing **V3 one-eye-up** duration for a flock of greylag geese (n=43) for three experimental phases. **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon The response variable is the behavioral duration of VO non-feeding behavior (square root in second) fitted in the model in correlation to the aggressiveness Quartile (Q1-Q4) and random factors like BirdID (variance: 0.03 ± 0.18) or sector (n=6, variance =0.02 ± 0.16) of the area the experiment is conducted Signif = Statistically significant values are marked with asterisks, p-value = significant values under p< 0.05, highly significant p<0.001, Estimate = estimated coefficients, , SE = Standard Error, Chisq = Chi-squared statistic, df = degree of freedom, z-value = z statistics, ^{AN} values derived from the ANOVA analysis*

	Estimate	SE	z value	p value	Chisq	Df	Signif
(Intercept)	0.93	0.14	6.36	**<0.001**			***
phasebefore_launch_duration	-0.29	0.026	-11.18	**<0.001**			***
phaseafter_landing_duration	-0.29	0.02	-10.80	**<0.001**			***
QuartileQ2	0.10	0.02	4.80	**<0.001**			***
QuartileQ3	0.02	0.01	1.54	0.122			
QuartileQ4	0.06	0.02	2.24	0.024			*
Pairing.yunpaired^{AN}	-0.03	0.08	-0.42	0.672	0.17	1	
sqrt(Age.y) ^{AN}	-0.006	0.04	-0.14	0.883	0.02	1	
Sex.yM^{AN}	0.047	0.07	0.67	0.499	0.45	1	
phasebefore_launch_duration:QuartileQ2	-0.46	0.04	-10.52	**<0.001**			***
phaseafter_landing_duration:QuartileQ2	-0.26	0.04	-5.45	**<0.001**			***
phasebefore_launch_duration:QuartileQ3	-0.19	0.04	-4.82	**<0.001**			***
phaseafter_landing_duration:QuartileQ3	-0.007	0.04	-0.19	0.849			
phasebefore_launch_duration:QuartileQ4	-0.40	0.06	-5.86	**<0.001**			***
phaseafter_landing_duration:QuartileQ4	-0.15	0.05	-3.00	**0.002**			**
Phase ^{AN}				**<0.001**	974.75	2	
Quartile^{AN}				0.9685	0.25	3	
Phase:Quartile^{AN}				**<0.001**	136.30	6	

TA.8: Output from the generalized mixed model result GLMM analyzing ***VO non-feeding*** *duration for a flock of greylag geese (n=43) for three experimental phases.* ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon The response variable is the behavioral duration of VO non-feeding behavior (square root in second) fitted in the model in correlation to the aggressiveness Quartile (Q1-Q4) and random factors like BirdID (variance: 0.07 ± 0.28) or sector (n=6, variance =0.01 ± 0.10) of the area the experiment is conducted, Signif = Statistically significant values are marked with asterisks, p-value = significant values under p< 0.05, highly significant p<0.001, Estimate = estimated coefficients, , SE = Standard Error, Chisq = Chi-squared statistic, df = degree of freedom, z-value = z statistics, [AN] values derived from the ANOVA analysis*

	Estimate	SE	z value	p value	Chisq	Df	Signif
(Intercept)	0.32	0.33	0.97	0.328			
phasebefore_launch_duration	0.08	0.04	1.69	0.090			
phaseafter_landing_duration	0.44	0.04	9.18	**<0.001**			***
QuartileQ2	-0.05	0.15	-0.37	0.708			
QuartileQ3	-0.20	0.13	-1.50	0.131			
QuartileQ4	-0.02	0.14	-0.19	0.844			
Sex.yM [AN]	0.08	0.38	0.23	0.815	0.16	1	
sqrt(Age.y)[A]	0.15	0.10	1.40	0.023	5.12	1	*
Pairing.yunpaired[AN]	0.20	0.10	1.91	0.056	3.65	1	.
phasebefore_launch_duration:QuartileQ2	0.20	0.07	2.79	**0.0052**			***
phaseafter_landing_duration:QuartileQ2	0.27	0.06	4.13	**< 0.001**	.		
phasebefore_launch_duration:QuartileQ3	0.10	0.06	1.62	0.105			
phaseafter_landing_duration:QuartileQ3	0.11	0.07	-1.58	0.112			
phasebefore_launch_duration:QuartileQ4	0.07	0.06	1.21	0.226			
phaseafter_landing_duration:QuartileQ4	0.30	0.06	4.61	**< 0.001**			
Phase [AN]				<0.001	616.75	2	***
Quartile [AN]				0.089	6.50	3	.
Phase:Quartile [AN]				<0.001	68.50	6	***
Sex.y:sqrt (Age.y) [AN]	-0.01	0.13	-0.13	0.894	0.017	1	***

9.2 post-hoc analysis output

*TA.9: post hoc comparison of aggressiveness quartiles (Q1-Q4)using Bonferroni adjustment comparing **V2 long neck vigilance** within each experimental phase, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

phase = before launch

contrast	estimate	SE	df	t.ratio	p.value
Q1- Q2	0.3430	0.631	1111	0.543	1.0000
Q1- Q3	-0.3440	0.146	1111	-2.359	0.1111
Q1- Q4	0.6191	0.187	1111	3.314	**0.0057**
Q2- Q3	-0.6870	0.626	1111	-1.097	1.0000
Q2- Q4	0.2760	0.637	1111	0.433	1.0000
Q3-Q4	0.9630	0.168	1111	5.720	**<.0001**

phase = exposure phase

contrast	estimate	SE	df	t.ratio	p.value
Q1- Q2	-0.3041	0.117	1111	-2.590	0.0584
Q1- Q3	0.1403	0.104	1111	1.348	1.0000
Q1- Q4	0.0284	0.131	1111	0.217	1.0000
Q2- Q3	0.4445	0.114	1111	3.886	**0.0006**
Q2- Q4	0.3326	0.139	1111	2.385	0.1036
Q3- Q4	-0.1119	0.128	1111	-0.871	1.0000

phase = after landing duration

contrast	estimate	SE	df	t.ratio	p.value
Q1- Q2	-0.6809	0.250	1111	-2.721	**0.0396**
Q1- Q3	0.1150	0.222	1111	0.518	1.0000
Q1- Q4	0.4367	0.445	1111	0.982	1.0000
Q2- Q3	0.7959	0.214	1111	3.716	**0.0013**
Q2- Q4	11.176	0.441	1111	2.534	0.0685
Q3- Q4	0.3217	0.426	1111	0.756	1.0000

TA.10: post hoc comparison of aggressiveness quartiles (Q1-Q4)using Bonferroni adjustment comparing ***V3 one-eye-up*** *vigilance within each experimental phase,* ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

phase = before launch					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
Q1-Q2	-0.1014	0.266	1544	-0.382	1.0000
Q1-Q3	0.2596	0.262	1544	0.990	1.0000
Q1-Q4	0.3180	0.325	1544	0.977	1.0000
Q2-Q3	0.3609	0.288	1544	1.254	1.0000
Q2-Q4	0.4194	0.346	1544	1.211	1.0000
Q3-Q4	0.0585	0.344	1544	0.170	1.0000
phase = exposure phase					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
Q1-Q2	0.5097	0.127	1544	4.006	**0.0004**
Q1-Q3	0.2315	0.103	1544	2.248	0.1482
Q1-Q4	0.3190	0.103	1544	3.108	0.0115
Q2-Q3	-0.2781	0.129	1544	-2.149	0.1905
Q2-Q4	-0.1906	0.129	1544	-1.476	0.8408
Q3-Q4	0.0875	0.105	1544	0.831	1.0000
phase = after landing duration					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
Q1-Q2	1.0270	0.321	1544	3.200	**0.0084**
Q1-Q3	0.5565	0.501	1544	1.110	1.0000
Q1-Q4	0.6903	0.270	1544	2.553	0.0646
Q2-Q3	-0.4705	0.564	1544	-0.835	1.0000
Q2-Q4	-0.3367	0.374	1544	-0.901	1.0000
Q3-Q4	0.1338	0.537	1544	0.249	1.0000

*TA.11: post hoc comparison of aggressiveness quartiles (Q1-Q4)using Bonferroni adjustment comparing **V1 short-neck** vigilance within each experimental phase, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

phase = before launch

contrast	estimate	SE	df	t.ratio	p.value
Q1-Q2	-0.23981	0.0930	4155	-2.577	0.0599
Q1-Q3	-0.11892	0.0721	4155	-1.648	0.5960
Q1-Q4	-0.14163	0.0714	4155	-1.984	0.2838
Q2-Q3	0.12089	0.1000	4155	1.207	1.0000
Q2- Q4	0.09818	0.0996	4155	0.985	1.0000
Q3- Q4	-0.02271	0.0805	4155	-0.282	1.0000

phase = exposure phase

contrast	estimate	SE	df	t.ratio	p.value
Q1-Q2	-0.60661	0.0889	4155	-6.824	**<.0001**
Q1-Q3	0.04344	0.0751	4155	0.578	1.0000
Q1-Q4	0.37865	0.0775	4155	4.885	**<.0001**
Q2-Q3	0.65005	0.0881	4155	7.379	**<.0001**
Q2- Q4	0.98526	0.0902	4155	10.926	**<.0001**
Q3-Q4	0.33522	0.0766	4155	4.376	0.0001
Q1-Q2	-0.60661	0.0889	4155	-6.824	**<.0001**

phase = after landing duration

contrast	estimate	SE	df	t.ratio	p.value
Q1-Q2	0.66754	0.1050	4155	6.350	**<.0001**
Q1-Q3	0.51074	0.0869	4155	5.877	**<.0001**
Q1-Q4	0.66122	0.1020	4155	6.496	**<.0001**
Q2- Q3	-0.15680	0.1050	4155	-1.494	0.8115
Q2- Q4	-0.00632	0.1180	4155	-0.054	1.0000
Q3- Q4	0.15048	0.1020	4155	1.481	0.8325

*TA.12: post hoc comparison of aggressiveness quartiles (Q1-Q4)using Bonferroni adjustment comparing **V0 non- feeding** duration within each experimental phase, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

phase = before launch

contrast	estimate	SE	df	t.ratio	p.value
Q1-Q2	-0.63596	0.188	2473	-3.379	**0.0044**
Q1-Q3	0.16696	0.150	2473	1.114	1.0000
Q1-Q4	-0.52909	0.158	2473	-3.344	**0.0050**
Q2-Q3	0.80292	0.179	2473	4.485	**<.0001**
Q2-Q4	0.10688	0.186	2473	0.574	1.0000
Q3-Q4	-0.69605	0.147	2473	-4.729	<.0001

phase = exposure phase

contrast	estimate	SE	df	t.ratio	p.value
Q1-Q2	0.31940	0.204	2473	1.568	0.7018
Q1-Q3	0.61832	0.184	2473	3.354	**0.0049**
Q1-Q4	-0.49251	0.172	2473	-2.870	**0.0248**
Q2-Q3	0.29892	0.197	2473	1.517	0.7767
Q2-Q4	-0.81191	0.185	2473	-4.384	**0.0001**
Q3-Q4	-1.11083	0.164	2473	-6.785	**<.0001**

phase = after landing duration

contrast	estimate	SE	df	t.ratio	p.value
Q1-Q2	-0.00508	0.173	2473	-0.029	1.0000
Q1-Q3	0.66126	0.194	2473	3.408	**0.0040**
Q1-Q4	-1.91931	0.196	2473	-9.778	**<.0001**
Q2-Q3	0.66634	0.186	2473	3.588	**0.0020**
Q2-Q4	-1.91423	0.188	2473	-10.177	**<.0001**
Q3-Q4	-2.58057	0.208	2473	-12.419	**<.0001**

*TA.13 post hoc pairwise t-test comparison using a Bonferroni method of **V0 feeding duration** for each experimental phase against one another separately for Quartiles ranking from high level of aggressiveness (Q1) to low levels (Q4), **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

Quartile = Q1					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	-0.43	0.13	2522	-3.35	**0.002**
exposure_duration - after_landing_duration	-1.17	0.14	2522	-7.94	**<.0001**
before_launch_duration - after_landing_duration	-0.74	0.12	2522	-5.82	**<.0001**
Quartile = Q2					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	-2.34	0.23	2522	-10.11	**<.0001**
exposure_duration - after_landing_duration	-0.66	0.21	2522	-3.13	**0.005**
before_launch_duration - after_landing_duration	1.68	0.23	2522	7.11	**<.0001**
Quartile = Q3					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	-0.74	0.17	2522	-4.40	**<.0001**
exposure_duration - after_landing_duration	-1.01	0.16	2522	-6.10	**<.0001**
before_launch_duration - after_landing_duration	-0.26	0.14	2522	-1.83	0.2020
Quartile = Q4					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	-0.23	0.15	2522	-1.50	0.3979
exposure_duration - after_landing_duration	-1.35	0.19	2522	-6.96	**<.0001**
before_launch_duration - after_landing_duration	-1.11	0.18	2522	-6.15	**<.0001**

*TA.14 post hoc pairwise t-test comparison using a Bonferroni method of **overall vigilance duration** for each experimental phase against one another separately for Quartiles ranking from high level of aggressiveness (Q1) to low levels (Q4), **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, contrast = of the Quartiles, Estimate = of the differences between Quartiles, SE = Standard Error, df = degree of Freedom, t ratio = standardized difference between Quartiles, p-value = significant value threshold p<0.05 , highly significant p<0.001*

Quartile = Q1					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	0.74	0.08	3459	9.15	**<.0001**
exposure_duration - after_landing_duration	0.41	0.09	3459	4.18	**0.0001**
before_launch_duration - after_landing_duration	-0.33	0.10	3459	-3.28	**0.003**
Quartile = Q2					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	0.59	0.12	3459	4.77	**<.0001**
exposure_duration - after_landing_duration	0.81	0.12	3459	6.48	**<.0001**
before_launch_duration - after_landing_duration	0.21	0.14	3459	1.47	0.423
Quartile = Q3					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	0.37	0.08	3459	4.20	**0.0001**
exposure_duration - after_landing_duration	0.63	0.09	3459	6.65	**<.0001**
before_launch_duration - after_landing_duration	0.26	0.10	3459	2.48	**0.039**
Quartile = Q4					
contrast	**estimate**	**SE**	**df**	**t.ratio**	**p.value**
exposure_duration - before_launch_duration	0.35	0.09	3459	3.75	**0.0005**
exposure_duration - after_landing_duration	0.47	0.11	3459	4.22	**0.0001**
before_launch_duration - after_landing_duration	0.12	0.12	3459	1.00	0.939

TA.15: Results of the two-sampled t-test comparing vigilance duration between the lowest Quartile (Q1, high level of aggressiveness) and highest Quartile (Q4, low level of aggressiveness), significant differences were found in the exposure phase (p=<0.001, t= 4.34) and after landing phase (p<0.001, t= 8.05), the before launch phase is not significant (p= 0.445, t= -0.076)

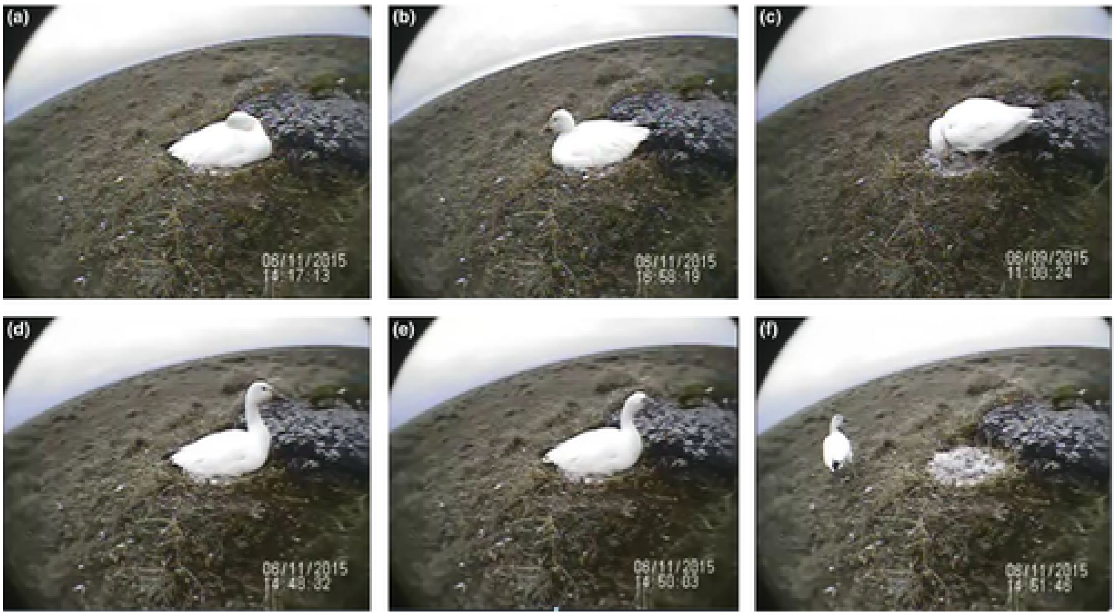
phase	p value	t statistic	result
before launch duration	0.445243	-0.07603441	Not signficant
exposure duration	<0.001	4.348021	significant
after landing duration	<0.001	8.0501033	significant

*TA.16: normalized duration vigilance vs. foraging (in %) for each aggressiveness Quartile (Q1-Q4, aggressiveness quartiles (Q1-Q4, Quartile 1 indicating the highest score of aggressiveness, while Q4 being the lowest level of aggressiveness) and across experimental phases, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon, Behavioral Category = individual is either foraging (feeding) or vigilant, vigilance is subdivided into three categories: V1-short neck, V2 long-neck, V3 one-eye-up),Normalized duration = total duration normalized in %*

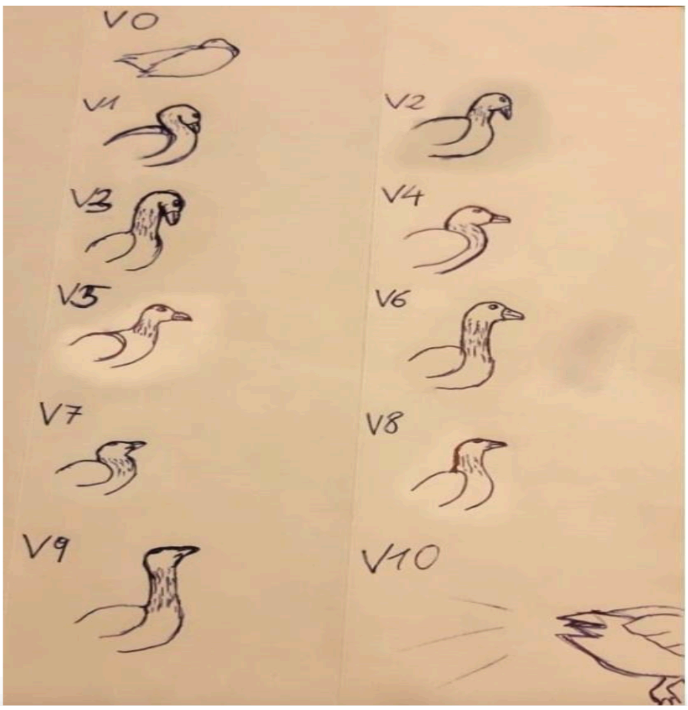
phase	Quartile	Category	Subcategory	Normalized_Duration
exposure_duration	Q1	Feeding	Feeding	0.1977
exposure_duration	Q1	Vigilance	Long-neck	0.1602
exposure_duration	Q1	Vigilance	One-eye-up	0.3222
exposure_duration	Q1	Vigilance	Short-neck	0.3197
exposure_duration	Q2	Feeding	Feeding	0.1504
exposure_duration	Q2	Vigilance	Long-neck	0.2036
exposure_duration	Q2	Vigilance	One-eye-up	0.2420
exposure_duration	Q2	Vigilance	Short-neck	0.4038
exposure_duration	Q3	Feeding	Feeding	0.1803
exposure_duration	Q3	Vigilance	Long-neck	0.1449
exposure_duration	Q3	Vigilance	One-eye-up	0.3167
exposure_duration	Q3	Vigilance	Short-neck	0.3580
exposure_duration	Q4	Feeding	Feeding	0.2914
exposure_duration	Q4	Vigilance	Long-neck	0.0878
exposure_duration	Q4	Vigilance	One-eye-up	0.3045
exposure_duration	Q4	Vigilance	Short-neck	0.3161
before_launch_duration	Q1	Feeding	Feeding	0.5011
before_launch_duration	Q1	Vigilance	Long-neck	0.0738
before_launch_duration	Q1	Vigilance	One-eye-up	0.0402
before_launch_duration	Q1	Vigilance	Short-neck	0.3848
before_launch_duration	Q2	Feeding	Feeding	0.4552
before_launch_duration	Q2	Vigilance	Long-neck	0.0121
before_launch_duration	Q2	Vigilance	One-eye-up	0.0879
before_launch_duration	Q2	Vigilance	Short-neck	0.4446
before_launch_duration	Q3	Feeding	Feeding	0.4828
before_launch_duration	Q3	Vigilance	Long-neck	0.1562
before_launch_duration	Q3	Vigilance	One-eye-up	0.0357
before_launch_duration	Q3	Vigilance	Short-neck	0.3250
before_launch_duration	Q4	Feeding	Feeding	0.5326
before_launch_duration	Q4	Vigilance	Long-neck	0.0504
before_launch_duration	Q4	Vigilance	One-eye-up	0.0219
before_launch_duration	Q4	Vigilance	Short-neck	0.3949
after_landing_duration	Q1	Feeding	Feeding	0.4970
after_landing_duration	Q1	Vigilance	Long-neck	0.0481
after_landing_duration	Q1	Vigilance	One-eye-up	0.0843
after_landing_duration	Q1	Vigilance	Short-neck	0.3704
after_landing_duration	Q2	Feeding	Feeding	0.4580
after_landing_duration	Q2	Vigilance	Long-neck	0.1258
after_landing_duration	Q2	Vigilance	One-eye-up	0.0381
after_landing_duration	Q2	Vigilance	Short-neck	0.3778

after_landing_duration	Q3	Feeding	Feeding	0.6288
after_landing_duration	Q3	Vigilance	Long-neck	0.0740
after_landing_duration	Q3	Vigilance	One-eye-up	0.0131
after_landing_duration	Q3	Vigilance	Short-neck	0.2839
after_landing_duration	Q4	Feeding	Feeding	0.5829
after_landing_duration	Q4	Vigilance	Long-neck	0.0171
after_landing_duration	Q4	Vigilance	One-eye-up	0.0527
after_landing_duration	Q4	Vigilance	Short-neck	0.3471

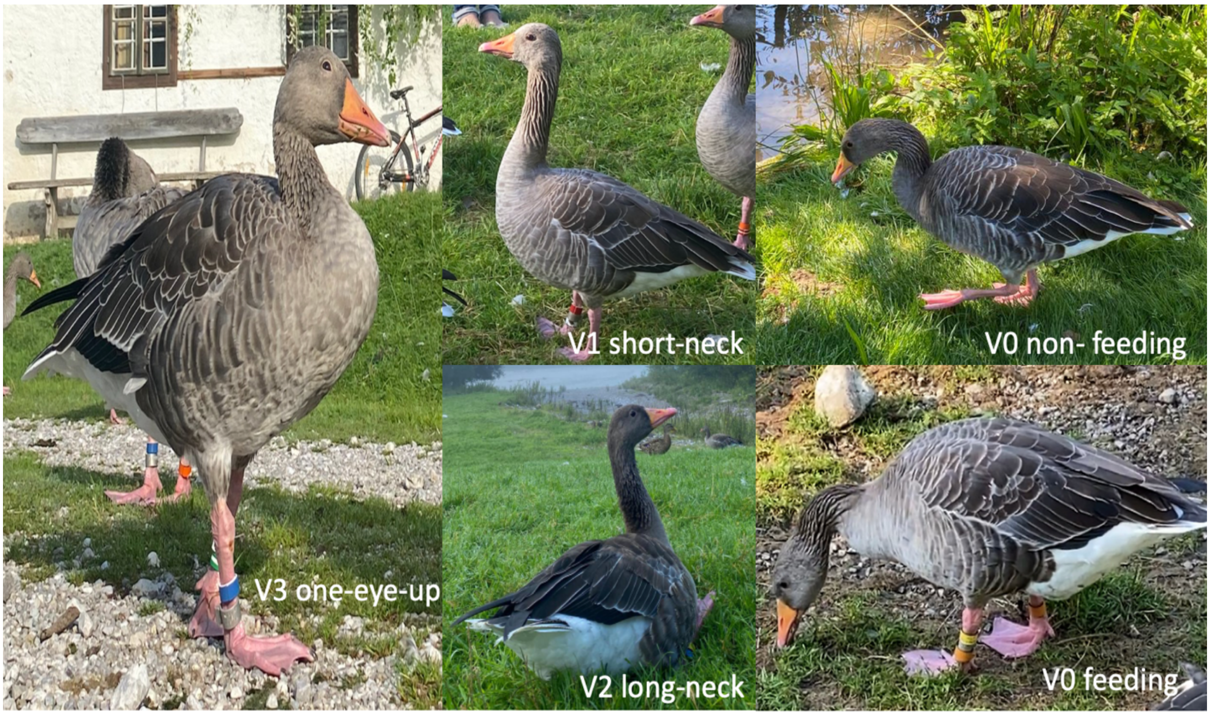
10. Supplementary material



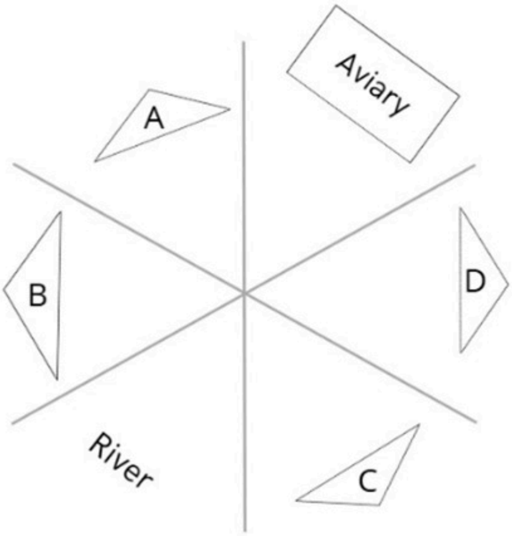
Supplementary Figure 1: six pictures showing a nesting waterfowl and its behavioral classification according to Barnas et.al. (2018), (a) bird is resting (b) Low Scan state, (c)bird is in Nest Maintenance, (d) High Scan state (e) Head Cock state (f) bird is being off the nest,



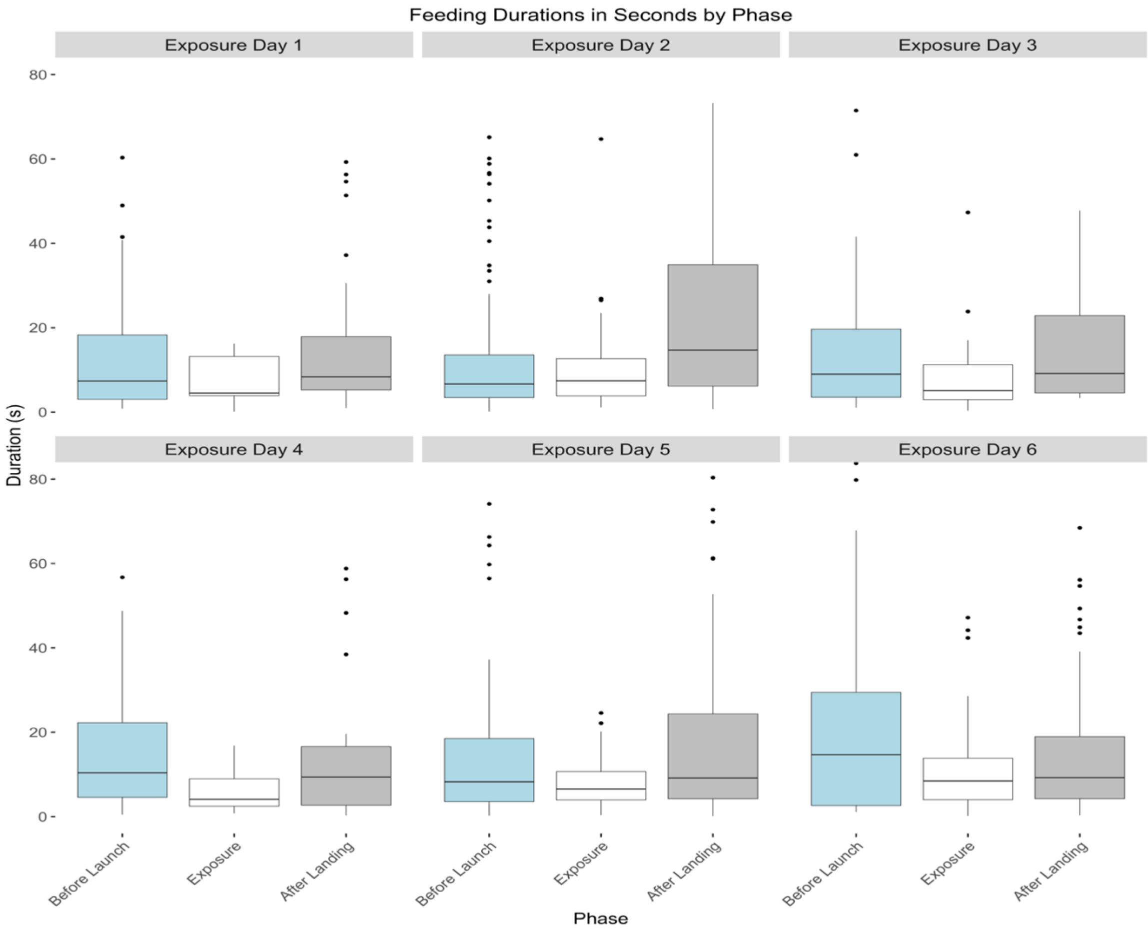
Supplementary Figure 2: Vigilance Ethogram (Lorenz, 1988), V0 head tucked, V1 short neck, beak-down, V2 Mid neck, beak down,V3 long neck, beak-down, V4 Short neck, beak-straight, V5 Mid neck, beak-straight, V6 Long neck, beak straight, V7 short neck, one eye-up, V8 Mid neck, one eye-up, V9 Long neck, one eye-up, V10 Flight.



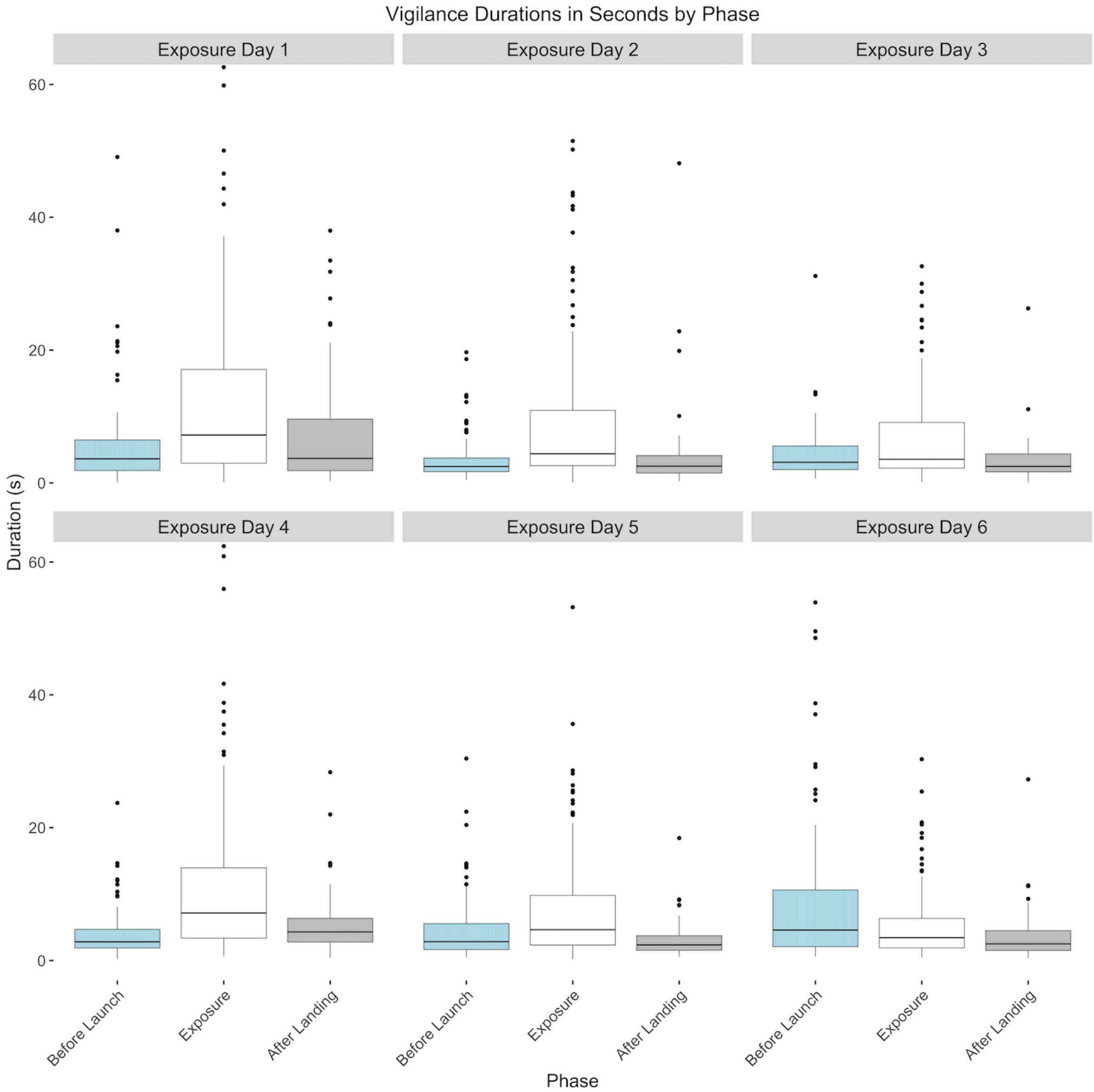
Supplementary Figure 2: vigilance categories used in the behavioral coding analysis with the video coding software BORIS, V0 non-feeding = beak of the individual is pointing downwards, also included behaviors like resting or preening, state of non-vigilance, V0 feeding = individual is foraging on the ground, V1 short-neck = beak is straight, slightly alerted, also included agonistic interactions with another conspecific, V2 long neck = neck is elongated and beak is pointing upwards, V3 one-eye-up = individuals tilts their head and eyes are looking up , highly alerted



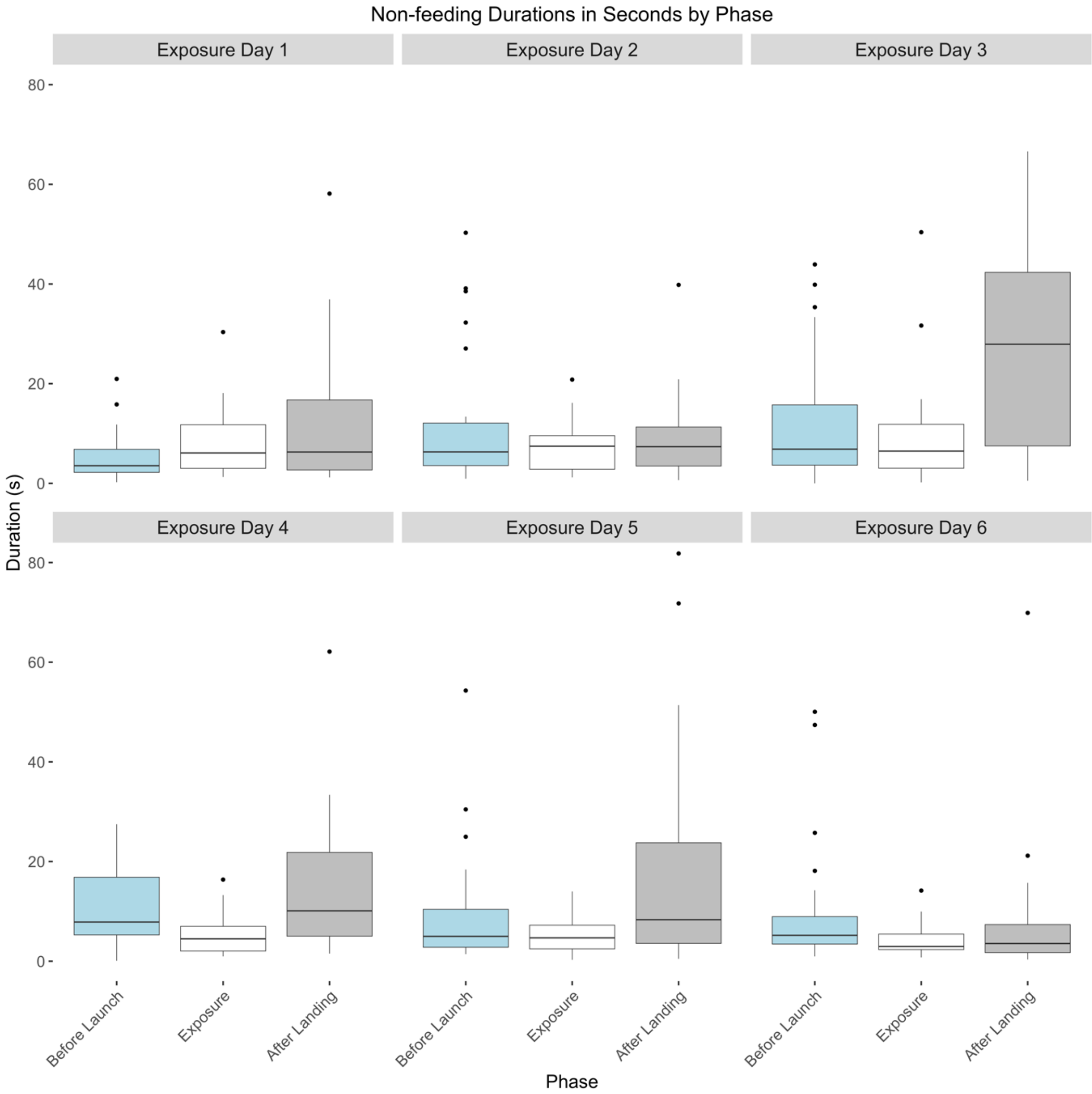
Supplementary Figure 3: starting quadrants or sector for the conducted experiment, quadrant A,B,C, D are feeding sections with feeding trays included, Aviary quadrant was next to an aviary and the river quadrant was adjacent to the river



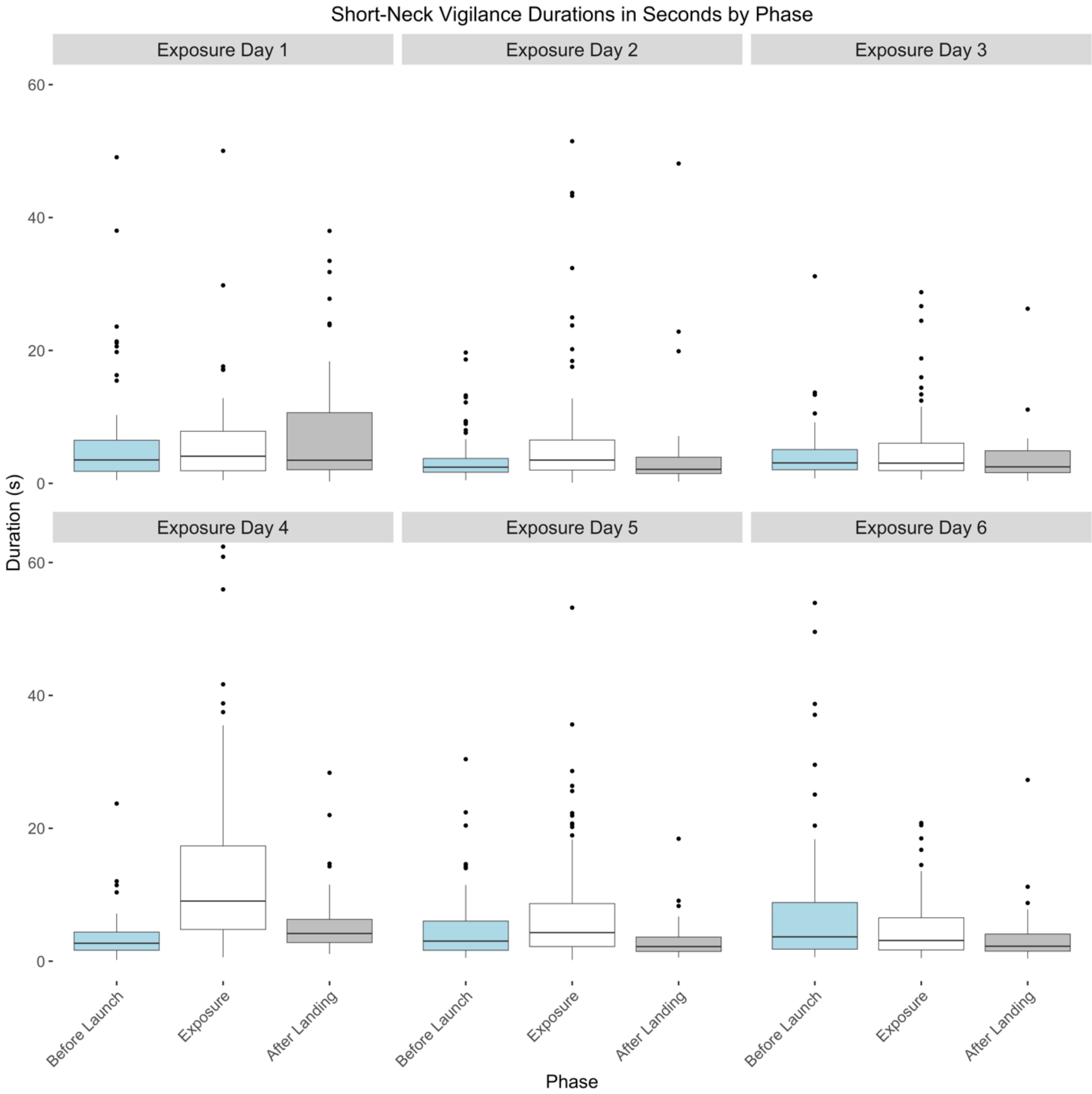
*Supplementary Figure 4: Comparative analysis of the behavior V0 feeding duration across the exposure days (1-6) within each phase during the Robotfalcon experiment, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon behavioral duration measured in seconds with a range of 60 seconds, in comparison to the exposure phase, both the before launch (Estimate=0.39 ±0.15, p-value= 0.001) and the after landing phase (Estimate =0.82 ±0.12, p-value=<0.001) are significantly higher in feeding duration*



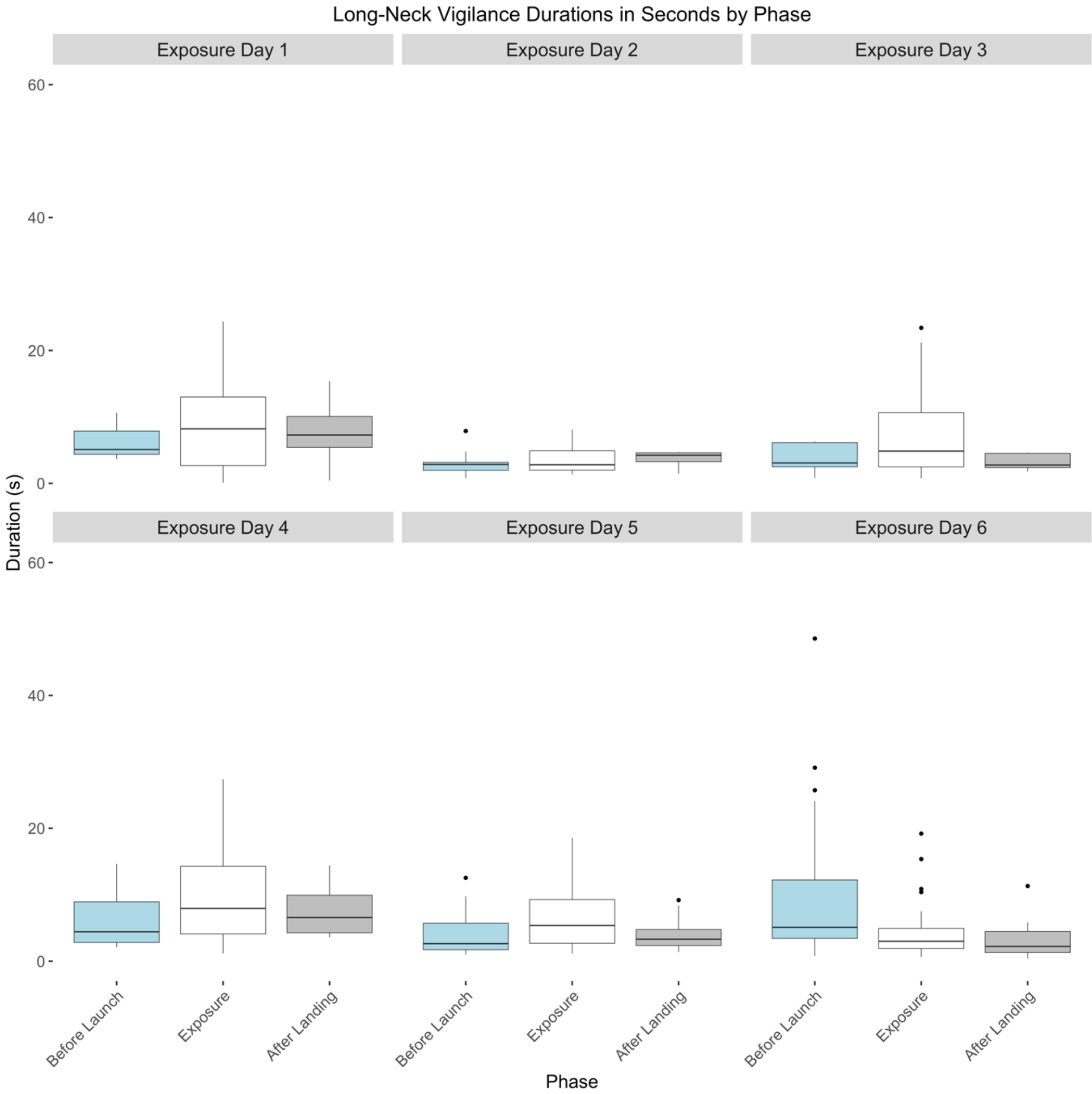
Supplementary Figure 5: *Comparative analysis of the behavior V0 non feeding duration across the exposure days (1-6) within each phase during the Robotfalcon experiment,* ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 60 seconds due to greater outliers, the before launch phase is significant (Estimate =-0.49± 0.14, p-value= 0.001)(compared to the reference phase, whereas after landing is not significant (Estimate = -0.08 ±0.18, p-value = 0.652)*



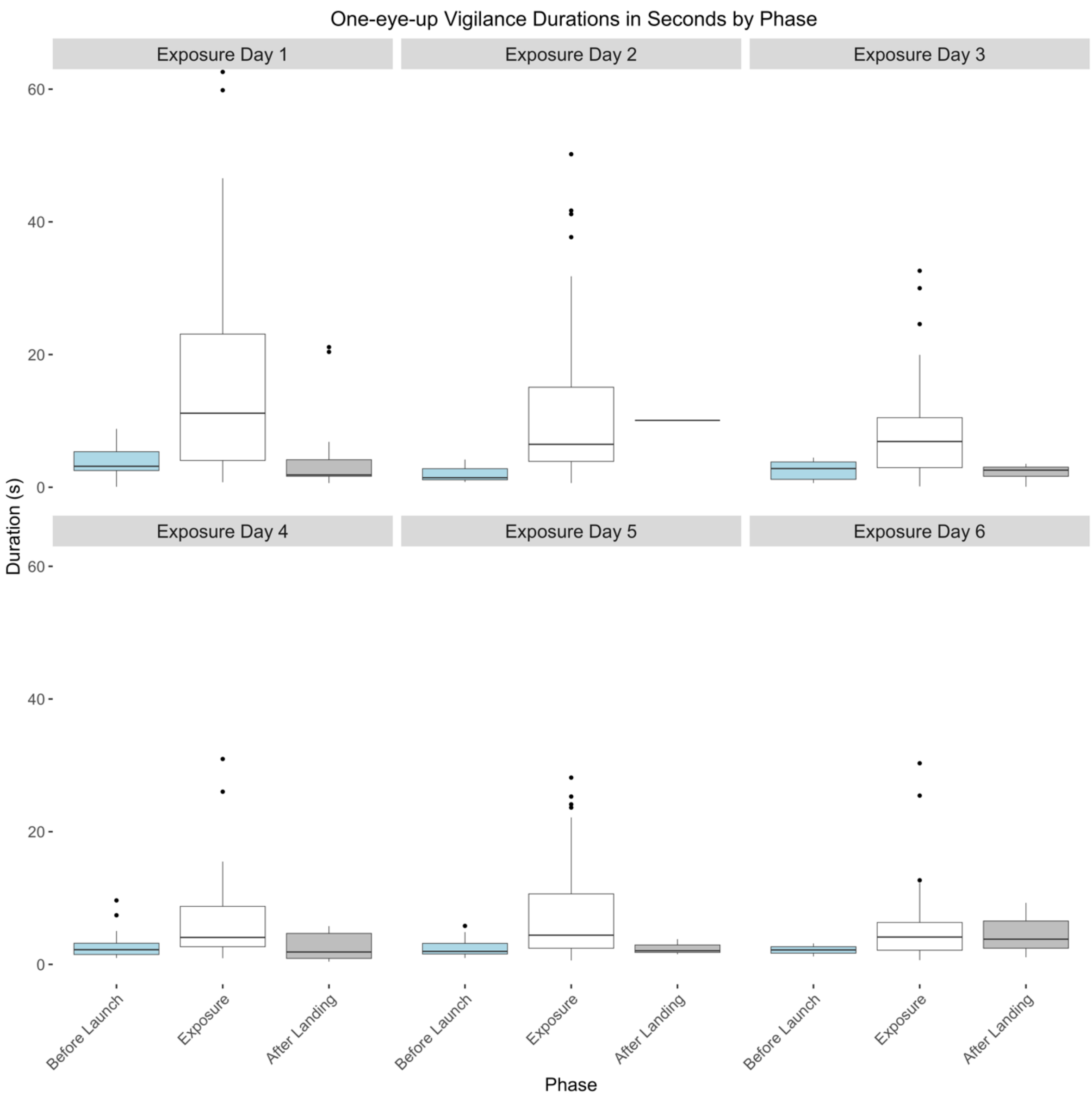
Supplementary Figure 5: *Comparative analysis of the behavior V0 non feeding duration across the exposure days (1-6) within each phase during the Robotfalcon experiment,* ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 80 seconds due to greater outliers, The after landing phase (0.47 ±0.10, p-value=<0.001) is significantly higher in non-feeding duration compared to the exposure phase, this is not the case for the before launch phase (Estimate = 0.12 ±0.10, p-value=0.235)*



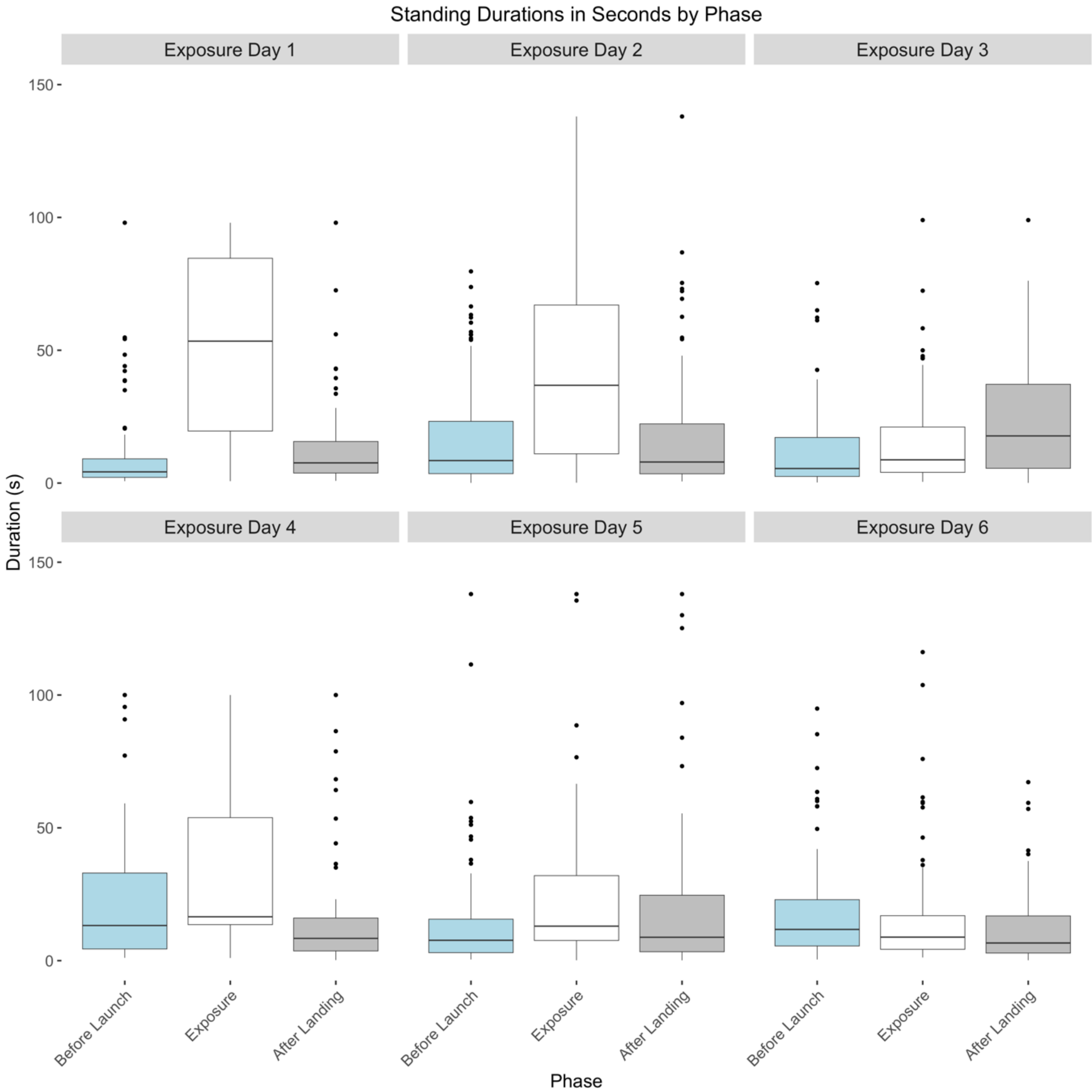
Supplementary Figure 6: Comparative analysis of the behavior V1 short neck vigilance duration across the exposure days (1-6) within each phase during the Robotfalcon experiment, ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 60 seconds, according to the generalized linear mixed model results short-neck vigilance duration is significantly increased during exposure in comparison to before launch (Estimate -0.18 ± 0.09, p-value= 0.047), but not for after landing (Estimate =-0.17 ±0.10, p-value= 0.085)*



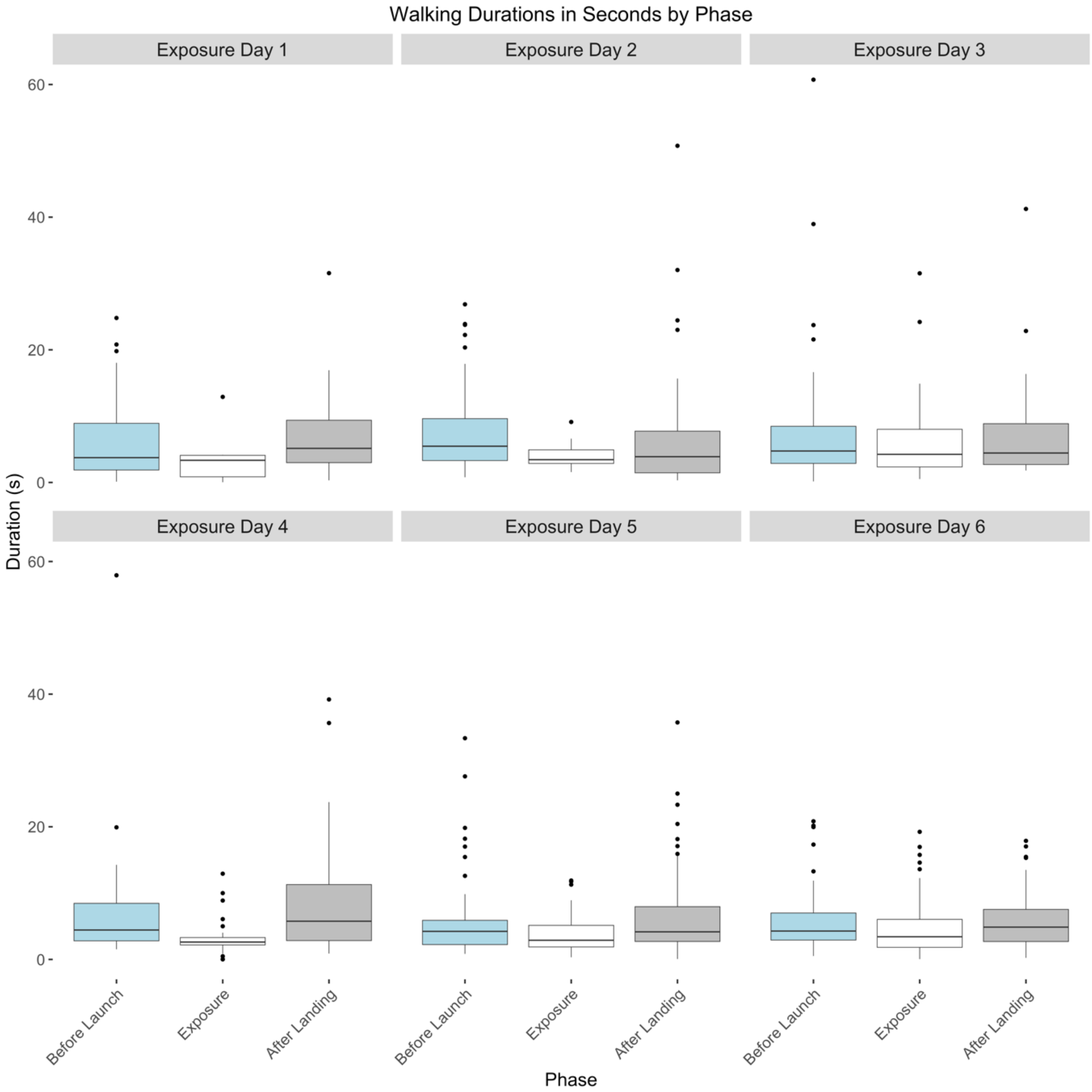
*Supplementary Figure 7: Comparative analysis of the behavior **V2 long neck** vigilance duration across the exposure days (1-6) within each phase during the Robotfalcon experiment, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landnig phase**: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 60 seconds, the before launch (Estimate =-0.79 ±0.48, p-value=0.109)) and after landing phase(Estimate = -0.26 ±0.31, p-value=0.402) are not significantly lower in V2 long neck vigilance duration compared to the reference phase (exposure)*



*Supplementary Figure 8: Comparative analysis of the behavior V3 one eye up vigilance duration across the exposure days (1-6) within each phase) during the Robotfalcon experiment, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 60 seconds, The before launch phase has significantly lower one-eye- up vigilance duration compared to the exposure phase (Estimate=-0.54±0.16, p-value=0.033), in contrast to the after landing phase (Estimate=-0.26 ±0.30, p=0.383)*



*Supplementary Figure 9: Comparative analysis of the movement type standing duration across the exposure days (1-6) within each phase during the Robotfalcon experiment, **Before Launch phase:** time period before the artificial predator (Robotfalcon) launches, **Exposure phase**: period where the flock of greylag geese is exposed to the Robotfalcon, **After landing phase**: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 150 seconds due to greater outliers , both before launch (Estimate -0.34 ±0.01, p-value= <0.001) and after landing phase (Estimate =-0.24 ±0.04, , p-value = <0.001) are significantly lower in standing duration compared to the reference phase (Exposure)*



Supplementary Figure 10: *Comparative analysis of the movement type walking duration across the exposure days (1-6) within each phase during the Robotfalcon experiment,* ***Before Launch phase:*** *time period before the artificial predator (Robotfalcon) launches,* ***Exposure phase****: period where the flock of greylag geese is exposed to the Robotfalcon,* ***After landing phase****: period including the landing of the Robotfalcon the duration is measured in seconds with a range of 60 seconds, both before launch phase (Estimate 0.17 ±0.03, p-value =<0.001) and after landing phase (Estimate = 0.16 ±0.04, p-value = <0.001) significantly higher in walking duration compared to exposure phase*