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The effect of anthropogenic noise on foraging and vigilance in zoo housed pied tamarins

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ABSTRACT

The phenomenon of human-induced rapid environmental change (HIREC) is a great challenge in the modern world that presents a threat to all species. Research on the effect of anthropogenic noise on free-living wildlife is increasing but the effect of anthropogenic noise on the behaviour and welfare of captive wildlife has received limited attention, even though captive settings are full of human activity and a wide range of sounds. Moreover, studies in captivity tend to classify noise subjectively by volume according to human hearing and as part of the overall 'visitor effect' rather than a stressor in its own right. Research on free-living wildlife suggests that anthropogenic noise can negatively impact foraging behaviour; similar impacts in captive species could have a detrimental effect on their health and welfare if animals cannot perform functional feeding behaviours and access adequate nutrition. In the current study, we designed a forage box experiment for captive pied tamarins, a Critically Endangered callitrichid primate species that is prone to poor physical health and breeding success in captivity. Ten pairs of tamarins housed at Jersey Zoo were provided with a forage box containing cryptic (hidden) prey items (waxworms). Using a within-subjects design, tamarins were provided access to the forage box in noise and non-noise conditions of anthropogenic noise (machinery used for gardening in the zoo). Both active (foraging with the hands) and observational (looking into the forage box) foraging were significantly less frequent in the presence of anthropogenic noise; however, there was no difference in the duration of these behaviours or in foraging success. Furthermore, the presence of anthropogenic noise did not significantly affect vigilance behaviour. We found no sex differences in the effect of noise, and our results suggest that the anthropogenic noise we tested was only a minimal distractor for tamarins. However, large individual differences in foraging suggest that other factors may have a larger impact on foraging than the anthropogenic noise used in this experiment. More research into how captive animals may respond to the presence of anthropogenic noise is needed.

1. Introduction

Human-induced rapid environmental change (HIREC; Sih et al., 2016) is a modern-day phenomenon, arising from population growth, urbanisation, and industrialisation. Under the umbrella of HIREC, habitat loss and fragmentation, climate change and various forms of pollution can compromise the fitness and behaviour of animals at a

greater rate than they have previously experienced or have the cognitive flexibility to overcome (Greggor et al., 2019). Anthropogenic (human-generated) noise, defined as unwanted, unpleasant, or non-functional sound (Clark and Dunn, 2022; McKenna et al., 2016), is an integral part of HIREC (Antrop, 2009) that can negatively affect the health and well-being of humans (Goines and Hagler, 2007; Jariwala et al., 2017) and other animals (Kunc and Schmidt, 2019; Slabbekoorn,

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2019). Impacts on animals can include the masking of biologically relevant information, distracting attention away from performing behaviours important for fitness and survival, causing negative stress (distress), and disrupting a number of important physiological processes (Barber et al., 2010; Luo et al., 2015; Wale et al., 2013).

Over the last decade, the effect of anthropogenic noise on animal behaviour, welfare and conservation have gained more interest (Harding et al., 2019) and to date, noise has been shown to adversely affect foraging in a range of free-living taxa, including bats (Bunkley and Barber, 2015; Finch et al., 2020; Luo et al., 2015), mongooses (Kern and Radford, 2016), birds (Injaian et al., 2018; Francis et al., 2011; Senzaki et al., 2016), fish (Hawkins et al., 2014; Mills et al., 2020; Payne et al., 2015) and primates (Duarte et al., 2011). Noise can detrimentally impact an animals' foraging behaviour in different ways. Firstly, loud anthropogenic noise can distract and shift an animal's attention from key tasks such as foraging, and towards vigilance or defence (Chan et al., 2010; Kern and Radford, 2016; Le et al., 2019; Shannon et al., 2014). Second, because foraging involves several cognitive processes to detect, classify and make decisions related to food (Evans et al., 2018; Shettleworth, 2010), distraction also impacts cognitive processes, leading to slower and/or less accurate foraging (Bunkley and Barber, 2015; Payne et al., 2015; Quinn et al., 2006; Senzaki et al., 2016). Furthermore, anthropogenic noise can induce an avoidance response in which animals avoid and/or spatially distance themselves from the noise source (Francis and Barber, 2013; Kok et al., 2018; Proppe et al., 2013; Schaub et al., 2008).

Given that anthropogenic noise is also often a factor in captive environments and animals cannot escape the noise generated in captivity, it is incongruous that the vast majority of research has taken place on free-living wildlife and there is a clear gap in captive animal research. In captive environments, animals are consistently exposed to a variety of sounds including visitor noise, ground maintenance such as gardening machinery and construction events, traffic, etc. Moreover, these sounds can vary in intensity (i.e. quiet vs. loud), duration (i.e. seconds vs. months or years), predictability (i.e. regularly vs. sporadically) and novelty (i.e. visitors vs. construction events). Previous studies have shown that noise can cause stress responses in several animals (Birke, 2002; Powell et al., 2006; Sulser et al., 2008).

However, the limited studies on the effect of anthropogenic noise on captive animals often suffer from methodological problems. Clark and Dunn (2022) recently highlighted several salient issues with noise measurements in captive research, including a predominant research focus on measuring decibels (dB) rather than trying to assess how an animal might perceive noise. Clark and Dunn (2022) also drew attention to studies investigating what has been termed the 'visitor effect'; in other words, the overall effect of visitor presence in facilities such as zoos, rather than the effect of noise as a potential stressor in its own right (Hosey, 2000; Rose et al., 2020; Sherwen and Hemsforth, 2019). Overall, a more thorough understanding of anthropogenic noise is needed to inform best practices in captive husbandry and welfare.

The pied tamarin (*Saguinus bicolor*) is a highly sensitive callitrichid primate species that has historically struggled in captivity (Armstrong and Santymire, 2013; Richards-Rios et al., 2021). It shows a highly activated physiological and behavioural distress response, chronic physical health problems, and poor breeding success (Lopez et al., 2001; Morgan, and Tromborg, 2007; Wormell et al., 1996). Wild pied tamarins live in forested areas in and around the city of Manaus, Brazil (Gordo et al., 2013) which is one of the fastest-growing cities in the Amazon basin (Ramos et al., 2018). For this reason, HIREC has left the pied tamarin with the smallest range of any Amazonian primate (~7500 km²) (Gordo et al., 2013), which is also highly impacted by noise (Farias et al., 2015; Gordo et al., 2013). Studies on the hearing capabilities of pied tamarins are lacking, however audiograms of other related South American primate species (including the common marmoset (*Callithrix jacchus*) (Osmanski and Wang, 2011), squirrel monkey (*Saimiri sciureus*) (Beecher, 1974a)) and owl monkey (*Aotus trivirgatus*) (Beecher, 1974b)

show a hearing sensitivity from around 100 Hz to over 30 kHz (Osmanski and Wang, 2011) Therefore, a similar hearing range is expected of the pied tamarin. Moreover, pied tamarins, like other callitrichids, have a large vocal repertoire (with 12 distinct calls, ranging from 2 to 11 kHz; Sobroza et al., 2017) making the acoustic environment an important element of their ecology.

In the current study, we undertook the first known investigation of captive pied tamarin foraging behaviour under experimentally induced anthropogenic noise. We presented tamarins with a naturalistic foraging task involving cryptic prey items that would require effort to find. Broadly, we hypothesized that anthropogenic noise would serve as an environmental distractor (thus disrupting the cognition and behaviour involved in foraging) and/or a negative stressor. We thus predicted that anthropogenic noise would reduce foraging frequency and total duration, reduce foraging success and tamarins would shift to more vigilance behaviour.

2. Materials and methods

2.1. Subjects

The study took place at Jersey Zoo, British Channel Islands. Out of a total population of 34 individuals at the zoo, 20 individuals were selected to participate in this study (Table 1). Only pied tamarins that were housed as single-species pairs were studied in order to keep consistency in the experimental design. Pairs comprised six mixed-sex non-breeding pairs and four same-sex pairs in five different locations (including two on-show and three off-show locations). One individual's physical health declined during the study and so trials were ceased for one pair after the first four trials. In order to commit to the STRANGE framework proposed by Webster and Rutz (2020), which encourages animal cognition and behaviour and cognition researchers to identify potential biases in their study populations, Table 1 provides information on age, sex, and rearing history for all subjects. Further subject information held by Jersey Zoo can be requested from the study authors.

2.2. Housing and husbandry

All pairs of pied tamarins were housed in callitrichid buildings. A building consisted of three identical, adjacent enclosures of which pied tamarin pairs were only housed in the end enclosure with the middle

Table 1
Detailed information about study subjects.

Pair	Individuals	Sex	Rearing	Age (years)	Location
1	F1	F	Parent	17	On-Show location 1, Free ranging
	M1	M	Parent	11	
2	F2	F	Hand	11	Off-Show location 1, Building 1
	M2	M	Parent	13	
3	F3	F	Parent	11	Off-Show location 1, Building 1
	M3	M	Parent	11	
4	F4	F	Parent	15	Off-Show location 1, Building 2
	M4	M	Parent	15	
5	F5	F	Parent	17	Off-Show location 2, Building 1
	M5	M	Parent	23	
6	F6	F	Parent	7	Off-Show location 2, Building 1
	M6	M	Parent	17	
7	F7-1	F	Parent	17	Off-Show location 2, Building 3
	F7-2	F	Parent	13	
8	F8-1	F	Parent	19	Off-Show location 2, Building 3
	F8-2	F	Parent	7	
9	M9-1	M	Hand	11	Off-Show location 3
	M9-1	M	Hand	11	
10	M10-1	M	Parent	7	On-Show location 2
	M10-1	M	Parent	7	

Age was rounded to the nearest whole year. On-show refers to being on display to the visiting public. Off-show groups were in private areas of the zoo.

enclosure either being empty or occupied by a different callitrichid species. Each enclosure consisted of an indoor (average of 18 m³) and an outdoor area (average of 68 m³) connected by a small, 0.5 × 0.5 m sliding door, which could be locked by keepers. Throughout the year, animals had access to the outdoor areas at all times during the day (08:00–16:30), but the sliding door was shut overnight, and animals were kept indoors. The indoor areas were equipped with a nest box, feeding platform, and several wooden planks, ladders and ropes for perching. The outdoor areas had a variety of plants and were equipped with natural branches for perching, tree trunks, and ropes. The tamarins' diet consisted of a mix of commercial pellets, fruit and vegetables, and a variety of live insects. Food was provided in bowls and live insects were scattered on their food platforms. Tamarins were fed three times a day (08:30, 12:00 and 16:00). The main cleaning and husbandry routine occurred in the morning (between 08:00 and 11:00).

2.3. Experimental device

The forage box consisted of a black plastic box (dimensions: 380 mm long, 240 mm wide and 55 mm deep) filled with 1400 ml of unbleached wood shavings as the foraging substrate and 14 live waxworms as the cryptic prey item, scattered randomly throughout. Wood shavings were the normal enclosure flooring substrate and waxworms were a component of the normal diet, therefore limiting a strong novelty response or potential for injury or harm. Two 5 mm holes were drilled into the wall of the forage box so it could be secured onto the feeding platform in the enclosure using plastic cable ties.

2.4. Noise playback

As an anthropogenic noise stimulus, we recorded gardening machinery noise, more specifically the sound of a hand-operated hedge-cutting machine. This noise already occurred around the zoo every few months due to ongoing maintenance, and was thus intended to be a brief, mild to moderate stressor. Moreover, gardening machinery is a low frequency broadband noise and therefore within the hearing range of callitrichids and audible to the tamarins. The original recording was made in and around the zoo at a sampling rate of 44.1 kHz with a 16-bit resolution, using a linear PCM Tascam DR40 recorder (TEAC Corporation, Tokyo, Japan) and a handheld Shot Gun Microphone (Rode, Silverwater, Australia) with a windshield. The acoustic stimulus was recorded from a 1–2 m horizontal distance away from the source (a gardener cutting a hedge) and saved as .wav files. The recorded sound files were then edited (including cutting and splicing) with Audacity (Audacity® version 3.0.2) to produce a file of constant hedge-cutting noise (.wav file) lasting 20 mins. The sound file was purposely made 20 mins to allow the sound stimulus to run for a short time before and after each trial so that the noise did not abruptly start or end during trials. As a final step, the sound file was manipulated to include a 30 second fade-in period to avoid startling the animals with an abrupt change in noise (Wale et al., 2013).

An appropriate sound pressure level for the playback experiments was determined beforehand. Since we dealt with a critically endangered and very sensitive species, noise intensity had to be within 'natural' and therefore acceptable levels. Therefore sound pressure level (SPL) measurements taken 2 m away from naturally occurring gardening noise (mainly hedge cutting) around the zoo revealed noise intensity levels of 70–75 dB. When this occurred at the same distance and decibel levels outside the enclosure, SPL measurements of noise intensity levels inside the pied tamarins' building translated to 45–50 dB levels. For the experiments, the speaker was therefore set to play the sound files inside the buildings at 45–50 dB during noise trials to represent 'normal' noise levels of gardening noise perceived inside the building. Sound intensity was calibrated before each experiment and an SPL meter (Precision Gold NO5CC Sound Level Meter, Maplin Electronics Ltd, Rotherham, UK) was used during trials to maintain the appropriate dB level. Noise was played

through a portable Bluetooth speaker (Wonderboom, Ultimate Ears, Irvine, USA) inside the building in the keeper corridor in front of the empty middle enclosure, which was approximately 2–3 m from the study subject's enclosures. To ensure that the visibility of the speaker did not cause any behavioural changes, it was also present during the non-noise trials but was switched off.

2.5. Trial setup and procedure

Trials took place between 13th November and 12th December 2021 and were filmed with a HD action camera (GoPro Hero 5, California, USA). The camera was secured onto a tripod and placed next to the speaker and focused on the forage box (at approximately 150 cm vertical height). The camera was positioned slightly above the forage box and angled downwards to create a narrow-angle view for optimal behavioural observation of foraging behaviour.

All trials were conducted between 13:00 and 15:00. Throughout a trial, animals could move freely around enclosures including the inside and outside area. The experimenter set up all playback and recording equipment (speaker, tripod, and camera) quickly before a trial (set up took less than five min). Subjects were motivated by a small reward to move to a side compartment of the main enclosure using a small food reward and temporarily shut into this while the forage box was secured in place. In some cases, it was not possible to move animals, so the box was secured while the animals were in the enclosure. In these cases, the top of the forage box was obscured with a sheet of white paper while being secured. For the noise condition, the noise playback started before the animals were moved (roughly three min before), then the forage box was put into place; this was to avoid startling the animals at the beginning of the trial. Once the box was secured, either the animals were let back into their main enclosure, or the obscuring paper was removed and the experimenter moved in front of the empty middle enclosure and remained quiet and still to cause as little distraction as possible. After about 12 min (allowing for some extra time in case the tamarins did not approach the forage box straight away) the volume of the playback was gradually reduced over a period of 30 s to silence.

A total of eight trials, including four non-noise and four noise trials were conducted on each of the 10 pairs of tamarins. A within-subject design was used so all pairs were exposed to both conditions. The order of the two conditions was randomized without replacement between pairs using a random number generator. Some tamarin enclosures were housed in the same building, so in order to prevent over-exposing these subjects to the noise condition; both pairs were tested simultaneously using the same playback. Because the speaker was always located in front of the middle enclosure, dB levels for each pair at either end of the enclosure were the same. Every pair participated in only one trial per day. For practical reasons, pairs were trialled two batches (Batch 1 = Pair 1, 2, 3, 4, 7 & 8; Batch 2 = Pair 5, 6, 9 & 10). Trials took place every day or every-other day, with exceptions depending on working schedules and husbandry needs.

2.6. Behavioural data collection and coding

Continuous behaviour sampling (Altmann, 1974) was used to capture both behavioural states and events (Table 2) and coded from video recordings with BORIS software version 7.12.2 (Friard and Gamba, 2016). Behaviour coding was done separately for each individual. Although the pied tamarins had access to the forage box during the trial for 12 min, we only looked at 10 min trial duration starting when the first subject in the pair actively approached the forage box. Only behaviours related to foraging were analysed, including: 1) active foraging; 2) observational foraging; 3) vigilance; 4) presence at the forage box; 5) foraging success (number of waxworms eaten per individual per trial) (Table 2). The frequency (number of occurrences of a behaviour per the 10 min trial period (count)) and total duration (total length of time of all occurrences of a behaviour over the 10 min trial

Table 2

A description of the state and event behaviours relevant for this experiment.

Behaviour	Description
State behaviours	
Actively foraging	Actively searching through the box using one or both hands
Observational foraging	Gazing directed towards/into the forage box (without the use of hands). This includes watching the partners' foraging activity
Vigilant	Visually scanning the surroundings, head pointed horizontal, upwards or onto the ground. Importantly the gaze is directed out of the forage box
Presence	The time an animal spend at the box gathered by the "approaching" and "leaving" of an individual
Event behaviours	
Foraging success	Retrieving a wax worm (either by use of hands or directly by mouth) is counted as a success

Behaviour of an individual was only coded when it was (at least) in touching distance of the forage box. This means that the individual had to be able to reach onto or into the forage tray with one continuous movement.

period (sec)) was calculated for all but for foraging success. As foraging success is an event behaviour only the frequency was calculated.

To reduce observer bias, coding was done blind to condition (noise and non-noise condition), with trials coded in random order and sound muted. A subset (10 %) of the trial recordings were independently viewed and coded by a second observer and checked for inter-observer reliability using the Cohen's Kappa Coefficient computed by the coding program BORIS. This resulted in an average $K = 0.76$, which according to McHugh's (2012) agreement percentage represents moderate agreement.

2.7. Statistical analyses

All analyses were performed using R version 3.5.3 (R Core Team, 2013). Generalised Linear Mixed Models (GLMMs) in the lme4 package (Bates et al., 2014) analysed whether there was an effect of noise condition on foraging behaviours. Two metrics, total duration and frequency, of each behaviour were individually analysed as the dependent variable in separate models. A Gaussian model was used for duration data and a Poisson model for count data (Harrison et al., 2018). All possible explanatory terms were included in a global model, including the fixed effects of noise condition (noise/non-noise condition), subject sex, age, and group composition (single/mixed sex). Trial and subject ID nested within pair and location were included as random effects. Visual examination of residual plots was performed to verify model assumptions of normally distributed data and heteroscedasticity. From the global model, a stepwise backward elimination procedure was used to simplify the model. After model comparison using ANOVA likelihood ratio tests, the removal of model terms did not significantly improve the model, resulting in the global model being the most appropriate model. In addition, the MuMIn package (Bartoń, 2009) was used to calculate conditional R^2 and marginal R^2 values to provide more information on the model variation. The conditional R^2 values describe variation explained by fixed factors and random factors, whereas the marginal R^2 values describe variation explained by fixed factors only (Johnson, O'Hara, 2014).

2.8. Ethical note

This study underwent ethical review by Durrell Wildlife Conservation Trust (#ETH19/1112, received 21/01/19) and Anglia Ruskin University (FREP/SREP number: A&EB DREP19-126, received 09/12/19). All subjects were housed under their normal conditions, were not deprived of food or water, and moving animals between enclosure compartments is part of their normal daily husbandry routine.

3. Results

3.1. Overall effect of noise

A total of 76 trials (including 38 noise and 38 non-noise trials) were conducted with 10 different pairs of pied tamarins. The frequency of both metrics of foraging (active and observational) was significantly lower during noise conditions than non-noise conditions (Table 3, Fig. 1). The total duration of both foraging types, however, did not significantly differ between the conditions (active foraging: $X^2 = 1.486$, $p = 0.140$; observational foraging: $X^2 = 0.746$, $p = 0.457$) (see Table S2). No significant differences were found between noise conditions for vigilance, presence at the forage box, or foraging success (see Table S1 and S2).

3.2. Individual differences in foraging and habituation

A descriptive analysis of the data showed that there were individual differences in behaviour between noise and non-noise conditions. Individuals showed differences in their behavioural response to noise, some increasing and some decreasing their foraging duration/frequency with different levels of change between conditions Fig. 1. In addition, looking at the model variation, the conditional (variation explained by fixed and random factors) and marginal R^2 (variation explained by fixed factors) showed that the random factors (conditional R^2 minus marginal R^2) explained on average 65.2 % and 57.7 % of the variation for the GLMMs for frequency and total duration respectively (for specific values see Table 3 and Table S1 & S2).

Besides individual differences between noise conditions, there was

Table 3

Outputs of a generalized linear mixed models (GLMM) of the global model investigating pied tamarin foraging frequency in noise ($N = 4$ trials) and non-noise ($N = 4$ trials) conditions of background (gardening) noise. Significant terms are shown in bold.

	Fixed effect	Effect +/- SE	X^2	p
(1) Behaviour Count of Actively Foraging in the Tray				
Model	(Intercept)	2.118 ± 0.480	4.535	0.000
	Noise	0.081 ± 0.033	2.436	0.015
	Sex	0.104 ± 0.247	0.421	0.674
	Age	0.052 ± 0.030	1.748	0.081
	Group Composition	0.208 ± 0.262	0.796	0.426
Random terms	Individual ID nested in pairing, nested in location	0.292 ± 0.541		
	Trial	0.000 ± 0.009		
	<i>Marginal R^2 / Conditional R^2</i>	<i>12.5 % / 89.3 %</i>		
(2) Behaviour Count of Observational Foraging in the Tray				
Model	(Intercept)	2.561 ± 0.339	7.545	0.000
	Noise	0.067 ± 0.032	2.087	0.037
	Sex	-0.009 ± 0.175	-0.052	0.959
	Age	0.033 ± 0.021	1.568	0.117
	Group Composition	0.352 ± 0.185	1.898	0.058
Random terms	Individual ID nested in pairing, nested in location	0.145 ± 0.381		
	Trial	0.001 ± 0.033		
	<i>Marginal R^2 / Conditional R^2</i>	<i>22.7 % / 82.3 %</i>		

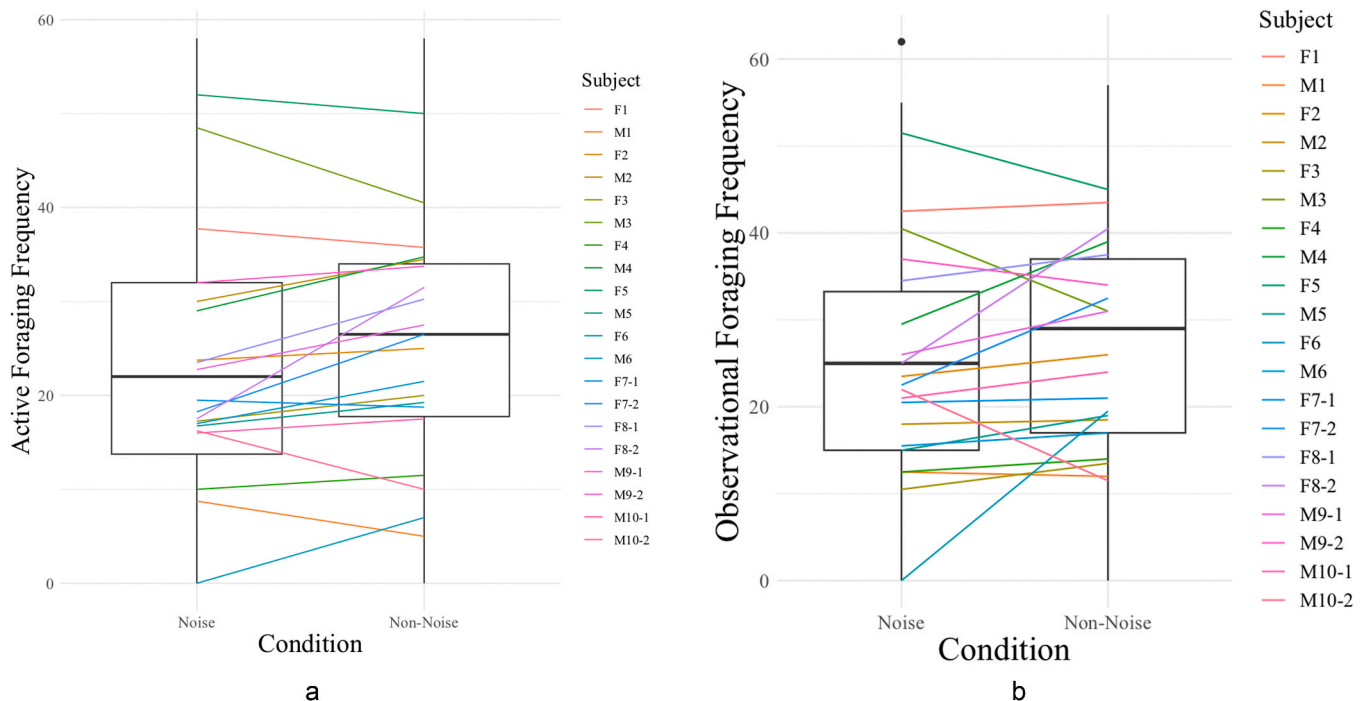


Fig. 1. Response of pied tamarins to noise (N = 4 trials) and non-noise (N = 4 trials) conditions of background (gardening) noise. (a) Active foraging frequency, and (b) observational foraging frequency. Each line represents the mean value for an individual pied tamarin (subject) for each treatment. The overall treatment average mean is represented by a box and whisker ± 1 SE.

also some variation in foraging by age. Age was significant in the models for foraging success and total duration of presence foraging in the forage box (see [Supplementary table](#)). The total duration of presence in the forage box and foraging success increased with age. Foraging success reaches its peak at the age of 17 years and then decreases with reduced foraging success showing at age 19 and older (see [Fig. 2](#)). We found no evidence of habituation to the forage box over time. Visual inspection of active foraging over the eight trials showed no obvious change in the duration of time spent at the forage box over the experimental period

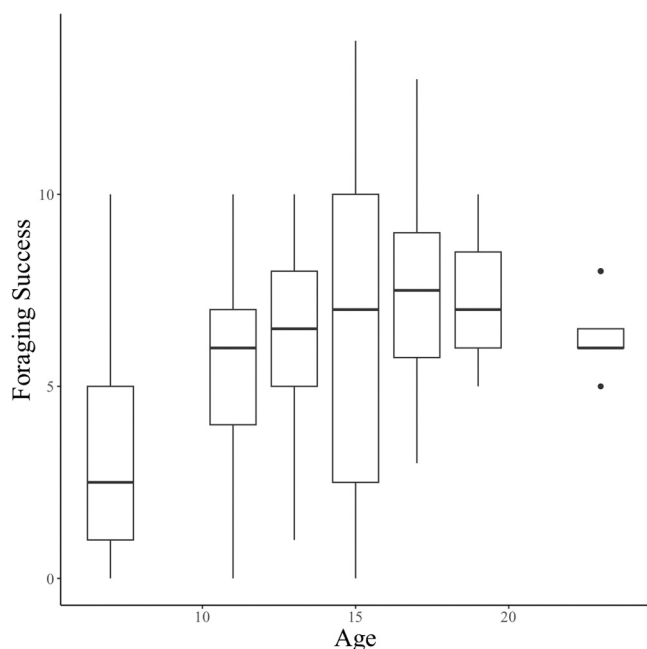


Fig. 2. Foraging success by age over all trials. The overall age average is represented by a box and whisker ± 1 SE.

(see [Fig. S3](#)).

4. Discussion

In this study, we tested the impact of anthropogenic noise on zoo housed pied tamarins foraging behaviour. We found that the noise of gardening machinery significantly reduced both active and observational foraging frequency, but not the total duration of foraging. Our predictions of reduced foraging success and increased vigilance were not supported by our results. Moreover, we found a significant increase in the total duration of presence in the forage box and foraging success with age. Our results also indicated individual differences in their behavioural response to noise.

4.1. Overall effect of noise

4.1.1. Foraging frequency and duration

Previous studies have shown that noise can affect animals' foraging behaviour in different ways ([Bunkley and Barber, 2015](#); [Kern and Radford, 2016](#); [Chan et al., 2010](#); [Luo et al., 2015](#)). The most obvious way is to reduce foraging activity. Our results showed that pied tamarins forage significantly less frequent in the presence of anthropogenic gardening noise and therefore supports this hypothesis. Similar to a study by [Wale et al. \(2013\)](#) on the effects of anthropogenic noise on foraging behaviour in crustaceans, there was however no significant difference in total foraging duration between the two noise conditions. Shore crabs (*Carinus menas*) were significantly more disturbed during their feeding behaviour in the presence of ship noise compared to ambient noise conditions but, similar to our results, the overall foraging duration did not change ([Wale et al., 2013](#)).

4.1.2. Vigilance

Previous research has shown that noise can cause a shift in attention away from key behaviours such as foraging, towards vigilance or other defence behaviours. A behavioural shift in the presence of noise (traffic playback) has been found in several wild studies on small terrestrial

mammals, including dwarf mongooses (*Helogale parvula*) (Kern and Radford, 2016), ground squirrel, (*Otospermophilus beecheyi*) (Le et al., 2019), and prairie dogs (*Cynomys ludovicianus*) (Shannon et al., 2014). Pied tamarins are small arboreal primates with a wide variety of predators (e.g. snakes, wild cats and birds of prey; Ferrari, 2009), so we predicted a similar behavioural shift, but failed to find this result. Although we did observe less active and observational foraging in the presence of noise, we did not observe an increase in vigilance. Previous research on saddleback tamarins (*Saguinus fuscicollis*) and moustached tamarins (*Saguinus mystax*) had concluded that the predominant function of vigilance is to detect predators (Smith et al., 2004). Anthropogenic noise, such as gardening noise, may not replicate predator presence and present a danger, and therefore might not have elicited vigilance.

Dealing with such a sensitive and critically endangered species in captivity meant that extra care had to be taken in our study and the right balance between novelty, familiarity and intensity of the noise stimulus had to be found. Therefore a less familiar, louder, or different anthropogenic noise stimulus might have evoked different or stronger responses and thus showed clearer results (Robbins and Margulis, 2014). Future research needs to be carried out to fully understand whether the responses of captive tamarins differ from those of wild pied tamarins, in which anthropogenic noise might be more novel and unpredictable. This may be highly relevant to conservation and management as the range of wild pied tamarins is centred around the metropolis of Manaus with about two million inhabitants, and therefore its acoustic environment is permeated by anthropogenic noise (Gordo et al., 2013). However, the areas the species occupies are diverse, ranging from small forest fragments within the city to continuous forest further away. A comparative study under these different conditions (including captivity) would allow for stronger conclusions about the effects of noise on pied tamarins.

4.1.3. Foraging success

The cognition involved in foraging involves many components, including food detection, classification, problem-solving (such as involved in the extraction of food from substrate) and decision-making (Luo et al., 2015; Shettleworth, 2010). We predicted that noise would distract the tamarins from the actual foraging task, thereby impacting cognition and overall foraging success. Reduced foraging efficiency and success in the presence of anthropogenic noise has been shown in several previous studies. For example, three-spined sticklebacks (*Gasterosteus aculeatus*) displayed more food-handling and food-discrimination errors in the presence of noise (Purser and Radford, 2011). In an experimental study on greater mouse-eared bats (*Myotis myotis*) Siemers and Schaub (2011) observed decreased foraging success (i.e., number of successful foraging bouts) during the presence of noise compared to silent conditions. However, our results did not support the prediction of reduced foraging success because pied tamarins found similar numbers of waxworms per trial in both conditions. Although we are aware that pairs were tested together and therefore social facilitation was possible (meaning the presence of one partner could have influenced engagement, motivation, and therefore foraging success; Koski and Burkart, 2015), social pairing is normal for pied tamarins, so it is biologically relevant to test them like this, both in captivity and in the wild.

One explanation for there being no effect of noise on foraging success in our study might be that captive animals have a greater familiarity and thus lower sensitivity level to anthropogenic noise. All study subjects had lived at Jersey Zoo their entire life (ranging from 7 to 22 years) and therefore may have simply habituated to gardening noise, a sound that frequently occurs at the zoo. In a study on mood changes in zoo housed primates exposed to anthropogenic noise (Cronin et al., 2018), subjects who had lived in the zoo longer were less affected by noise. Zoo animals may habituate to noises that occur frequently and therefore represent a 'familiar' acoustic environment (Bejder et al., 2009). This is in line with our results regarding foraging success and total duration of presence in the forage box, both of which increased with age.

4.1.4. Noise avoidance

Spatial avoidance of noise is a coping mechanism that has been documented in a range of species (Francis et al., 2009; Kok et al., 2018; Proppe et al., 2013; Schaub et al., 2008). For example, a study on wild urban callitrichids in Brazil showed that black-tufted marmosets avoided relatively louder areas (Duarte et al., 2011). It was not possible to perform a valid assessment of noise avoidance in our study. Due to the design of the tamarin enclosures, it was neither possible to create a very focal (concentrated) noise source paired to the forage box, or alternatively to fill the entire enclosure with the noise. Therefore, it is not possible to confidently evaluate whether tamarins in the study were avoiding the noise source *pe se*, noise source itself, or the forage box *pe se*.

We have some tentative thoughts about noise avoidance given that subjects could move to the back or outside areas of their enclosures or even retreated to their nest box. A recent study by Wark et al. (2022) modified the acoustic environment of the on- and off-show areas of the enclosure of a pair of zoo housed pied tamarins. When one area was loud (ambient noise in the on-exhibit area with loud noise from the on-site waterfall feature) and the other quiet (ambient noise in the off-exhibit area only), the pair spent significantly more time in the quieter area. In comparison, when both areas were either quiet or loud, there was no difference. Therefore, when given the choice pied tamarins actively avoid noisy areas.

Unlike Wark et al. (2022) we observed no significant differences in the frequency and total duration of presence at the forage box between the two noise conditions. It is important to note that Wark et al. (2022) only studied one pair of pied tamarins and thus had a very small sample size. Another major difference between the studies is the involvement of food. Thus, the motivation and reward of finding food may outweigh the cost of staying in a potentially more stressful environment. Although waxworms were part of the daily diet of the pied tamarins housed at Jersey Zoo, they are also considered a high value food item (personal comment, Dominic Wormell). Therefore, their motivation to forage might have outweighed the costs and potentially overshadowed the effects of the noisy environment. Giving subjects a foraging task with high-value food items can potentially be an enriching management tool to help the animals handle more stressful situations such as a noisier acoustic environment.

In comparison, the wild study on callitrichids living in an urban park showed that animals avoided louder areas even if these were areas of higher food availability (Duarte et al., 2011). However, Duarte et al. (2011) also noted the difference between high availability and high value and concluded that higher food availability does not compensate for the fact that low availability patches had highly valued food. Future studies may explore a similar experimental paradigm to ours, while also varying the value of the food provided in the foraging task. This may help disentangle the interaction between the impacts of noise and the motivation to forage for foods including foods of differing qualities.

4.2. Individual differences in foraging

Our results suggest that there were large individual differences amongst the pied tamarins in their response to noise. This might be caused by their individual personalities and temperaments, thus differential coping strategies towards novelty and/or a stressor (Coleman, 2012; Gottlieb et al., 2018; Ferreira et al., 2018). This is something that has not yet been studied in pied tamarins, and very little in callitrichids in general, with the majority of research being conducted on marmosets (Inoue-Murayama et al., 2018; Iwanicki and Lehmann, 2015; Masilkova et al., 2020; Weiss et al., 2021). Going forwards, we also suggest that an increased sample size (which would have to involve data collection at other zoos) will help to elucidate the role of individual variation in noise responses.

5. Conclusion

To our knowledge, this is the first study investigating the effect of noise on foraging behaviour in captive pied tamarins. We showed that the anthropogenic noise tested (gardening machinery noise) had only a modest effect on pied tamarins' foraging behaviour. Moreover, this study shows that possible modifications to the study design, such as the choice of food item or noise stimulus, might show clearer results on the effect of noise. Given that gardening noise reduced the pied tamarin foraging frequency we recommend limiting garden activity during key feeding times for pied tamarins. However, more research is needed on the effect of different sources of anthropogenic noise, in general as well as on foraging behaviour, in order to understand the possible practical implications of anthropogenic noise on zoo animals and pied tamarins specifically. As the pied tamarin is a critically endangered species and one that is prone to poor physical health and breeding in captivity, resilience in the captive population is critical for the future conservation of this species.

Credit authorship contribution statement

Fiene Steinbrecher: study design, data collection, data analysis and drafting/reviewing the manuscript. **Jacob Dunn:** study design, data analysis and revising the manuscript. **Claudia Wascher:** study design, data analysis and revising the manuscript. **Eluned Price:** study design, data analysis and revising the manuscript. **Fay Clark:** study design, data analysis and drafting/reviewing the manuscript. **Lisa Buck:** data collection, revising the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.applanim.2023.105989](https://doi.org/10.1016/j.applanim.2023.105989).

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