An Automated Intervention to Reduce Shelter Dog Barking:

A Hush Puppy Pilot Study

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Abstract

Objective: Barking is a ubiquitous problem in animal shelters, with noise levels exceeding the Occupational Safety and Health Administration's permissible exposure limits. This can cause significant health and welfare problem for workers, visitors, and the resident animals. The purpose of this study was to pilot and determine the efficacy of a computer-vision assisted classical conditioning procedure using automated food delivery with customizable automation scripts.

Methods: Shelter dogs were selected for participation in the study from the Roanoke Regional Center for Animal Care and Protection and housed at the Virginia-Maryland College of Veterinary Medicine in three cohorts. An automatic feeder was installed on the kennels that was triggered by two separate detection systems: infrared beam breaks at the door to the ward and a computer vision system that detected human forms in the ward walkway. This system automatically delivered food contingent on the arrival or continued presence of a person in the ward. A sound-level meter was used to measure the noise in the ward, and from that the equivalent continuous sound level and percentage of time above 85 dB was calculated and monitored. Each cohort experienced at least three experimental conditions with the first two conditions implemented as non-concurrent, multiple baseline phases. Visual and statistical analysis were performed for each condition.

Results: The method allowed for accurate and timely identification of people entering and lingering in the dogs' ward and for contingent food delivery. This successfully eliminated issues with human compliance in implementing the intervention that were seen in previous studies. The largest noise level reduction was seen with novel, high-value food included in the feeders, resulting in a 3-dB reduction of the median noise level. The reduction in the median amount of time that barking produced noise levels above 85 dB ranged from 4% to 25%.

Conclusions: The automation of a classical conditioning procedure using computer vision and automated food dispensers demonstrated that automated food delivery contingent on the arrival and continued presence of humans in the ward reduced the noise levels associated with barking. More work is required to reduce the noise levels below OHSA limits. Future studies can focus on optimizing the intervention parameters, the volume and type of food used, and integrating new technologies that may lead to more individualized and effective interventions.

Author Declaration

The Hush Puppy Pilot Study was a collaborative research project with a small group of individuals involved in running the experimental equipment, collecting and analyzing data, and sharing and interpreting results. The relative contributions to this thesis are outlined below:

- Yasmeen Gomez and Gabriella Doering provided on-site operations support, collected data, and assisted with analysis.
- Ryan Talbot designed, prototyped, and deployed the experimental apparatus, provided remote operations support, and supported data analysis.
- Dr. Virginia Edwards provided oversight of animal care and facilities.
- Dr. Lisa Gunter and Dr. Erica Feuerbacher developed the experimental design and oversaw the execution, provided on-site and remote operations support, and reviewed all aspects of operations and analysis.

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I, Tegan Macdonald, provided input on experimental set up and design, provided onsite and remote operations support, performed all data analysis and reporting, and coordinated collaborative data review and decision making. I declare that this thesis has been written by me and has not been submitted for any previous degree.

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Special thanks to Ryan Talbot, who made this study possible with his creative, low-cost engineering designs for the intervention automation.

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I am extremely grateful to the faculty at Virginia Tech, especially my committee members and Hush Puppy collaborators Dr. Erica Feuerbacher and Dr. Lisa Gunter, for their support and feedback during my pursuit of this degree and research.

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Table of Contents

List of Figures

List of Tables

Introduction & Literature Review

Dog barking in animal shelters is a ubiquitous problem impacting the health and welfare of the people and animals exposed to it. Noise levels caused by barking in these environments often exceed regulatory limits, with time-averaged noise levels exceeding 100 dB and peak levels exceeding 120 dB (Coppola et al., 2006; Sales et al., 1997; Scheifele et al., 2012). These noise levels are equivalent to working a jack hammer and a chain saw, respectively. This noise is a major source of noise pollution, which is a known health and welfare concern for both people and animals (Arcangeli et al., 2023; World Health Organization, 2011). In the United States, employers are required to have a hearing conservation program when the equivalent continuous sound level over an 8-hour shift exceeds 85 dB (Occupational Safety and Health Administration, 2006). Compliance with these regulations can be challenging and violations are frequent (Park et al., 2020), leaving workers vulnerable. Additionally, protective measures like earmuffs and time-restricted access afford animals no such protection.

The negative health effects of noise exposure are numerous. In humans, noise exposure is associated with adverse health outcomes, including noise-induced hearing loss, hypertension, cardiovascular disease, work-related injuries, diabetes, and acoustic neuromas (Pretzsch et al., 2021). Animal studies have similarly shown that noise exposure can change processes related to appropriate neural, developmental, immunological, and physiological functioning (see Kight & Swaddle (2011) for a review). Research on shelter dogs (Scheifele et al., 2012) and dogs exposed to similar noise levels in MRI studies (Venn et al., 2014) also showed noise-related hearing loss, although it is not known whether the hearing loss was temporary or permanent. A comprehensive review comparing the hearing and auditory function of dogs to humans concluded that until more information is available, it should be assumed that dogs are at least as sensitive to hearing damage as humans in equivalent settings (Barber et al., 2020). Given the wide range of health impacts, shelter noise is a clear health risk to both people and resident animals.

Another important aspect of shelter dog barking is the animal welfare implications. Animal welfare is an important societal issue, with a few countries even ranking dog welfare above that of humans (Sinclair et al., 2022). Shelters can be stressful environments and have many conditions associated with negative affective states, including unpredictable events, confinement, isolation, restricted choices, and a lack of opportunity for positive experiences, like playing, foraging, and socializing (Mellor et al., 2020). As dogs experience poor welfare, they may exhibit increased frequency of vocalizations (Beerda et al., 1997). An audit of behavioural indicators of poor welfare in kenneled dogs by Stephen & Ledger (2005) found that the incidence of barking increased steadily over the study period. Thus, a holistic approach to reducing noise levels in shelters might also improve and safeguard the welfare of the dogs.

Barking in animal shelters can also cause welfare and behaviour challenges in other species. Coppola et al. (2006) found that the building design of modern shelters often did not use adequate noise absorption, allowing noise to propagate throughout the shelter, and Eagan et al. (2021) reported that noise substantially affected the behaviour of shelter cats, increasing fearful and decreasing maintenance behaviours. While the sheltering of animals is unregulated, a set of standards based on scientific evidence and expert consensus is available from The Association of Shelter Veterinarians (2022). These standards emphasize that shelters must have protocols in place for safeguarding the welfare of the animals by mitigating stress and negative emotions including fear, anxiety, and frustration, which requires viable solutions to reduce shelter barking.

One final aspect of shelter dog barking to consider is its undesirability to adopters, owners, and the larger community (Flint, 2012). Undesirable behaviours in companion dogs were identified by expert consensus as one of the three highest priority issues in animal welfare (Buckland et al., 2014). A recent study looked at the prevalence of behaviour problems in companion dogs and found that nearly 50% of dogs engaged in moderate to severe levels of problematic barking as reported by owners (Beaver, 2024). Additionally, and perhaps most relevant to shelter dogs, when asked to make a choice between photos of dogs at the front and rear of the cage, potential adopters showed a strong preference for dogs at the front of the kennel and not barking (Wells & Hepper, 1992). First impressions in the shelter are important, as dogs only have a short window of time to impress upon potential adopters, with visitors typically visiting 30% of available dogs and stopping for only 70 seconds when they do look at an individual dog (Wells & Hepper, 2001). Although Protopopova et al. (2014) found that barking was not associated with increased length of stay, it is possible that improved viewing conditions may increase the opportunities for adopters to connect with the dogs, which could improve adoption rates. For example, Protopopova et al. (2014) found that certain dog behaviors, like lying in proximity to an adopter and playing with an adopter during shelter meet and greets were good predictors of adoption. If opportunities for adopters to interact with dogs in this way are improved, both dogs and potential adopters could benefit.

In summary, reducing noise levels in animal shelters has the potential to benefit the health and welfare of shelter workers and volunteers, the dogs themselves, other shelter animals, and potential adopters and visitors. With negative effects that range from noise-induced hearing loss to compromised welfare to negative impacts on the human-animal bond, finding solutions to shelter dog barking is a priority issue for the animal welfare community and the public at large. Given that dogs spend more time barking during times with kennel visitors (Wells & Hepper, 2000) and the noise in dog kennels is significantly lower when visitor access is restricted (Hewison et al., 2014), creating interventions for when there are passersby is paramount.

Interventions for Shelter Barking

A variety of intervention strategies have been used to reduce noise from barking in shelters. One of the most common noise-reduction recommendations is to provide a visual barrier in the kennel to reduce the dog's visual stimulation (American Society for the Prevention of Cruelty to Animals, n.d.; Best Friends Network Partners, 2022); however, this is not well researched, and what literature is available does not support this intervention. For example, Wells & Hepper (1998) found that adding a barrier had no impact on dog vocalizations, and that the welfare of shelter dogs may be improved by allowing visual access to other dogs. This is supported by Hetts et al., (1992), which found that kenneled dogs with the greatest degree of social isolation vocalized the most. Further, Wells & Hepper (1998) found that dogs who were allowed visual contact spent more time at the front of their kennel, which had previously been shown to be attractive to adopters (Wells & Hepper, 1992). Finally, Martin et al., (2023) examined the impact of removing visual barriers from kennels and found no change in dogs' stress behaviors or barking duration. Given the lack of success of this intervention, finding alternative solutions to address shelter barking is imperative.

Other environmental interventions have also had limited success. Wells (2004) investigated the impact of adding toys to dog kennels by using a scan sampling technique to record changes in instances of barking. There was no significant effect on vocalizations, even for the toys that generated the most interest. Similarly, when dog appeasing pheromone (DAP) electrical diffusers were mounted in the kennel ward, Tod et al. (2005) reported a reduction in the mean noise level, but the amount of the reduction was highly variable, and they saw no difference in the peak noise levels. Hermiston et al. (2018), however, reported some success assessing in reducing mean barking intensity by spraying DAP on the four corners of a dog's kennel. When they walked a novel dog past the kennel, they and found 6 dB decrease in the mean barking amplitude over a 10-second measurement period compared to the control condition. They measured the mean barking intensity during a 10-second observation period as they walked a novel dog past the shelter dog kennels and found a small reduction of 6 dB in the mean barking amplitude compared to the control condition. Given the need to bring shelter noise levels down from 100 dB to 85 dB to be compliant with regulatory limits, a 6-dB reduction, while more promising than some of the other interventions, does not fully address health and welfare concerns in the shelter environment.

A promising area of research to address the barking of shelter dogs to human visitors is the application of operant and classical conditioning via strategic food delivery. Protopopova & Wynne (2015) compared a response dependent and response independent treat-delivery intervention and found reductions in the dogs' frequency of engagement and the proportion of dogs engaging in undesirable behaviours, including barking, in both interventions. While the response-dependent intervention was slightly more effective, with an 88% decrease in undesirable behaviors, the response-independent intervention also reduced undesirable behavior by 66% and was much simpler to implement. A follow-up to this study was performed by Payne & Assemi (2017) using a response-independent, classical conditioning procedure that paired high-valued treats with a door chime. After a training phase, treats were discontinued and only the door-chime persisted. The mean noise level over the 5-minute measurement period reduced from 85 dB in baseline to 68 dB in the post-pairing phase, well below the OSHA protection levels, although it was unclear how many, if any, passersby were present during each experimental condition, which limits the conclusions we can draw from their results. Despite their promising results, both studies had limitations: only the experimenter implemented the intervention, the measurement period was short, and the generalization of the intervention's success under normal shelter operating conditions was not explored.

The generalizability of an intervention is an important consideration, especially in the applied setting of an animal shelter, and it can be limited by the diversity of techniques across individuals and reliance on expert implementation (Shnookal et al., 2024). To address these concerns, Baldan et al. (2023) included different conditions with novel and increasing numbers of human stimuli in their barking reduction protocol and showed promising results for generalizability across conditions. Carrero & Bennett (2025) took this further by implementing their study with a shelter population during normal operating conditions, taking measurements at three different times of day, and recruiting all passersby to implement the intervention protocol. The intervention was a classical conditioning pairing procedure in which passersby were asked to deliver a piece of high-value food to each dog as they passed the front of their kennel. They assessed the intervention impact on the maximum noise level over a 30-second measurement period. Despite the use of high value treats in their protocol, the largest decrease in the maximum decibel level was from 107 to 105 dB, which was achieved with a compliance rate of about 25%. The authors discuss that the low rate of compliance could be responsible for the small effect size. Their compliance rates were similar to those of Zurlinden et al. (2022), which examined the impact of the same intervention on owned dogs in a veterinary facility with staff implementing the procedure. Even with staff implementing the procedure, compliance rates were around 50% with no statistically significant effect in noise-level reduction observed. Given the resource demands on shelters (Kim, 2018) and the low rates of compliance within these studies, rates of compliance are likely to be much lower in day-to-day shelter operations.

A possible solution to issues with human compliance and the resource intensiveness of human-powered interventions is automation. A simple automation strategy that does not require knowledge about the dog's behaviour or environment is a fixed time schedule food delivery, wherein food is dispensed from an automated feeder at a regular, timed interval. This was conducted by Fernandez et al. (2023) in a study in which treats were dispensed from a feeder to dogs in a shelter for every minute during a 40-minute period. The average sound intensity was measured for the periods before, during, and after intervention and compared to baseline. While the authors saw a statistically significant intervention effect of automated treat delivery, the reduction in noise level was less than 1 dB and not sufficient to have meaningful impact on health and welfare. The magnitude of change observed may have been limited by the fixed time schedule, which fails to create any contingencies between the food delivery and the dog's behaviours (e.g., response dependent) or environment (e.g., classical conditioning).

More effective, individualized, and automated interventions may be possible with recent advances in machine learning and artificial intelligence. For example, recent studies have used deep learning and neural networks to develop methods to classify the identity, breed, age, sex and context associated with an individual dog's barks (Gómez-Armenta et al., 2024; Molnár et al., 2008). Extending classification models to triggers for barking, Li & Sinnott (2024) applied existing machine learning techniques to understand and predict dog barking behaviour, achieving over 87% accuracy for simple barking triggers and 81% for more complex ones. They developed their technology with the aim of future work being able to integrate with interventions using automated treat dispensing. Finally, advances in image classification with computer vision (see Voulodimos et al. (2018) for a review) may also elevate the potential of this technology in applied settings. Other research has assessed the welfare of dogs interacting with a positively reinforcing artificial agent and shown that it can contribute positively to dog welfare (Shaw et al., 2022).

In the current study, we implemented a novel, automated intervention to reduce barking in three cohorts of shelter dogs temporarily housed at a veterinary college. Based on the utility demonstrated by Protopopova & Wynne (2015), we evaluated a response independent, classical conditioning procedure that paired the arrival of kennel visitors with food delivery. To address issues with compliance seen in Carrero & Bennett (2025) and Zurlinden et al. (2022), we automated the treat delivery by using machine learning computer vision for people detection and a variety of sensors to trigger contingent treat delivery. We measured the sound level and percentage of time barking occurred throughout the day and assessed the impact of varying the timing, schedule of food delivery, and food quality. The goal of the study was to implement the intervention under typical shelter operating conditions, but on a stable population of dogs, and assess whether this intervention could improve upon the noise-reduction effects seen in the human-powered studies.

Methods

Subject Selection

Dogs were selected from the population of adoptable dogs at the Regional Center for Animal Care and Protection (RCACP), Roanoke, Virginia between February and May 2024. First, shelter staff recommended dogs for the study based on their legal status, health status, and assumed suitability, and then experimenters L.G. and E.F. performed informal in-shelter assessments. The assessment exposed dogs to conditions that they would typically encounter over the course of the study, including meeting unfamiliar people, interacting with toys, being in proximity to another friendly dog, taking treats, and having food and valued items removed. To participate in the study, dogs needed to be older than six months of age, in good health, show affiliative behaviors with people and other dogs, and not display or have a history of intense fear, anxiety, or stress under typical conditions (e.g., Fear Anxiety & Stress Score 3+ (Fear Free, 2022)).

We enrolled three cohorts of dogs, with a new cohort being selected approximately every four weeks from RCACP. Twenty-four dogs were selected for participation; however, one dog was excluded after he repeatedly destroyed experimental equipment, and another was excluded for issues with being handled. As a result, 22 dogs participated in the study. Their cohort assignments and identifying information are in Table 1.

Housing and Daily Care

Cohorts were housed in a room with 12 kennels at the Virginia-Maryland College of Veterinary Medicine in Blacksburg, Virginia for four-to-six weeks. The kennels were single-occupancy and indoor-only. Each kennel was approximately 2 m x 3 m, with a chain link front door and cinder block sides. Kennels lined both sides of the ward, separated by a walkway that had no visual barrier (i.e., six kennels on each side). To accommodate some of the technical equipment in the ward, dogs were not housed in the kennels at the back of the ward. Each kennel sloped towards a drain at the back of the kennel, and contained a water bowl, durable items to chew, and a raised platform lined with a towel. The kennel ward had one point of access and a single straight walkway that staff and students used to access the kennels. The ward contained a fan, a dehumidifier, and a white noise machine.

The dogs were cared for by Virginia Tech staff and undergraduate students. Each day, staff cleaned the kennels, provided short outings, and fed the dogs a combination of a commercial kibble diet and wet food in the morning and evening. They also provided libitum access to fresh water. Students provided regular daily enrichment, with each dog typically receiving six, 30-minute enrichment activities daily. Activities include walks, rewards-based training, and social interactions, and were scheduled between 7:00-9:00, 9:30-11:30, 12:00-14:00, 14:30-16:30, 17:00-19:00, and 19:00-19:45. Students also brought the dogs to a rewards-based dog training lab three times per week as part of an undergraduate course instructed by experimenters E.F. and L.G. These labs replaced two afternoon activities on these three days. All procedures involving animals were reviewed and approved by the Institutional Animal Care and Use Committee of Virginia Tech (IACUC protocol number: IACUC 23-157).

Table 1: Demographic information of the dogs that participated on the study.

Cohort	Dog's Name	Breed Estimate	Sex	Age Estimate (yrs)	Weight (kg)
1	Cane	Pit Bull Mix	M	1.2	27
	Bambi	Pit Bull Mix	F	1.1	29
	Will Furrell	Pit Bull Mix	M	1.1	17
	Jennifur	Hound Mix	F	1.0	14
	Benjamin	Great Pyrenees Mix	M	1.0	24
	Bea	Terrier Mix	F	2.1	11
	Harley	Malamute Mix	M	1.1	35
	Emmie	Hound Mix	F	0.8	20
2	Spears	Brittany Spaniel	M	5.0	16
	Lilly	Terrier Mix	F	8.1	8
	Elvis	Hound	M	1.1	30
	Eve	Labrador Retriever Mix	F	1.3	17
	Marcus	Pit Bull Mix	M	1.1	22
	Fleetfoot	Airedale Terrier	M	1	27
	Gamora	Labrador Retriever Mix	F	2.1	29
3	Beans	Hound Mix	M	1.1	30
	Napolean	Lab/Mastiff Mix	M	2.1	45
	Sky	Husky Mix	F	1.4	17
	Ollie	Pit Bull Mix	M	1.0	17
	Cheeto	Cavalier King Charles Mix	M	2.0	8
	Hammie	Staffordshire Terrier Mix	M	5.2	23
	Dakota	Husky	F	1.4	17

Feeders and Automation

Each kennel was equipped with a purpose-built feeder (Figure 1). The feeders were designed by experimenter R.T. for the study and consisted of PVC tubing, custom 3D-printed electronic housing, a microcontroller board (LILYGO, T-Display), a LIDAR module (ST Microelectronics, VL6180X) for reward delivery feedback, and a high-torque, continuous-rotation servo motor (SPT Servo, SPT5525LV-360 25KG) attached to a custom 3D-printed auger that moved kibble through the feeder. A PC (Lenovo ThinkCentre M900) running Home Assistant (OS 11.0 VM) on Proxmox (v. 8.0.4) gathered information from sensors throughout the ward and triggered the start and stop of food delivery based on customizable automations created in Home Assistant. The average kibble dispense rate varied with user-specified parameters and ranged from 2.4-8.9 kibbles per triggering event during the study.

Figure 1: Image of custom PVC feeders and associated electronics mounted to a kennel.

The customizable automations of the feeder system allowed us to manipulate the timing of food delivery relative to the arrival and ongoing presence of people in the ward walkway. Pilot interventions triggered the feeders upon the arrival of each new person to the ward and at a fixed time schedule of every 30 or every 60 seconds (FT30 or FT60) until the walkway was clear. The remaining interventions (Table 2, Row B-C) triggered the feeders upon the arrival of a person only if the walkway was empty and continued on an FT30 schedule while a person was present. For these interventions, the feeders were not triggered if a person entered the ward while someone was already in the walkway. When a feeder was triggered, the feeder motors continued to rotate until food was detected exiting the feeder or the dispensing period had elapsed, whichever occurred first.

Sensors were strategically placed in the ward to detect people, monitor feeder activity, and measure noise levels. A custom door sentry module (based on ST Microelectronics, VL53L1X) and a microcontroller (Espressif, ESP32) detected a person entering the ward, and a machine vision camera (Luxonis, OAK-D-PoE) running neural network object detection (MobileNet-SSD) and a custom Python script to integrate to Home Assistant detected the presence and number of people in the ward's walkway. A LIDAR sensor (ST Microelectronics, VL6180X) placed in the dispensing tube of the feeder detected whether food was delivered for each event. For noise monitoring, the ward was equipped with a sound level meter (BAFX products, BAFX3608), which measured the equivalent continuous sound level in decibels with A-weighting (dBA) each 0.36-second interval. Information from each of these sensors was written to an InfluxDB (v. 1.8.10) database, which could be accessed via a Chronograf (v. 1.10.1) web interface.

Intervention and Study Design

Each cohort experienced at least three experimental conditions (see Table 2 for a description of the conditions and their assigned alphabetic label). The first condition for all three cohorts was the Baseline (A) condition, in which no intervention was applied. Baseline started the day after all cohort dogs arrived at the facility and had variable durations to meet the experimental requirement of a non-concurrent multiple baseline design (Watson & Workman, 1981). The minimum duration of baseline was the amount of time needed for the kennel noise levels to either become stable or increase for three consecutive days. After baseline, cohorts entered an intervention condition.

The Main Intervention (B) condition was implemented all day, except for overnight and during abnormal operations, which included cleaning, undergraduate labs, and preparation for adoption events, as these were not the target of the intervention. During the Main Intervention, commercial kibble dispensed from the feeders immediately when a person entered the unoccupied ward walkway and on an FT30 schedule while someone was present in the walkway. The Novelty (C) condition was the same as the Main Intervention (B), except the feeders were dispensing a mix of commercial kibble and a more palatable food option (i.e., Crunchy Os [Fromm Family Pet Food, Mequon, Wisconsin] or Mini Natural's, [Zuke's, Neenah, Wisconsin]). Cohorts transitioned between intervention conditions when real-time daily visual analysis of the data showed a clear trend for three consecutive days.

Table 2: Description of experimental conditions.

Condition	**Intervention On**	**Food**	**Automation Triggers**
A. Baseline	Never	None	None
B. Main Intervention	All day*	Kibble	Person enters empty walkway. FT30 while person present.
C. Novelty	All day*	Kibble + high value mix	Person enters empty walkway. FT30 while person present.

** Interventions were turned off overnight and during abnormal operations including cleaning, undergraduate labs, and adoption events, which were not the target of intervention.*

Cohort 1 was intended to alternate between baseline and an intervention; however, during early data collection, it was observed that the intervention was triggering the feeders over 300 times per day, and the dispense rate was ~12 pieces of food per trigger. This resulted in an excessive amount of food being dispensed by the initial feeder prototype and pilot interventions. Additionally, the feeders were not reliably dispensing food, resulting in variable and sometimes low intervention integrity. Thus, Cohort 1 was used to refine the feeder prototype and food-delivery mechanics and to optimize the intervention settings. At the end of Cohort 1, the feeders were reliably dispensing food, the dispense rate was reduced to ~ 4 pieces per trigger, and the number of daily triggers was reduced. This work resulted in the Main Intervention (Table 2, Condition B). No further analysis was performed on Cohort 1 data. Cohorts 2 and 3 used all three conditions in an ABAC and ABACACA design, respectively.

Initial Test Probes: A Novel Person

Throughout Cohorts 2 and 3, we also characterized the dogs' response to a novel person test probe at multiple points across experimental phases. A novel person was selected for the probe to test the generalizability of the dogs' behaviour, as the dogs had regular exposure to the care team and few, if any, novel visitors. The goal was to assess the intervention's impact during a clearly defined walkthrough, simulating a shelter visitor. During each probe, an individual walked into the ward, passed each dog's kennel, turned around, walked past each dog's kennel again, and exited the ward without interacting with the dogs. The measurement period was the duration of time that the person was in the ward. No other people were in the kennel ward for the duration of a test probe.

Probes were scheduled on days without undergraduate labs, after morning cleaning and before evening activities (i.e., 11:00 to 17:30). On these days, two probes were conducted, with at least two hours between trials. In the baseline condition, the probe was conducted while the intervention was off. During the intervention conditions B and C, one probe was conducted with the intervention on, and the other was a reversal probe conducted with the intervention turned off, which allowed us to assess the immediate impact on noise levels.

We performed near-real time analysis of the test probes concurrent with data collection to inform refinements that could better characterize the dogs' behaviour. Changes to test probes were made as appropriate.

Updated Test Probes: People with and without Dogs

We updated the test probes for the final week of Cohort 3 based on the preliminary results of the near-real time data analysis of Cohort 2 and 3 novel person probes. We expanded the test probes to include novel and familiar people and dogs (see Table 3), expanded the measurement period to include 60 seconds before and after the walkthrough, and calculated the measures for the time with and without the individual in the ward. For scheduling, probe days had one of each probe type per day and varied in the order of presentation.

Table 3: Types of Updated Test Probes

Probe Type	Description
Novel Person	A person unfamiliar to the dogs.
Familiar Person	An individual from the dog's care team, alone.
Novel Dog	An individual from the dog's care team with an unfamiliar dog.
Familiar Dog	An individual from the dog's care team with another dog of that cohort.

Measures

To assess the intervention's efficacy in reducing noise when people were present in the ward, the output of the sound level meter was manipulated to provide two derivative measures. The first measure was the equivalent continuous sound level (LEQ), $L_{eq,T}$, for a period of interest from time T_1 to T_2, with duration $T = T_2 - T_1$. This was calculated as the time-average of the sound level meter readings $L_{eq,s}(t)$ over n measurements (Eq. 1). Because decibels are logarithmic values, the average was calculated by converting to sound pressure levels, averaging, and converting back to decibels (Workers' Compensation Board: WorkSafeBC, 2019):

$$L_{eq,T} = 10 \cdot \log_{10}\left(\frac{1}{n}\sum_{T_1 \le t_i \le T_2} 10^{\frac{L_{eq,s}(t_i)}{10}}\right) \quad (1)$$

The logarithmic nature of decibels makes it so that they are not particularly sensitive to potentially meaningful changes in dog behavior. For example, halving the amount of noise results in a 3 dB decrease in the noise level measured in decibels[1]. To address this insensitivity, the percentage of

[1] Consider producing a 100 dB sound over 30 minutes; the LEQ would be 100 dB. If that sound is then only produced for 15 minutes and the remaining 15 minutes is at an ambient background of 45 dB, the equivalent continuous sound level would be 97 dB. Note that this is not the arithmetic mean of 100 and 45.

time that the sound level meter exceeded 85 dB in the period of interest, $R_{t>85\ dB}$ (R_{85}), was also used to describe the study's data. This was obtained by summing the amount of time the sound level meter reading $L_{eq,s}(t)$ was above 85 dB and dividing by the total amount of time in the period of interest and reporting as a percentage:

$$R_{t>85\ dB} = \frac{\sum_{(T_1 \le t_i \le T_2)\ \&\ (L_{eq,s} > 85\ dB)} t_i}{\sum_{(T_1 \le t_i \le T_2)} t_i} \tag{2}$$

The 85-dB threshold was utilized as it was determined to be sensitive to the dogs' barking while reducing the impact of noise generated by people in the kennels. It is conveniently also the OSHA action level for implementing a hearing protection program for workers (Occupational Safety and Health Administration, 2006).

Our period of interest for daily sound measurements was 11:00 to 21:00, commencing post-feeding and cleaning and ending after the final activity of the day. The time of day when undergraduate labs were held during the week (i.e., 13:45 to 15:15) were also excluded. Both derivative measures were calculated in three ways: for the full period of interest, when people were present in the walkway, and when people were not present. Additional measures that were monitored and optimized in Cohort 1 include the number of daily feeder triggers, the feeder success rate at dispensing food, and the dispensed amount measured in number of pieces of food per trigger.

Analysis

Analysis was conducted throughout data collection using Chronograf, Excel (Microsoft® Excel® for Microsoft Office 365), and VBA (Microsoft Visual Basic for Applications 7.1). Each day, the measurements of the sound level meter were exported from Chronograf to an Excel spreadsheet. Custom macros were designed in VBA and run in Excel to exclude data outside the period of interest and calculate the derivative measures $L_{eq,T}$ and $R_{t>85\ dB}$. These measures were then graphed and visually analyzed in Excel to inform the transition between conditions along with any changes to the intervention conditions. After the data collection period, we calculated aggregate measures, including the mean, median, interquartile range, and range of the daily data, and the mean and standard deviation of the test probe data. Data were aggregated by condition only for the period while someone was in the ward walkway. If a condition was repeated (e.g., return to baseline), all data points for the condition were included to provide a single aggregate value. The intervention efficacy was assessed via visual analysis of the daily data along with comparisons between median values and interquartile ranges. Due to the exploratory nature of the study, no statistical tests were performed and no estimates for significance or effect size were made.

Results

Background Noise

To determine the lower threshold for intervention (i.e., the noise floor), the noise level was measured during the day when no people were in the ward and the dogs were resting. Under these conditions, the output of the sound level meter, $L_{eq,s}(t)$, ranged from 60 to 75 dB. Characterization of these background sounds was not performed beyond the observations of the experimenters, who noted auditory changes related to the facility's HVAC, plumbing, and dog-related movements.

Cohort Results

Cohort 2 followed an ABAC design in which the dogs spent 5 days in Baseline (A), followed by 8 days in the Main Intervention (B), 5 days in a return to Baseline condition, and 4 days in a final intervention in the Novelty condition (C) with a novel, high-value food item mixed into the kibble (Crunchy Os). Figure 2 displays the daily values for visual analysis of the LEQ (panel I) and R_{85} (panel V) along with the median, mean, interquartile range (IQR), and range, aggregated by condition for the period when people were in the walkway (panels II and VI, for LEQ and R_{85} respectively). The median and IQR for all conditions and the difference in medians between baseline and intervention conditions are described in Table 4 for LEQ and Table 5 for R_{85}.

The difference in median LEQ between baseline and main intervention was -0.5 dB, and the difference between baseline and novelty condition was -0.3 dB (Table 4). The median value for the intervention was within the baseline IQR in both cases. For the R_{85}, the relative percent change from baseline to the main intervention was -25%; and for the novelty condition, -4% (Table 5). The median value for intervention was below the baseline IQR for the main intervention, but not for the novelty condition. The novelty condition has the smallest IQR for both LEQ and R_{85}; however, the novelty condition also had the days of data collection.

Table 4: Summary LEQ Results for Cohorts 2 and 3. The median and interquartile range are shown by condition along with the difference between medians in baseline and intervention.

Measure	Statistic	Baseline LEQ (dB)	Main LEQ (dB)	Difference from Baseline (dB)	Novelty LEQ (dB)	Difference from Baseline (dB)
Cohort 2	Median	99.8	99.3	-0.5	99.5	-0.3
	IQR	2.0	2.7		1.4	
Cohort 3	Median	96.7	97.2	0.5	93.8	-3.0
	IQR	1.7	3.0		3.5	

Table 5: Summary R_{85} Results for Cohorts 2 and 3. The median and interquartile range are shown by condition along with the percent median change from baseline to intervention condition.

Measure	Statistic	Baseline (%)	Main (%)	% Change from Baseline	Novelty (%)	% Change from Baseline
Cohort 2	Median	9.6	7.2	-25%	9.2	-4%
	IQR	3.6	4.5		1.7	
Cohort 3	Median	13.9	11.3	-19%	12.6	-9%
	IQR	3.5	3.1		3.5	

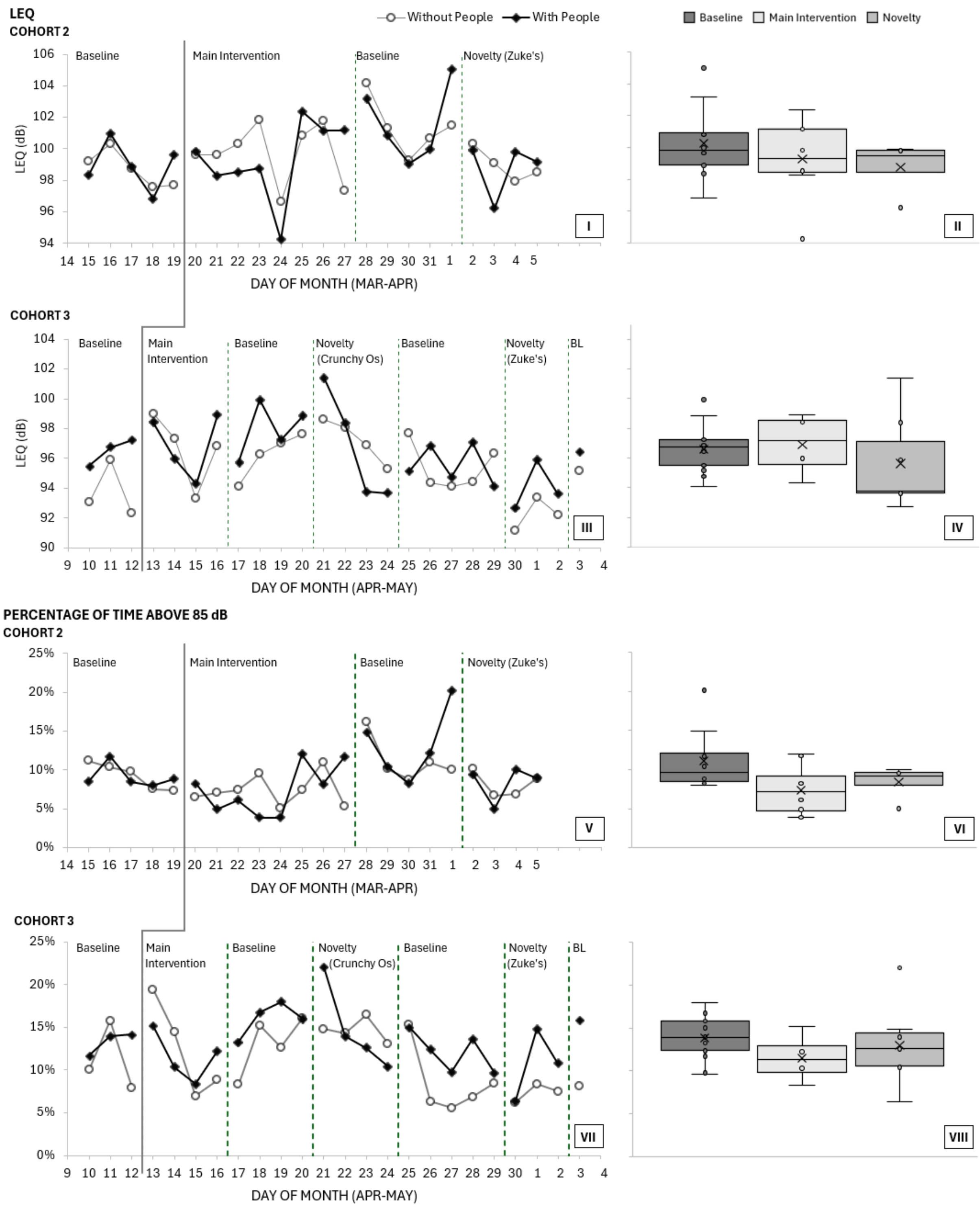

Figure 2: Daily and Aggregated Results from Cohorts 2 and 3 for LEQ (I-IV) and R_{85} (V-VIII). Left panels show daily values with and without people in the kennel walkway. Right panels show box and whisker plot of the time with people present, aggregated by condition. The box represents the median and interquartile range, whiskers represent range, x denotes the mean, o denotes additional daily values, including outliers.

Cohort 3 followed an ABACACA design with the dogs spending 3 days in Baseline (A), followed by 4 days with the Main Intervention (B), and then had a series of alternations between the baseline condition and intervention in the Novelty condition (C) with a novel with a novel, high-value food item (Crunchy Os or Zuke's) mixed into the kibble. Figure 2 displays the daily values for LEQ (panel III) and R_{85} (panel VII) along with the median, mean, interquartile range (IQR), and range, aggregated by condition for the period when people were in the walkway (panels IV and VIII, for LEQ and R_{85} respectively). The median and IQR for all conditions and the difference in medians between baseline and intervention conditions are available in Table 4 for LEQ and Table 5 for R_{85}.

The change in median LEQ from baseline to main intervention was +0.5 dB; and the change from baseline to novelty condition, -3.0 dB (Table 4). The median value for the novelty condition was lower than the lowest value in baseline (93.7 vs 94.1 dB, respectively). For the R_{85}, the relative percent change from baseline to the main intervention was -19%; and for the novelty condition. -9% (Table 5). The median value for intervention was below baseline IQR for the main intervention and at the lower end of the baseline IQR for the novelty condition.

Visual inspection of Figure 2 does not reveal a significant intervention effect for the Main Intervention as there are no clear and consistent level shifts or trend changes between baseline and intervention for either the LEQ or R_{85}. There is some evidence of an effect during transitions from Baseline to Novelty conditions for both cohorts. For example, in the Cohort 2 transition to Zuke's, a clear level shift and trend reversal occurs for both measures. A similar trend reversal in LEQ occurs when dogs transition to Crunchy Os in Cohort 3.

Initial Test Probes: A Novel Person

Twenty-two novel person walkthroughs were conducted during the initial test probes for Cohorts 2 and 3, with these typical probe walkthroughs lasting 20 seconds (*SD* = 4 s). Twenty-one of the 22 probes had LEQs below the OSHA limit of 85 dB (*M* = 69.5 dB, *SD* = 3.6) and were consistent with background noise levels in both the baseline and intervention conditions. The one session with an LEQ above 85 dB had elevated noise levels for only 1 second, consistent with a single, short bout of barking. The R_{85} in all other probes was 0%. These values are much lower than the 100-dB noise levels from our broader data when people were in the ward (Table 4). This informed our decision to add familiar people and familiar and novel dog test probes, as well as expand the measurement period to include 60 s before and after the walkthrough in our updated test probes.

Updated Test Probes: People with and without Dogs

Figure 3 displays the data from the four types of updated test probes (Table 3) that were implemented during the last week of Cohort 3. The average and standard deviation of each probe type are displayed in the rightmost panel. Regardless of whether the person was novel or familiar, noise levels during these test probes were consistent with background noise (novel *M* = 71 dB, *SD* = 2, familiar *M* = 72 dB, *SD* = 7). However, the noise levels prior to and following the walkthrough increased to 90 dB (*SD* = 9) for the novel person and 81 dB (*SD* = 11) for the familiar person.

Having a dog accompany a familiar person during the test probe increased the noise levels significantly. During the walkthrough, the LEQ increased to 104 dB (*SD* = 2) for the novel dog and 102 dB (SD = 5) for the familiar dog; and for the period before and after the walkthrough, the noise levels remained elevated (novel *M* = 98 dB, *SD* = 5 dB, familiar *M = 102* dB, *SD* = 2). Thus, a person walking a dog through the ward produced an increase of nearly 30 dB compared to background or having a novel or familiar person walk through the ward alone.

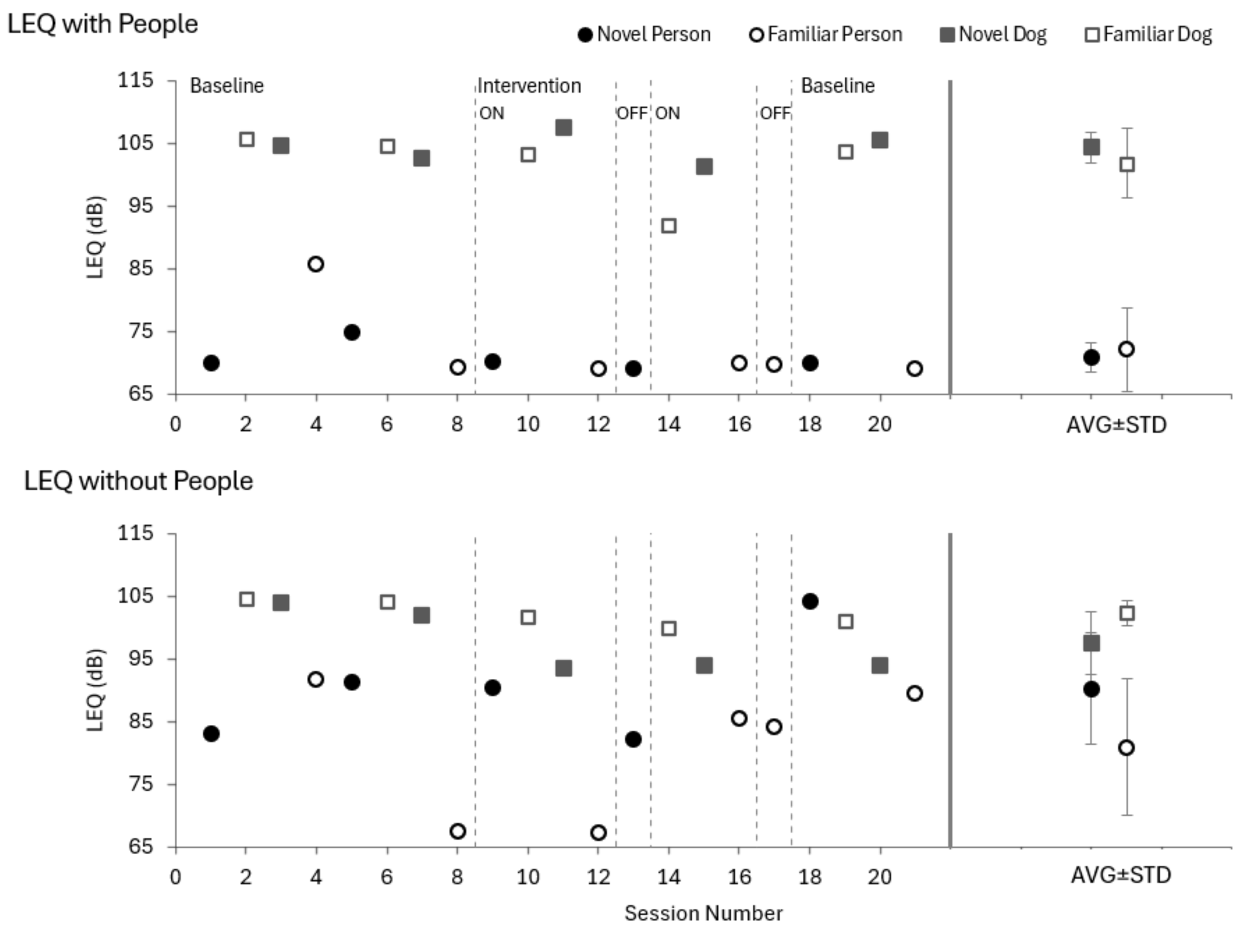

Figure 3: Updated Test Probe Data from Cohort 3. The LEQ was calculated for the time the individual was in the ward (TOP) and the period immediately before and after their walkthrough (BOTTOM). During the intervention condition, probes were conducted both with and without the intervention occurring for the duration of the probe.

Discussion & Recommendations

We investigated a first-of-its-kind implementation of a computer-vision assisted intervention to address shelter dog barking by using food delivery with customizable automation. The method allowed for accurate and timely identification of people entering and lingering in the dogs' ward and for contingent food delivery, which successfully eliminated issues with human compliance that were observed in previous studies (Carrero & Bennett, 2025; Zurlinden et al., 2022). Despite these technological improvements, the daily LEQs persisted around 100 dB, which is well above the 85-dB regulatory threshold for implementing a hearing conservation program (Occupational Safety and Health Administration, 2006) and about 30 dB higher than background noise levels for the study.

The main intervention, which provided kibble to the dogs, showed no clear or consistent effect on either the ward's noise levels or dog's percentage of time barking. Visual inspection of the daily LEQ values show large variability across days and lacked clear level shifts or trend reversals for either cohort. Additionally, the change in median noise level from baseline was in opposite directions for Cohort 2 and Cohort 3 (-0.5 dB and +0.5 dB, respectively). Furthermore, the median values for both cohorts lay within the interquartile range for baseline, suggesting that the observed difference may likely result from variability in the data rather than an effect of the intervention.

For the percentage of time that the ward was above 85 dB, there was some evidence of intervention effect in the aggregate data. The median value for intervention for both cohorts was lower than their respective baseline values and fell outside the baselines' interquartile ranges. The relative percent change from baseline to intervention was -25% for Cohort 2 and -19% for Cohort 3; however, the decrease in the percentage of time above 85 dB did not correlate with a lower LEQ. This may suggest that during the main intervention, the dogs spent less time barking but barked with greater intensity. Assessing this was beyond the scope of this study, but it is possible that the intervention influenced the dogs' behavior and could be explored in future work.

The novelty condition showed some promise for decreasing noise levels in the kennel ward. Despite large variability across days, both level shifts to lower daily LEQs and trend reversals were present in the daily data, especially when including Zuke's in the mix. Furthermore, the median LEQ values decreased from baseline for both cohorts (-0.3 and -3.0 dB, respectively). The 3-dB decrease for Cohort 3 (96.7 dB in baseline to 93.8 dB in intervention) was lower than any daily LEQ detected during the baseline condition. Additionally, the percentage of time that the ward was above 85 dB also decreased with both cohorts. The relative percentage change from baseline was -4% for Cohort 2 and -9% for Cohort 3. Interestingly, this is a smaller change than was observed with the main intervention, despite the larger change in LEQ. These findings may suggest that during the novelty condition, dogs spent less time barking than in baseline but more time than in the main intervention and that they barked with lower intensity. If this is the case, our study demonstrates promise for future research with automated interventions that utilize more palatable foods. From a classical conditioning perspective, such an approach would be supported as the strength of conditioning is understood to be related to the quality of the food utilized (Frieman & Reilly, 2016).

The largest reduction in noise level occurred in Cohort 3 with novel, high-value food mixed with the kibble. The resulting 3-dB reduction of the median noise level corresponds to a halving of the sound intensity and is an improvement on the less-than-1-dB change seen with a fixed-time schedule automated intervention (Fernandez et al., 2023). We attribute the improvement to the inclusion of contingencies between food delivery and changes in the dog's environment compared to a fixed schedule food delivery. By employing classical conditioning contingencies, dogs were likely able to make associations, anticipate food delivery, and change their behavioral responding. The 3-dB reduction was also consistent with what was seen in a similar human-powered intervention (Carrero & Bennett, 2025), although with our improved reliability in treat delivery, we expected greater change in the noise levels. One notable procedural difference between the two studies was that the Carrero and Bennett (2025)'s human-powered intervention used exclusively high-value, palatable food options, whereas we used kibble or a kibble mix. Thus, it is possible that the automated intervention may have a greater impact on noise levels with more palatable treats.

Despite our positive findings, the noise levels during intervention far exceeded our background noise levels (range 60-75 dB), leaving the possibility for much larger intervention effects. In fact, other studies examining shelter interventions have reported larger changes in noise levels. For example, Hermiston et al. (2018) found a 6-dB decrease in noise when using dog appeasing pheromone spray in the dogs' kennels; however, they had a 10-second measurement period, whereas our design utilized full day measurements, making a direct comparison of the studies challenging. Additionally, Payne & Assemi (2017) reported a larger intervention impact in their classical conditioning pairing procedure using a door chime and food in the shelter's, with a near 20 dB change in noise levels. While their post-intervention noise levels were consistent with our background noise levels, they did not proceduralize or quantify the number of walkthroughs of their kennel area, and it is unclear if their results were impacted by the lack of passersby or the intervention. Nevertheless, significant noise reduction beyond the findings of our study is required to recover noise levels near the noise floor.

Understanding why dogs in shelters bark is vital for designing and optimizing effective interventions. While the reasons are not well characterized, underlying emotions of fear and frustration resulting from sub-optimal welfare conditions likely play a role (Mellor et al., 2020; Pongrácz et al., 2010). Our intervention was designed on assumptions that dogs may be fearful or wanting to interact with people as they approached or passed by the dogs' kennels. Under these assumptions, we would expect to see an increase in dogs' barking during walkthroughs, consistent with what has been found in previous studies (Hewison et al., 2014; Wells & Hepper, 2000). As such, the most appropriate approach to program treat delivery would have been contingent on people approaching, as done in our study and others (Baldan et al., 2023; Carrero & Bennett, 2025; Payne & Assemi, 2017; Protopopova & Wynne, 2015; Zurlinden et al., 2022). However, during our novel and familiar person test probes, we found that the dogs were nearly silent during the walkthroughs (approx. 70 dB) regardless of the cohort or study condition, and they barked only before and after the walkthrough (approx. 90 dB). This behavioral response is counter to our expectations, challenging the underlying assumptions and the resulting intervention design.

Decisions around the selection of dogs and their care routine may provide insights as to why the dogs did not respond to our interventions as expected. First, the dogs were selected for their sociability with people and other dogs to accommodate the busy college campus where the study was conducted. Second, the enrichment and care routine provided an abundance of human interactions, often six activities a day. These decisions may have biased the emotional and motivational states of the participating dogs compared to a typical shelter population. For example, selecting for positive social traits might have biased the cohorts of dogs, reducing the prevalence of fear when a person approached the kennels, and instead produced more frustration-related barking when a human was absent. Moreover, the relatively high frequency of human interactions might have further changed the dogs' motivational states and reduced barking by creating positive associations and anticipation when a person approached their kennel, similar to what has been achieved in typical human-powered quiet kennel exercises (Carrero & Bennett, 2025; Payne & Assemi, 2017; Zurlinden et al., 2022). This pattern of barking matches what was observed in the novel and familiar test probe data. An opportunity for future work includes assessing the classical conditioning pairing procedure implemented here on a more representative population of dogs and enrichment routines.

Interestingly, when our study's test probes included either a novel or familiar dog, we observed the expected increase in barking that is typical in an animal shelter. The amount of barking during these novel and familiar dog test probes increased the noise levels to 98-104 dB, which was consistent with noise levels observed throughout the study (daily LEQ range: 90-105 dB). This is a 30-dB increase in the noise level compared to a person walking through the ward without a dog. Since dogs were always escorted to and from their kennel by a person, our intervention did dispense food when dogs were present, but it also dispensed food when dogs were not present. In consideration of this strong relationship between barking and dog walkthroughs as well as the critical role of contingency in effective classical conditioning (Frieman & Reilly, 2016), an intervention that was delivered contingent upon the presence of other dogs in the ward's walkway, not people, may have been more effective. Nevertheless, as our study's population and subsequent findings differ from previous literature, optimizing the intervention based on our test probe data for use in typical animal shelters may not be ideal. Thus, we recommend that future studies prioritize testing the existing intervention on a more representative population of shelter dogs instead.

Based on the wealth of information provided by our test probe data, we recommend that further research into or application of an automated intervention begin with probes to gain insight as to what contingencies would best serve their population of dogs. Probes could include walkthroughs performed by staff, volunteers, and/or visitors, accompanied by another dog or not, and at various times of day, or other custom probes based on the potential stressors in that environment. Such insights could be used to optimize the intervention and likely improve efficacy.

Another challenge that the dog's care and enrichment routine created for the success of the intervention was the subsequent number of intervention-triggering events, which ranged from 100 to 300, daily. This likely had an impact on the dogs' motivational states as the value of the dispensed food diminished over the day, with dogs satiating with repeated exposure and consumption. Consumption was not measured in our study, but members of the care team did report that most dogs left at least some food, typically kibble, uneaten. Additionally, the volume of food being dispensed limited the food options to low-calorie and less palatable foods. Thus, the large number of triggers would limit the intervention efficacy through satiation and low palatability.

To confirm that the high volume of triggers observed in our study was representative of what might occur in a typical shelter environment, we reviewed the visitor and volunteer logs and had students log foot traffic at the Montgomery County Animal Care and Adoption Center, Virginia, USA. Given the intervention parameters used in our study, we found that there would have been around 240 triggers over a 4-hour visiting period. This strongly suggests the need to find interventions that can accommodate high foot traffic through the dog kennels. Opportunities for future work in this area include hardware refinements to further reduce the volume of food dispensed per triggering event; investigating the optimal food mix, which may include reducing the amount of kibble in the mix and conducting preference assessments to audition various palatable, low-calorie options for intervention; and optimizing the automation parameters to reduce the trigger frequency while maintaining or improving efficacy.

Conclusion

In conclusion, the utilization of a classical conditioning procedure using computer vision and automated food dispensers is a promising avenue for reducing the barking of dogs in animal shelters. This study demonstrates that automated food delivery contingent on the arrival and continued presence of humans in the ward can reduce the noise levels associated with barking, which could improve human and animal health and welfare in this environment. Future studies would likely benefit from optimizing the intervention parameters, the volume and type of food used, and the inclusion of new technologies that may lead to more individualized and effective interventions.

References

American Society for the Prevention of Cruelty to Animals. (n.d.). *Three Tips for Reducing Barking in the Shelter* . Retrieved February 17, 2025, from https://www.aspcapro.org/resource/three-tips-reducing-barking-shelter

Arcangeli, G., Lulli, L. G., Traversini, V., De Sio, S., Cannizzaro, E., Galea, R. P., & Mucci, N. (2023). Neurobehavioral Alterations from Noise Exposure in Animals: A Systematic Review. *International Journal of Environmental Research and Public Health*, *20*(1), 591. https://doi.org/10.3390/ijerph20010591

Baldan, A. L., Ferreira, B. L., Warisaia, V., Feuerbacher, E. N., Monticelli, P. F., & Gunter, L. M. (2023). Reducing barking in a Brazilian animal shelter: A practical intervention. *Applied Animal Behaviour Science*, *265*. https://doi.org/10.1016/j.applanim.2023.105992

Barber, A. L. A., Wilkinson, A., Montealegre-Z, F., Ratcliffe, V. F., Guo, K., & Mills, D. S. (2020). A comparison of hearing and auditory functioning between dogs and humans. *Comparative Cognition & Behavior Reviews*, *15*, 45–94. https://doi.org/10.3819/CCBR.2020.150007

Beaver, B. V. (2024). The prevalence of behavior problems in dogs in the United States. *Journal of Veterinary Behavior*, *76*, 34–39. https://doi.org/10.1016/j.jveb.2024.11.001

Beerda, B., Schilder, M. B. H., Van Hooff, J. A. R. A. M., & De Vries, H. W. (1997). Manifestations of chronic and acute stress in dogs. *Applied Animal Behaviour Science*, *52*(3–4), 307–319. https://doi.org/10.1016/S0168-1591(96)01131-8

Best Friends Network Partners. (2022, May). *Canine Care and Enrichment Playbook*. https://network.bestfriends.org/education/manuals-handbooks-playbooks/canine-care-and-enrichment

Buckland, E. L., Corr, S. A., Abeyesinghe, S. M., & Wathes, C. M. (2014). Prioritisation of companion dog welfare issues using expert consensus. *Animal Welfare*, *23*(1), 39–46. https://doi.org/10.7120/09627286.23.1.039

Carrero, J. C., & Bennett, S. L. (2025). Effect of classical counterconditioning (Quiet Kennel Exercise) on barking in sheltered dogs. *Journal of Veterinary Behavior*, *77*(September 2024), 42–51. https://doi.org/10.1016/j.jveb.2024.09.004

Coppola, C. L., Enns, R. M., & Grandin, T. (2006). Noise in the animal shelter environment: Building design and the effects of daily noise exposure. *Journal of Applied Animal Welfare Science*, *9*(1), 1–7. https://doi.org/10.1207/s15327604jaws0901_1

Eagan, B. H., Gordon, E., & Fraser, D. (2021). The effect of animal shelter sound on cat behaviour and welfare. *Animal Welfare*, *30*(4), 431–440. https://doi.org/10.7120/09627286.30.4.006

Fear Free. (2022). *FAS Spectrum*. https://fearfreepets.com/fas-spectrum/

Fernandez, E. J., Anderson, W., & Kowalski, A. (2023). Evaluation of an automated response-independent schedule on the behavioral welfare of shelter dogs. *Journal of the Experimental Analysis of Behavior*, *120*(1), 50–61. https://doi.org/10.1002/jeab.849

Flint, E. L. (2012). The function, social implications and management of barking in dogs. *CABI Reviews*, *7*, 1–8. https://doi.org/10.1079/PAVSNNR20127039

Frieman, J., & Reilly, S. (2016). Identifying the Predictors of Significant Events. *Learning: A Behavioral, Cognitive, and Evolutionary Synthesis*, 109–140. https://doi.org/10.4135/9781071800867

Gómez-Armenta, J. R., Pérez-Espinosa, H., Fernández-Zepeda, J. A., & Reyes-Meza, V. (2024). Automatic classification of dog barking using deep learning. *Behavioural Processes*, *218*, 105028. https://doi.org/10.1016/j.beproc.2024.105028

Hermiston, C., Montrose, V. T., & Taylor, S. (2018). The effects of dog-appeasing pheromone spray upon canine vocalizations and stress-related behaviors in a rescue shelter. *Journal of Veterinary Behavior*, *26*, 11–16. https://doi.org/10.1016/j.jveb.2018.03.013

Hetts, S., Derrell Clark, J., Calpin, J. P., Arnold, C. E., & Mateo, J. M. (1992). Influence of housing conditions on beagle behaviour. *Applied Animal Behaviour Science*, *34*(1–2), 137–155. https://doi.org/10.1016/S0168-1591(05)80063-2

Hewison, L. F., Wright, H. F., Zulch, H. E., & Ellis, S. L. H. (2014). Short term consequences of preventing visitor access to kennels on noise and the behaviour and physiology of dogs housed in a rescue shelter. *Physiology and Behavior*, *133*, 1–7. https://doi.org/10.1016/j.physbeh.2014.04.045

Kight, C. R., & Swaddle, J. P. (2011). How and why environmental noise impacts animals: An integrative, mechanistic review. *Ecology Letters*, *14*(10), 1052–1061. https://doi.org/10.1111/j.1461-0248.2011.01664.x

Kim, J. (2018). Social finance funding model for animal shelter programs: Public–private partnerships using social impact bonds. *Society and Animals*, *26*(3), 259–276. https://doi.org/10.1163/15685306-12341521

Li, Z., & Sinnott, R. (2024). Predicting and Avoiding Dog Barking Behaviour through Deep Learning. *ACM International Conference Proceeding Series*, 26–35. https://doi.org/10.1145/3641142.3641176

Martin, A. L., Walthers, C. M., Pattillo, M. J., Catchpole, J. A., Mitchell, L. N., & Dowling, E. W. (2023). Impact of Visual Barrier Removal on the Behavior of Shelter-Housed Dogs. *Journal of Applied Animal Welfare Science*, *26*(4), 596–606. https://doi.org/10.1080/10888705.2021.2021407

Mellor, D. J., Beausoleil, N. J., Littlewood, K. E., McLean, A. N., McGreevy, P. D., Jones, B., & Wilkins, C. (2020). The 2020 five domains model: Including human–animal interactions in assessments of animal welfare. *Animals*, *10*(10), 1–24. https://doi.org/10.3390/ani10101870

Molnár, C., Kaplan, F., Roy, P., Pachet, F., Pongrácz, P., Dóka, A., & Miklósi, Á. (2008). Classification of dog barks: A machine learning approach. *Animal Cognition*, *11*(3), 389–400. https://doi.org/10.1007/s10071-007-0129-9

Occupational Safety and Health Administration. (2006). *Standard Number 1910.95: Occupational noise exposure.* https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.95

Park, S., Johnson, M. D., & Hong, O. S. (2020). Analysis of Occupational Safety and Health Administration (OSHA) noise standard violations over 50 years: 1972 to 2019. *American Journal of Industrial Medicine*, *63*(7), 616–623. https://doi.org/10.1002/ajim.23116

Payne, S. W., & Assemi, K. S. (2017). An Evaluation of Respondent Conditioning Procedures to Decrease Barking in an Animal Shelter. *Pet Behaviour Science*, *3*(3), 19–24. https://doi.org/10.21071/pbs.v0i3.5858

Pongrácz, P., Molnár, C., & Miklósi, Á. (2010). Barking in family dogs: An ethological approach. *Veterinary Journal*, *183*(2), 141–147. https://doi.org/10.1016/j.tvjl.2008.12.010

Pretzsch, A., Seidler, A., & Hegewald, J. (2021). Health Effects of Occupational Noise. *Current Pollution Reports*, *7*(3), 344–358. https://doi.org/10.1007/s40726-021-00194-4

Protopopova, A., Mehrkam, L. R., Boggess, M. M., & Wynne, C. D. L. (2014). In-kennel behavior predicts length of stay in shelter dogs. *PLoS ONE*, *9*(12), 1–21. https://doi.org/10.1371/journal.pone.0114319

Protopopova, A., & Wynne, C. D. L. (2015). Improving in-kennel presentation of shelter dogs through response-dependent and response-independent treat delivery. *Journal of Applied Behavior Analysis*, *48*(3), 590–601. https://doi.org/10.1002/jaba.217

Sales, G., Hubrecht, R., Peyvandi, A., Milligan, S., & Shield, B. (1997). Noise in dog kennelling: Is barking a welfare problem for dogs? *Applied Animal Behaviour Science*, *52*(3–4), 321–329. https://doi.org/10.1016/S0168-1591(96)01132-X

Scheifele, P., Martin, D., Clark, J. G., Kemper, D., & Wells, J. (2012). Effect of kennel noise on hearing in dogs. *American Journal of Veterinary Research*, *73*(4), 482–489. https://doi.org/10.2460/ajvr.73.4.482

Shaw, N., Wemelsfelder, F., & Riley, L. M. (2022). Bark to the future: The welfare of domestic dogs during interaction with a positively reinforcing artificial agent. *Applied Animal Behaviour Science*, *249*, 105595. https://doi.org/10.1016/j.applanim.2022.105595

Shnookal, J., Tepper, D., Howell, T., & Bennett, P. (2024). Counterconditioning-based interventions for companion dog behavioural modification: A systematic review. *Applied Animal Behaviour Science*, *276*(April), 106305. https://doi.org/10.1016/j.applanim.2024.106305

Sinclair, M., Lee, N. Y. P., Hötzel, M. J., de Luna, M. C. T., Sharma, A., Idris, M., Derkley, T., Li, C., Islam, M. A., Iyasere, O. S., Navarro, G., Ahmed, A. A., Khruapradab, C., Curry, M., Burns, G. L., & Marchant, J. N. (2022). International perceptions of animals and the importance of their welfare. *Frontiers in Animal Science*, *3*, 960379. https://doi.org/10.3389/fanim.2022.960379

Stephen, J. M., & Ledger, R. A. (2005). An audit of behavioral indicators of poor welfare in kenneled dogs in the United Kingdom. *Journal of Applied Animal Welfare Science*, *8*(2), 79–95. https://doi.org/10.1207/s15327604jaws0802_1

The Association of Shelter Veterinarians. (2022). The Guidelines for Standards of Care in Animal Shelters: Second Edition. *Journal of Shelter Medicine and Community Animal Health*, *December*. https://doi.org/10.56771/asvguidelines.2022

Tod, E., Brander, D., & Waran, N. (2005). Efficacy of dog appeasing pheromone in reducing stress and fear related behaviour in shelter dogs. *Applied Animal Behaviour Science*, *93*(3–4), 295–308. https://doi.org/10.1016/j.applanim.2005.01.007

Venn, R. E., McBrearty, A. R., McKeegan, D., & Penderis, J. (2014). The effect of magnetic resonance imaging noise on cochlear function in dogs. *Veterinary Journal*, *202*(1), 141–145. https://doi.org/10.1016/j.tvjl.2014.07.006

Voulodimos, A., Doulamis, N., Doulamis, A., & Protopapadakis, E. (2018). Deep Learning for Computer Vision: A Brief Review. *Computational Intelligence and Neuroscience*, *2018*. https://doi.org/10.1155/2018/7068349

Watson, P. J., & Workman, E. A. (1981). The non-concurrent multiple baseline across-individuals design: An extension of the traditional multiple baseline design. *Journal of Behavior Therapy and Experimental Psychiatry*, *12*(3), 257–259. https://doi.org/10.1016/0005-7916(81)90055-0

Wells, D., & Hepper, P. G. (1992). The Behaviour of Dogs in a Rescue Shelter. *Animal Welfare*, *1*(3), 171–186. https://doi.org/10.1017/S0962728600014998

Wells, D. L. (2004). The influence of toys on the behaviour and welfare of kennelled dogs. *Animal Welfare*, *13*(3), 367–373. https://doi.org/10.1017/s0962728600028499

Wells, D. L., & Hepper, P. G. (1998). A note on the influence of visual conspecific contact on the behaviour of sheltered dogs. *Applied Animal Behaviour Science*, *60*(1), 83–88. https://doi.org/10.1016/S0168-1591(98)00146-4

Wells, D. L., & Hepper, P. G. (2000). The influence of environmental change on the behaviour of sheltered dogs. *Applied Animal Behaviour Science*, *68*(2), 151–162. https://doi.org/10.1016/S0168-1591(00)00100-3

Wells, D. L., & Hepper, P. G. (2001). The behavior of visitors towards dogs housed in an animal rescue shelter. *Anthrozoos*, *14*(1), 12–18. https://doi.org/10.2752/089279301786999661

Workers' Compensation Board: WorkSafeBC. (2019). *Measuring Occupational Noise*.

World Health Organization. (2011). *Burden of Disease from Environmental Noise*. 128.

Zurlinden, S., Spano, S., Griffith, E., & Bennett, S. (2022). Impact of Classical Counterconditioning (Quiet Kennel Exercise) on Barking in Kenneled Dogs—A Pilot Study. *Animals*, *12*(2), 171. https://doi.org/10.3390/ani12020171