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RESEARCH ARTICLE

Environmental Conditions and Vehicle Disturbance Influence Stress Behaviors in a Working Harris's Hawk (*Parabuteo unicinctus*)

Bryony M. Jenner [a] and Todd R. Lewis [b]

[a]Department Animal Welfare and Science, Kingston Maurward College, Dorchester, UK; [b]Department Geography and Environmental Management, UWE Bristol -Frenchay Campus, Bristol, UK

ABSTRACT
Harris's hawk (*Parabuteo unicinctus*) is used for pest control, as their presence can deter wild birds such as gulls. Working Harris's hawk on UK waste sites is permitted in accordance with regulations and legislation. This study investigated the general environment of a waste site compound yard where a single Harris's hawk was flown for pest control. The hawk's behaviors were evaluated in an ethogram, alongside environmental measures, and disturbance levels. Data was analyzed using Generalised Linear Latent Variable Models (GLLVM) to elucidate the effects of disturbance and environment on hawk behaviors. Results suggested cloudy conditions encouraged grooming responses that were normal and relaxed in their nature. Rain, sun and wind conditions increased recognized stress behaviors. Frequency of disturbance by construction vehicles inside the compound increased stress behaviors, such that keepers are recommended to revise welfare conditions. Increased stress behaviors by birds worked in dynamic environments like waste recycling yards could potentially elicit damaging illness such as feather breaking behavior. Reducing stress factors for Harris's hawk in industrial working yards combined with amending husbandry practices will improve welfare for the species.

KEYWORDS
Animal welfare; Harris's hawk; stress behavior; environment conditions; vehicle disturbance

Introduction

Birds of prey are kept captive for many purposes including work (Baxter & Allan, 2006), zoology, entertainment (Smith, Broad, & Weiler, 2008), personal gain, hunting, and conservation (Boal, 2018). Working birds of prey can be from raptor guilds as wide as owls (Strigiformes), eagles (Accipitriformes), hawks (Accipitriformes), and falcons (Falconiformes) (Boal, 2018). Harris's hawk (*Parabuteo unicinctus*) is used commonly in work environments as a method of pest control, as their presence and trained behaviors can deter wild birds such as gulls (Laridae) (Baxter & Allan, 2006; Dalton, 1997). Falcons specifically are used for deterring carrion crow (*Corvus corone*), rook (*Corvus frugilegus*), and wood pigeon (*Columba palumbus*) as these are common food sources for this group, and they can successfully reduce Corvid and Columbid presence in an area (Baxter & Allan, 2006; Cook, Rushton, Allan, & Baxter, 2008). Working birds of prey can also be used to control rabbits (Leporidae) and rodents (Muridae), however, this is an uncommon deployment due to disease risk, poison consumption, and poorer effectiveness (Antkowiak & Hayes, 2004).

CONTACT Todd R. Lewis Todd.Lewis@uwe.ac.uk Geography and Environmental Management, UWE Bristol -Frenchay Campus, Coldharbour Ln, Bristol BS16 1QY, UK

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Using birds of prey such as Harris's hawk on landfill waste sites as avian pest control is efficient as often the presence of the bird is enough to ward away other birds. Many UK landfill waste sites are legally required to supply a bird control method with subsequent handler under the Wildlife and Countryside Act (1981) (WCA), Protection of Birds Acts (1954 to 1967), and the Wild Birds: License to Control Certain Species (2019). These legal articles are governed by the Environment Agency (EA) (1995) and supported by the Department for Environment Food and Rural Affairs (2001), the International Civil Aviation Organization (ICAO) and the UK Civil Aviation Authority (CAA) (1972). The EA enforce provision due to the impacts of avian pest species, especially gulls, on landfill waste sites: the crop and webbed feet of gull's transfer disease to both offspring and public places (Baxter, 2001; Baxter & Allan, 2006; Cook, Rushton, Allan, & Baxter, 2008). Keeping flocks of gulls out of the surrounding skies of landfill waste sites also clears flight pathways for aeroplanes by decreasing potential airstrike risk (Baxter, 2001; Baxter & Allan, 2006; Cook, Rushton, Allan, & Baxter, 2008). Under WCA (1981) a falcon must be carried/owned with an Article10 certificate allowing the bird to be identified by ring number, breed, and background. For Harris's hawk a ring must be applied and registered with statutory authorities (Cooper, 1986). Despite the above legal requirements, welfare standards for Harris's hawk can become questionable as there is little legislation to monitor welfare conditions upheld by keepers and husbandry practices (Durman-Walters, Mroczek, Bonczar, & Nowak, 2009; Harris, 1998; Parry-Jones, 2012).

Literature reviewing captive birds of prey is extensive for those being used in hunting practices (Harris, 1998), training methods (Parry-Jones, 2012), and housing/keeping methods (Arent, 2007; Burke, Swaim, & Amalsadvala, 2002; Durman-Walters, Mroczek, Bonczar, & Nowak, 2009; Harris, 1998; Parry-Jones, 2012). Despite this detailed knowledge of housing options, there is little information on environment, training, and husbandry factors that affect raptor behaviors and that subsequently compromise their welfare. Research has outlined health implications, such as breaking of feathers, but does not detail the specific effects on the birds themselves (Hudelson & Hudelson, 1995). The effects of practices and housing of birds can affect their behavior dramatically, potentially causing feather breaking and illness (Hudelson & Hudelson, 1995). Only through following good husbandry practices and decreasing factors causing stress behaviors can keepers improve health and welfare. Such stress behaviors can include reactions to working in noisy environments (Hennessy, Willen, & Schiml, 2020), hotter climates or seasons (Ratnakara et al., 2017; Soravia, Ashton, Thornton, & Ridley, 2021).

To the best of our knowledge there are no standardized ethograms for falcon and Harris's hawk behaviors and only sparse detailed explanation of flights for hunting practices (Durman-Walters, Mroczek, Bonczar, & Nowak, 2009; Harris, 1998; Parry-Jones, 2012), therefore outlining detailed behaviors of Harris's hawk, and defining causes of stress among husbandry practices is crucial to improving welfare standards. This study created an ethogram for a single working Harris's hawk behavior and modeled how environment and working conditions in a waste recycling compound yard affected the bird's behavior.

Methods

Captive Conditions

The Harris's hawk used in this study was a 21-year-old female in good physical condition. Condition was verified by biannual veterinary inspection and daily falconer checks. The hawk was kept in a wooden enclosed aviary when not worked and tethered to a bow perch. Fresh water was provided in a round bath with full access. The Harris's hawk was weighed every morning between 09:00–10:00. The hawk was fed daily between 14:00–18:00 and flown loose a minimum of three times a week. During this study, the Harris's hawk was observed working whilst tethered to a modified bow perch that enabled it to have full spectral vision of the compound yard. The hawk's work comprised presence only to deter other bird species. The working regime of the Harris's hawk was supplemented by a patrol of the compound yard with the handler every hour for 10 minutes on the fist/glove. Patrols and flying on site did not form part of this behavioral study. The hawk worked for 8 hours a day, 5 days per week.

Data Collection

Behavioral observation took place at a UK commercial waste recycling compound yard. The study comprised 65 observation hours over 3 months (February, June, and July 2019) and therefore represents a partial seasonal study. Pilot observations were conducted at the same site for 30 hours over 7 days, 2 weeks prior to the study commencing to identify the individual Harris's hawk behavior traits and establish an ethogram of behaviors to contrast alongside environmental factors. These pilot observations informed and established the baseline ethogram but were excluded from analysis (Table S1). During the creation of these baseline behaviors, we identified and derived those behaviors that were indicative of a "stressful" state and those that we considered a "relaxed" state. This differentiation in behaviors being stressed or relaxed was then set for use to enable interpretation of the hawk's responses (Table S1). Once baseline behaviors and environmental factors were identified, observation sessions commenced. All behaviors and environmental factors were abbreviated to improve recording speed (Table S2). Initially, sessions completed comprised four 1-hour sessions per day (09:00–10:00, 10:00–11:00, 12:00–13:00, 13:00–14:00). Toward the end of July sessions contracted to two 1-hour sessions per day (09:00–10:00, 12:00–13:00) due to site health and safety access requirements. Within individual hourly sessions behavior and environmental factors were observed using scan sampling every 3 minutes. Before behavioral observation, time of year, time of day, weight of the bird (lbs+oz/kg/g), food type, and food ration quantity (N food items fed that day) were recorded (Table S2). Behavior data was subsequently scored in binary presence/absence and predictor factors as categorical or scale data. Activity frequency of vehicle traffic entering the compound yard was recorded as ordinal data (Table S3). Zones within the compound yard were recorded and identified as separate "areas" categorically (Figure 1). Data can be accessed open source at https://doi.org/10.5281/zenodo.8061400.

Data Analysis

We used Generalised Linear Latent Variable Models (GLLVM) in the R package gllvm (Niku et al., 2019) to model behaviors of a Harris's hawk as responses to predictors of time of year, time of day, activity level (vehicle traffic), other birds being present (gulls), highest daytime temperature, weather at the observed behavior time, weight of the bird, food type, food ration quantity, spatial areas of environment, and the number of blank pistol shots fired to deter other bird species (N blank pistols fired) (see Tables S1 and 2).

GLLVM use factor analytics to incorporate latent variables that combine values to model correlation between responses. Latent variables can be used in ordination, predict values, control variables, and assist model selection (Hui & Poisot, 2016; Hui et al., 2015). The hawk behavior multivariate data was constructed as a matrix with n rows (behaviors) and m columns (categories) by the hawk during observation sessions. GLLVM regressed mean behaviors μij against predictors as vectors of $d<md<m$ latent variables, $ui = (ui1, \ldots, uid)$,

$$g(\mu ij) = \eta ij = \alpha + \ \beta 0j + \boldsymbol{x}'\boldsymbol{i\beta j} + \boldsymbol{u}'\boldsymbol{i\theta j},$$

Where $g(.)$ is a known link function, $\boldsymbol{u}'i$ are d-variate latent variables $(d<md<m)$, αi is an optional row effect at behavior i, $\beta 0j$ is an intercept for predictor j, and $\boldsymbol{\beta} j$ and $\boldsymbol{\theta} j$ are column specific coefficients for covariates and latent variables, respectively.

Models used binomial families with probit and logit link functions via the template model builder (TMB) package, with Laplace distributions (Kristensen, Nielsen, Berg, Skaug, & Bell, 2016). Probit and logit link functions help logistic regression models using maximum likelihood to classify

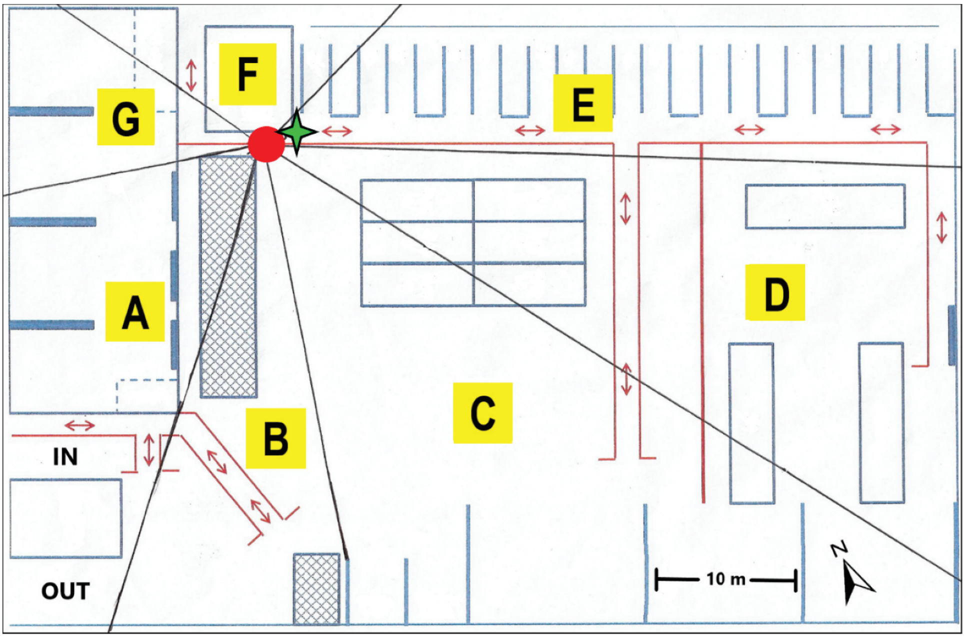

Figure 1. Diagram of compound yard and zone areas. Red spot = Harris's hawk observation perch, green star = observer location, yellow lettered zones (A–G) = observation area direction of hawk, black lines from red spot = segregated zones (A–G), blue outlines = working bays and buildings, gray hatched boxes = no vehicle stopping zones, red arrows = unidirectional pedestrian walkways, red outlines = internal walkway perimeter.

variables in binary either on the cumulative distribution function of a standard normal distribution (for probit) or the cumulative distribution function of a logistic distribution (for logit). Dunn–Smyth residuals and Q–Q plots were used to inspect model fit. Model fit was assessed by the Akaike information criterion (AIC)/Bayesian information criterion (BIC), and a for-loop iteration used to select appropriate numbers of latent variables. Models used a best of five run routines with the highest log-likelihood model selected (Niku et al., 2019). Latent variables induce correlation across response variables to estimate patterns. The getResidualCor function was used for this and visualized using package corrplot (Wei & Simko, 2017).

The final models were selected based on residual fit, AIC/BIC, moderation of correlation, suitable number of latent variables, and then estimated coefficients for predictors plotted with their confidence intervals and used for interpretation. Additional plots, figures, and tables visualizing analysis and results can be viewed in the supplementary material.

Results

Model Fit and Selection

Summary frequencies for all behaviors (responses) and factors (predictors) are presented in Figure 2 and Table S4. Model fit using quantile plots and residual fits is presented in Figure S3 with BIC selection of latent variables in Figure S4. Two models (Models 1 and 2) fitted successfully. Model 1 was a GLLVM with binomial logit link and Model 2 was the same model but performed with a binomial probit link. Dunn–Smyth residuals revealed a good fit, and minimal over-dispersion for both models. AIC and BIC values confirmed Model 2 (probit) was the better fit (mod_1 AIC: 6360.2 BIC: 13536.2/mod_2 AIC: 6210.6 BIC: 13386.6). The for-loop iteration utilizing BIC recommended $N = 2$ latent variables as appropriate (Figure S4). Residual correlation across responses is presented in corrplot Figure 3 and final coefficient

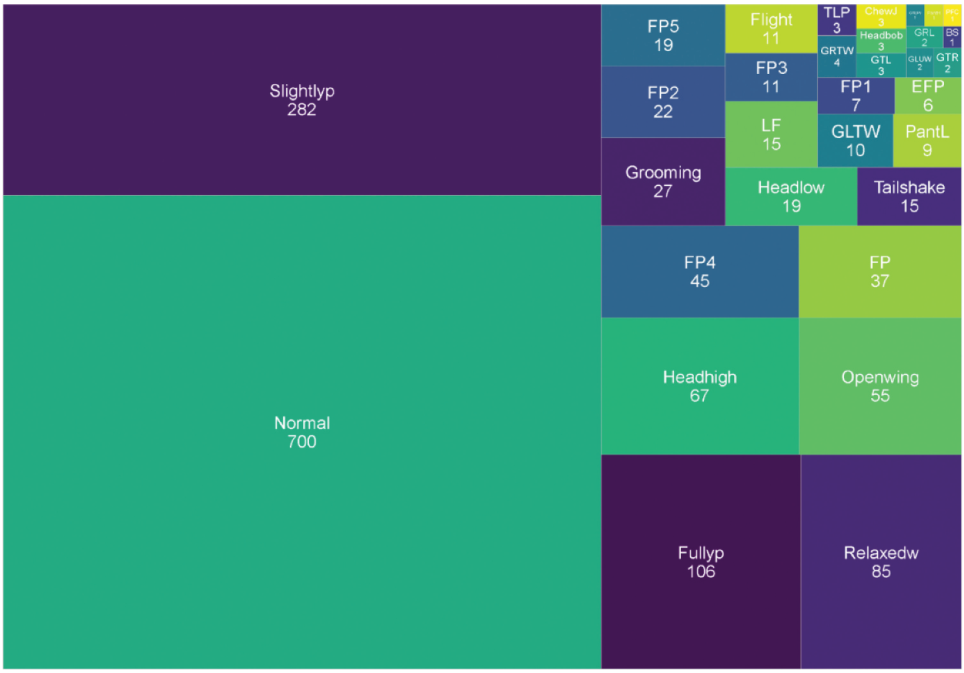

Figure 2. TreeMap of the frequency of exhibited behaviors by Harris's hawk. Types of behavior are shown in white with frequency of occurrence. Size of blocks are relative to frequency number. See Table S2 for explanations of acronyms of behaviors.

plots for selected Model 2 are presented in Figs. 4 and Figure S5(a–d). Proceeding with Model 2, we used function getResidualCor to plot a residual correlation matrix of all hawk behaviors. Inspecting correlation using the adjust= command in gllvm found adjust = 2 (specified in Niku et al., 2019) to reduce correlation the most across the model (Figure 3). Coefficient plots were derived from Model 2. Plots showed the different hawk behaviors expressed significantly both positively and negatively for each predictor variable (Figures. 4 and Figure S5(a–d)). The hawk exhibited some behaviors common to birds held in captivity state and others that were more expressive of a specific individual responding to a specific predictor.

Behavioural Response Correlation

Appreciable levels of correlation in the model confirmed some hawk behaviors naturally co-occurred in the model. Figure 3 showed most relaxed and natural grooming behaviors were positively correlated. This is expected of a Harris's hawk with low stress levels as behaviors such as plumped feathers and body shaking would occur synchronously during a grooming or rest session. Negative correlations presented in the plot show clearly that grooming behaviors such as Grooming Left Tail, Grooming Left Top Wing, Grooming, Grooming Left Under Wing, and relaxed behaviors such as Slightly Plumped, did not co-occur with typical stress behaviors such as Leaning Forward, Chewing Jesses, and Open Wing. Residual correlation also showed sparse association between stressful behaviors and relaxed behaviors, indicating that stress can interrupt and limit relaxed behavior expression.

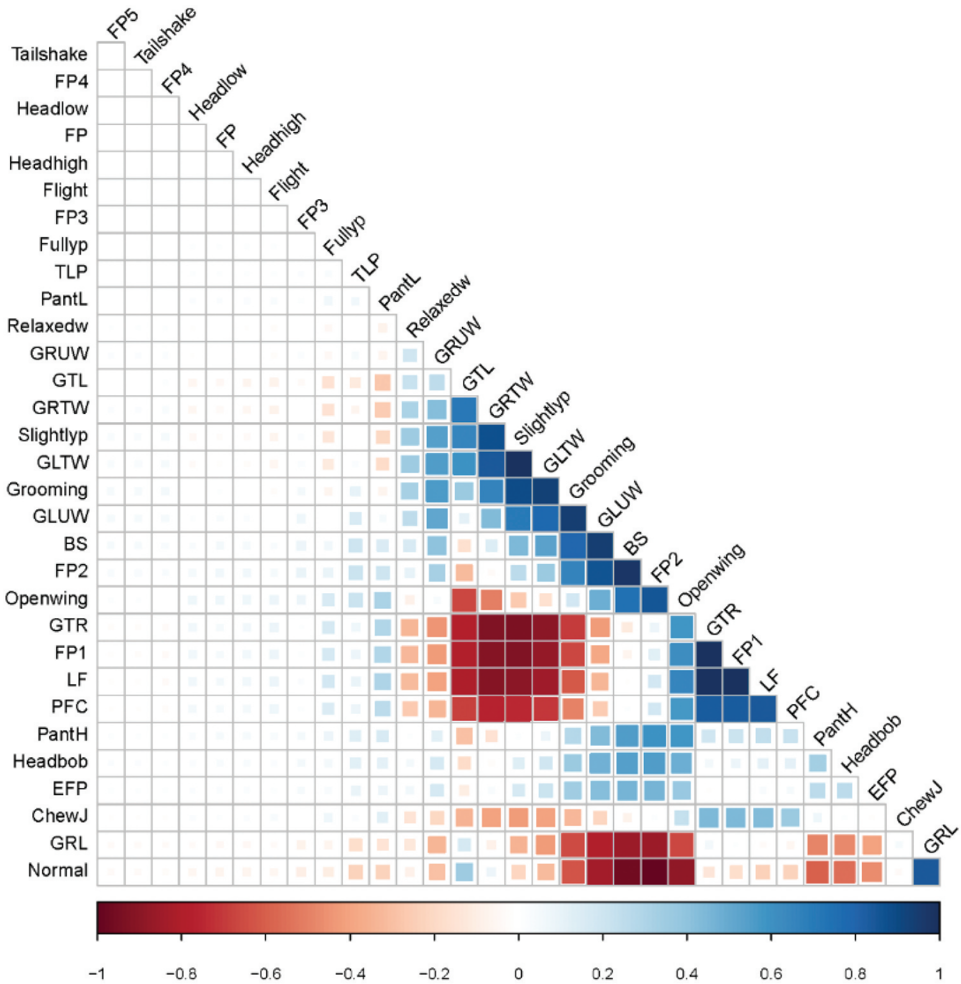

Figure 3. Residual correlation plots, model 2 with adjust = 2 method. Regions colored blue in correlation plot indicate clusters of behaviors positively correlated. Red indicates negative correlation between paired behaviors. Size and depth of color indicates strength of correlation.

Physical Health Coefficients

Increased weight of the Harris's hawk (Weight of the Bird – recorded in the morning) (Figure S5(d)) positively associated with grooming behaviors and negatively associated with stress behavior responses such as Entering Flight Position, Leaning Forward, Head Bobbing, Panting Lightly and Panting Heavily.

Time of Day Coefficients

Figure 4 details the effects of Time of Day (10–11:00/12–13:00/13–14:00) for each observation session as categorical predictors of behaviors. Results signaled earlier daily observations related to increased frequency of stressful behaviors. For example, panting behaviors (Panting Lightly/Panting Heavily) increased alongside the hawk opening its wings (Open Wing) to cool down/dry out. Behavior response Entering Flight Position presented a strong coefficient signal earlier in the day (10–11:00 and 12–13:00), demonstrating that the hawk reduced this stressful behavior of preparing

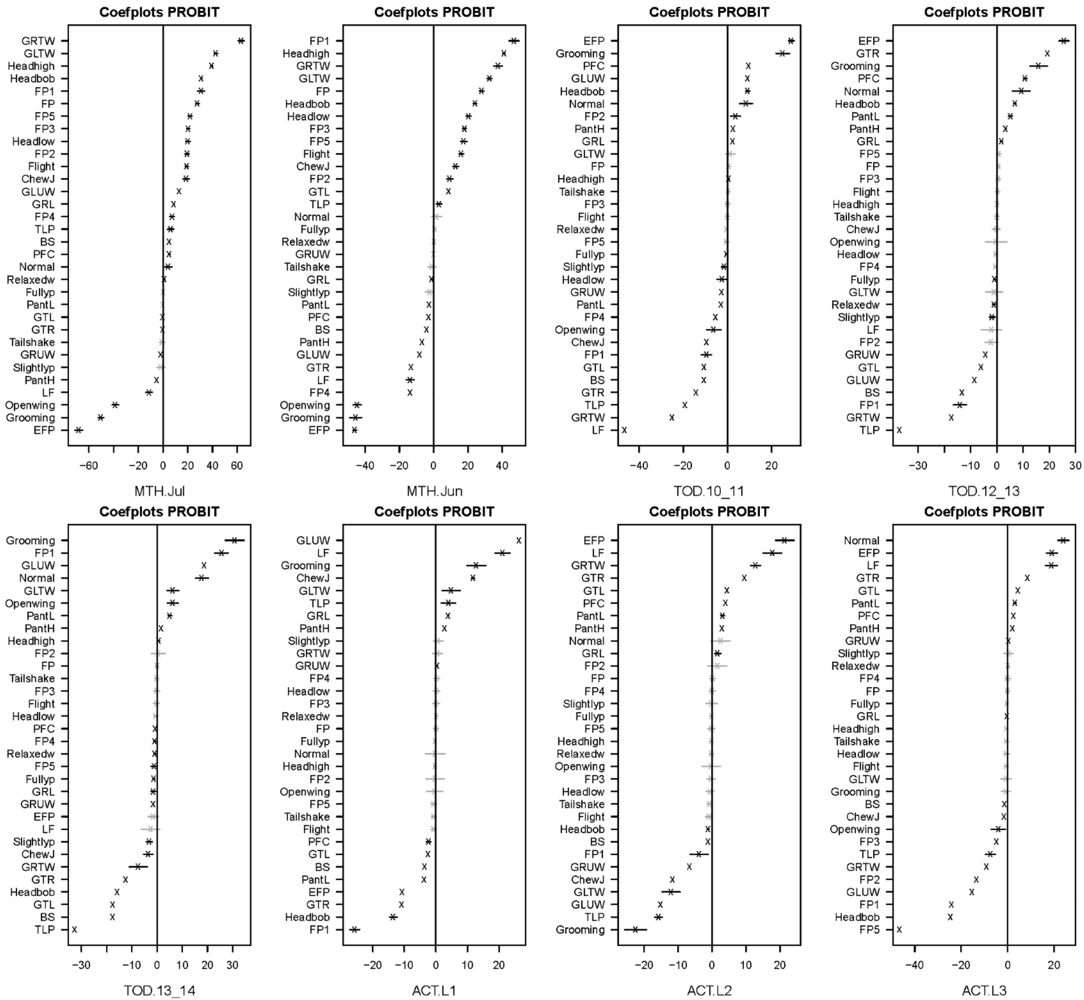

Figure 4. Example coefficient plots from model 2: predictor effects on hawk behaviors. The coefplot comprises point estimates (crosses/ticks) for coefficients of variables and their 95% confidence intervals (lines). Black ticks to the right of the zero-crossing express positive coefficients, and to the left negative coefficients. Those colored gray denote intervals that are zero-crossing. See Table S2 for abbreviation explanations.

to fly as its time at the perch increased. Minutes (Figure S5(d)) as a numerical predictor had only a slight effect on behavior, as many coefficient values were between −1 to 1 or significant to the zero-crossing. Results did show a mixture of both stress and relaxed behaviors trending either at the beginning, or end of, sessions with no real indication of either stressed or relaxed behaviors being more prevalent at a specific time during observation periods.

Environmental Coefficients

Weather, as a general predictor, had many specific coefficient plots as there were a range of factors influencing hawk behavior (see Table S2 and Figure S5(a/b)). Windy and Cloudy weather, and Leaning Forward behavior were highly associated, suggesting that during windy conditions on site, combined with reduced sun, the bird frequently leaned forward for balance. Sunny and Windy predictors exhibited positive association with the hawk moving from Flight Position into Flight (also known as Bating), Entering Flight Position and Chewing Jesses. These movements eliciting Bating are indicative of increased stress. The predictor Sunny showed that behavior of Open Wing (a behavior made to cool down/dry out the body) increased with Leaning Forward and decreased alongside all grooming related behaviors. Sunny and Cloudy also showed an increase in Open Wing, and associated with an increase in Grooming, decrease in Chewing Jesses, Flight Position into Flight (Bating) and Entering Flight Position. Raining coefficient signaled with Normal behavior, Open Wing and Foot Position 1, whereas Raining and Windy signaled increased Normal behavior and Open Wing. Cloudy and Sunny, and Cloudy and Windy had positive association to all grooming behaviors. In contrast with other weather predictors, Cloudy and Sunny increased the number of positive behaviors. These weather predictors showed that wind can increase frequency of stress behaviors whilst Cloudy conditions and small amounts of sun can reduce them. Rainy weather signaled an increase in Normal behavior (a static pose suggesting no activity). Higher daily temperatures (Temperature) (Figure S5(d)) were associated with stress behaviors such as Head Bobbing, Flight Position, Panting Lightly, Panting Heavily, Chewing Jesses, and adjusting foot positioning, suggesting that increased temperatures can also trigger stress behaviors. The plot also displayed the reverse for Grooming, indicating that cooler temperatures encouraged grooming behaviors.

Dietary Coefficients

Food Type (Figure S5(b)) showed little evidence of an impact on the Harris's hawk as both positive and negative behaviors were associated with a mixture of relaxed/calm, neutral, and stress behavior responses. Predictor Food Amount (FDA) (Figure S5(d)) clearly showed that when food supplied to the hawk was reduced, due to weight increase of the bird, the behavior of the hawk exhibited lower stress behaviors. Most positive grooming behaviors were negatively associated with increased food amount. The abundance of prey items, N gulls present (Other Birds Present or Visible) (Figure S5 (d)), revealed minimal effects on Harris's hawk behavior, indicating that when gulls were present, their presence did not disrupt the hawk's behaviors significantly either positively or negatively. Grooming was positively associated with gull presence, and this could just be an artifact in the data, or a continuation of normal baseline behaviors by the hawk.

Position, Vehicle Noise and Blank Firing Coefficients

Area Head Facing (Figure S5(b/c)) and Area Chest Facing (Figure S5(c/d)) were associated in parallel and co-occurred during the hawk's response to stimuli. The Harris's hawk in this study was highly observant, often responding to stimuli or disturbance with the movement of its head (Area Head Facing) in unison with directional body and area facing movements (Area Chest Facing). Preference of observations by the hawk to specific areas within the compound were detected within coefficients. These differences, when cross-referenced with Figure 1, confirmed certain stress behaviors were elicited by the hawk, indicating a directional bias of observation by the bird. The clearest coefficients of stress behaviors are linked to areas B, F, and G where the hawk frequently displayed Flight Position into Flight (Bating). In contrast, in facing areas C, D, and E the hawk exhibited more calm/relaxed behaviors. Area A had a mix of stress and neutral behaviors due to its increased frequency of vehicle traffic (Activity in Yard) (Table S5). For Area H the hawk faced herself, and thus was associated with grooming behaviors (Figure S5(c)). Areas A, B, F, and G were all characterized by greater vehicle traffic, residual noise, and human activity. These areas had spikes in activity levels by construction machinery loading material onto transportation lorries that coincided with stress response behaviors by the Harris's hawk. Areas C, D, and E were characterized by vehicle and material storage in the compound and had distinctly less use by construction machinery and vehicles, and therefore lower frequency of noise. Subsequently these areas elicited less stress behaviors and greater relaxed behaviors by the hawk. Blank pistols fired (Blanks Fired) to scare gulls often caused the Harris's hawk to react by Bating (Figure S5(d)).

Other stress behaviors were also triggered in unison with increased frequency of blanks fired. Coefficients signaled that grooming and normal behaviors were clearly not associated with blank pistols being used.

Discussion

GLLVM has only recently become a useful addition to multivariate GLM statistics (Niku et al., 2019a). The use of such models in behavior studies is therefore novel (Rice, Lewis, Griffin, & Grant, 2022). There is little other contrastable work other than GLLVM and Bayesian equivalent models that focus on multivariate data in ecology (Herliansyah & Fitria, 2018; Hui & Poisot, 2016; Lewis et al., 2021; Ovaskainen, Abrego, Halme, Dunson, & Warton, 2016; Rice, Lewis, Griffin, & Grant, 2022). We believe the technique shows great promise for behavior ethograms with large, complex data sets.

Behaviour Responses and Predictors

To describe associations in behavioral responses by the Harris's hawk we first inspected the residual precision correlation matrix (Figure 3). Strong residual covariance/correlation between response behaviors can be interpreted as evidence of autocorrelation in a model, however, appreciable levels in GLLVM are permitted and recognized as evidence of interaction/association (Ovaskainen, Abrego, Halme, Dunson, & Warton, 2016; Pollock et al., 2014). The correlations observed in responses by the Harris' hawk herein were somewhat expected, for example grooming behaviors occurring synchronously. These types of association have been evidenced for other animal groups (Dosmann, Brooks, & Mateo, 2015; Redondo, Romero, Díaz-Delgado, & Nagy, 2019) yet until now have been inadequately reported for working birds of prey (Corbani, Martin, & Healy, 2021).

The physical weight of the Harris's hawk and corresponding numerical coefficient signals (Figure S5(d)) indicated that when the Harris's hawk was of satisfactory and healthy weight there was no association to stress behavior. Overall, during the sessions the Harris's hawk weight ranged from 2 to 2lb 5oz (0.907 to 1.049 kg), indicating a healthy state of weight for the bird through the study period (Ford, 1982; Walker, 1999). In this study stress related behaviors were only measured for a period of under one year so their relation to weight would need constant monitoring and further data to observe if stress contributed longer term to any weight changes by the bird. Many falconers already regularly weigh their birds of prey for health and welfare monitoring, so we recommend continuing with the practice and developing more awareness of subtle changes in behavior associated with weight fluctuations using our ethogram.

Chronological differences in behavior during the day (Figure 4) showed Entering Flight Position presented a strong coefficient signal earlier in the day. We consider this to be more related to morning activity levels of vehicle movement in the compound and therefore signaling an increase in stress for the hawk during this period. Other variables associated to time of day signaled a uniform association between time spent on the perch and expected behaviors of Grooming and self-maintenance by the Harris' hawk, signaling less chronological patterns and more randomization of such behaviors through the day.

Environmental coefficient plots (Figures. 4 and Figure S5(a–d)) displayed how environmental factors effected the Harris's hawk behaviors using predictor plots for monthly differences (Figure 4). July and June showed a similar blend of positive and negatively associated behaviors such as Flight and Open Wing, and only a minor increase in stress behavior Chewing Jesses during July. Overall, the plots for month as predictor variables showed little temporal difference in behavior. We consider seasonal weather patterns, in particular hotter weather in July (Figure 4) when conditions are dustier at the site, to be jointly responsible with increased vehicle frequency for elevated stress behaviors during this month. The Harris's hawk in this study was hatched and raised in the UK and therefore is likely pre-acclimated to a UK climate. Therefore, our observations of stress behavior relate to upper and lower temperatures for the UK climate specifically. Such temperature ranges may vary for hawks kept in hotter or cooler climates in other countries such as North America.

Dietary influence on grooming responses expressed in the model were somewhat expected because as Food Amount is increased by a handler, this can signal the bird's weight is lower, therefore increasing stressful behaviors due to hunger and natural instincts to fly (Figure S5(b)). Van Krimpen et al. (2005) also report that feeding strategies and diet composition can affect behaviors of feather pecking in domestic hens (*Gallus gallus domesticus*). This study correlates with our findings that food type and amount can elicit changes in stress behaviors for birds. The abundance of prey items on site in our findings is somewhat unexpected given that the presence of birds that can potentially mob birds of prey can subsequently elicit changes in behavior and flight (Pettifor, 1990). Additionally, territoriality and predatory behavior might be expected to change for a bird of prey when in the presence of other bird species that may compete for its resources (Akçay, Clay, Campbell, & Beecher, 2016; Baxter & Allan, 2006).

Coefficient plots for activity levels (Figures. 4 and Figure S5(a) and (b)) clarified there was positive correlation between an increase of vehicles on site (mostly during mornings) and stress behaviors exhibited by the Harris's hawk. This can be shown by factors such as Chewing Jesses and Entering Flight Position which increased when vehicle activity levels rose. Grooming behavior also decreased when activity levels increased overall, suggesting that a rise in activity level upsurges stress behaviors and reduces relaxed behaviors. All activity levels presented association in the coefficient plots, suggesting there was a clear influence by vehicle traffic as a predictor of stress behavior. Brouček (2014) reviewed farm animal responses to noise increases, proving that farm vehicle mechanization and helicopters can influence heart rate and cortisol levels across a range of animal groups. It is therefore possible that our findings might also suggest that Harris's hawk could suffer from similar stress level elevations, and that this invites further physiological study. Corbani, Martin, and Healy (2021) reported on the impact of acute loud noise on laboratory birds (Passerine finches) for the first time. Their findings also suggest that welfare of birds might be compromised by low frequency fire alarms and potentially other non-natural humancentric noises. The findings herein link blank firing links to known findings by Corbani, Martin, and Healy (2021) that recognize stress levels increase by birds of prey to loud, acute, human-centric noises.

Animal Welfare Implications

Captive birds of prey can be used for several practices and their use as a pest control method is one that can change the behavior of the recipient bird being dissuaded (Baxter & Allan, 2006; Boal, 2018; Smith, Broad, & Weiler, 2008). Working birds of prey have little regulation and legislation to enforce and monitor welfare standards to control for environmental conditions that might cause stress (Baxter, 2001; Cook, Rushton, Allan, & Baxter, 2008). It is recognized that the role of birds of prey such as Harris's hawk on waste sites is an essential service and of key importance to integrated pest management (Baxter, 2001; Baxter & Allan, 2006; Cook, Rushton, Allan, & Baxter, 2008). Therefore, the use of these working birds is unlikely to be reduced in future due to the demands for their efficient and essential work. Legislation, guidelines, policies, and regulations on keeping and using birds of prey as tools for pest control currently do not consider sufficiently how behavior of the bird is affected by the workplace environment, and thus may leave birds vulnerable to mistreatment, and their behaviors to be misunderstood (Durman-Walters, Mroczek, Bonczar, & Nowak, 2009; Harris, 1998; Parry-Jones, 2012). By identifying factors in a working bird's environment that can have both negative and positive effects on behavior, handlers can enhance their understanding of an individual bird's behavior. This can then promote discussion about an individual bird's needs and help tailor its welfare requirements. By improving the welfare of the working bird, the physical health of the bird can be improved considerably in parallel with decreasing "undesirable" behaviors such as Bating (Durman-Walters, Mroczek, Bonczar, & Nowak, 2009). In consideration of the behavioral observations herein, we propose the following subtle changes to keeper regimes with working Harris's hawk to counter-mitigate stress behaviors and levels in the working place:

- Shorter, divided working periods during a hawk's working day to incorporate breaks
- Shelter from weather extremes during a hawk's working daily regime
- Temporary cessation of a hawk's work during increased vehicle frequency at a place of work.

Applying the basic changes stated above to the way a Harris's hawk is kept, and its working regime, will likely increase calmness and improve behaviors, human–animal relationships, husbandry, health, and the overall welfare for the hawk in this study. If implemented, such changes may also become exemplary of the use of, and captive homing of, a working Harris's hawk. Such improvements to Harris's hawk welfare may call to action improvements in welfare for all working birds of prey and arguably help inform legislation evolution to further their protection.

Limitations

This study was conducted on a single specimen of Harris's hawk ($N = 1$) and would statistically be improved by replication. Notwithstanding, the hawk used in this study was behaviorally examined while tethered, which is in itself, we consider, a stressful state, and as such, we deem replication undesirable from a welfare perspective. The Harris's hawk used in this study was an independent bird that had limited social contact with other raptors during its lifetime. Harris's hawks are known for social interaction (Dawson, 1988; Dawson & Mannan, 1991) and therefore consideration for their use in a group social pack setting would potentially influence behaviors displayed. Due to the hawk herein being raised independently, and being an older bird, introducing other specimens to its regime could have unknown behavior or welfare implications. This aspect warrants further study. This study was conducted over 3 months and did not include all four seasons due to permissions, practicality, and access to the hawk. Two of the three months studied (February and June) are part of the known breeding season for Harris's hawk which may have also affected results. To extend on this study, a full year of behavior investigation across all seasons and months would be beneficial to understand phenological changes in behaviors.

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Author contribution

BJ conceived the ideas, designed the methodology, completed the fieldwork, performed data analysis and led writing of the manuscript; TL performed data analysis and contributed to writing of the manuscript. Both authors contributed critically to the drafts and gave their final approval for publication.

Ethics approval statement

All applicable international, national, and institutional guidelines for the use of animals were followed. This research was conducted under a Wildlife and Countryside Act (1981) Article 10 falconer handling certificate.

Significance statement

Working birds of prey are beneficial to humans and their use as a pest control method is widespread. Despite this, there is insufficient detailed knowledge about their captive behaviors, and limited regulation to enforce welfare standards to control for environmental conditions that can cause stress. By improving basic husbandry using recommendations herein, keepers can decrease levels of undesirable behavior such as Bating, and subsequently improve health, welfare, and conditions for working hawks. This work provides the first applied ethogram to a working Harris' hawk and will stand as a model template for how to perform a detailed bird behavior inspection aimed at assessing stress behaviors in working birds of prey.

ORCID

Bryony M. Jenner http://orcid.org/0000-0003-2285-6283
Todd R. Lewis http://orcid.org/0000-0001-5433-8777

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