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Cross-modal impacts of anthropogenic noise on information use

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Anthropogenic noise is a global pollutant, and there is rapidly accumulating evidence of impacts on a range of animal taxa [1,2]. While many studies have considered how additional noise may affect information provision and use, they have focused on the masking and consequent alteration of acoustic signals and cues; so-called unimodal effects [3]. Using field-based experimental trials on habituated wild dwarf mongooses (*Helogale parvula*) [4], we combine sound playbacks and faecal presentations to demonstrate that anthropogenic noise can disrupt responses to information from different sensory modalities. The adaptive, stronger response exhibited towards predator faeces compared with control faeces in ambient-noise conditions was detrimentally affected by road-noise playback. Specifically, having taken longer to detect the faeces, the mongooses interacted less with the predator cue, did not show increased vigilance following its detection, and spent less time in the safe vicinity of a burrow refuge, thus suffering a potentially increased predation risk. Our results are the first to show that anthropogenic noise could alter responses to olfactory cues, strongly indicating the possibility of cross-modal impacts of noise pollution on information use [3].

Many prey species respond to secondary predator cues, such as urine and faeces, with inspection and over-marking, increased vigilance, reduced feeding and changed habitat use [5]. To investigate whether anthropogenic noise disrupts responses to a secondary predator cue, we conducted a 2x2 repeated-measures experiment on dwarf mongooses in their natural habitat. Dwarf mongooses are threatened by a wide variety of predators [4]; they also have well-developed olfactory-based communicative abilities [6]. In a given trial, either predator or herbivore (control) faeces were placed near the overnight sleeping burrows of groups that had been habituated to the close presence of observers [4,6], and the behaviour of the mongooses on emergence was monitored during playback of either ambient or road noise (see Supplemental Experimental Procedures).

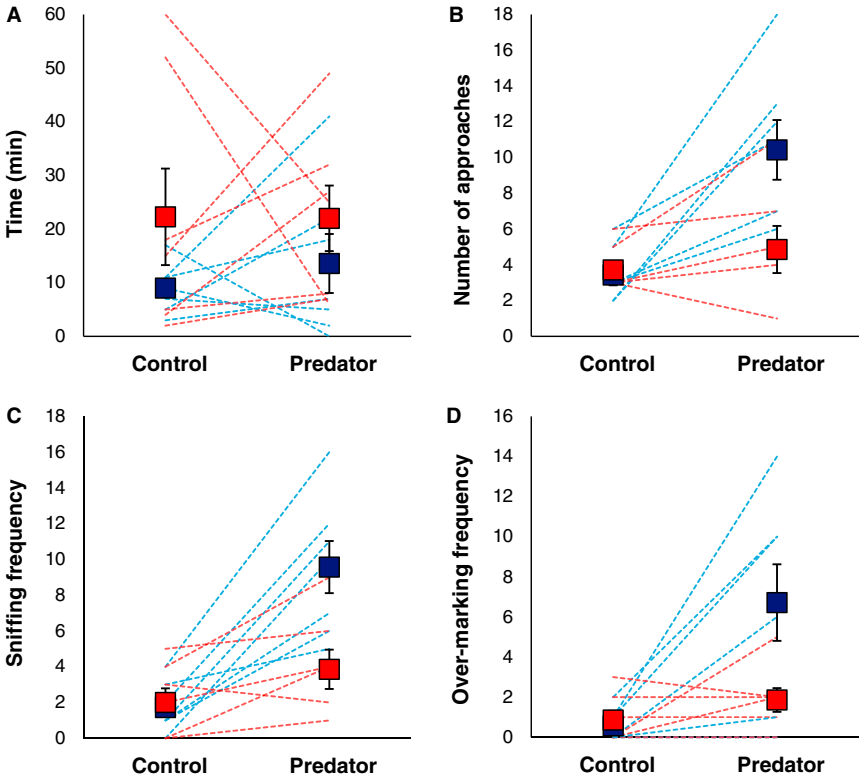

Figure 1. Responses of dwarf mongooses to predator and herbivore (control) faeces during ambient-noise and road-noise playback.
(A) There was a strong trend for sound treatment to affect the time to first approach for both types of faecal presentation. Subsequent interactions with the faeces were affected by the interaction between faecal type and sound treatment, with predator faeces eliciting (B) more approaches, (C) sniffing and (D) over-marking than herbivore faeces in ambient-noise trials but not road-noise trials. Shown in all cases are results for each mongoose group separately (dotted lines; n = 7, although data values for some groups are the same, thus the number of dotted lines can appear less than 7) and the overall treatment mean (solid squares) ± SE (solid squares overlap in some cases). Values for ambient-noise playback trials are given in blue and those for trials in road-noise playback are given in red.

We found a strong trend for the dwarf mongooses to take longer to approach the faecal presentations when experiencing road-noise playback compared with ambient-noise playback (LMM: $\chi^2_1 = 3.672$, p = 0.055; Figure 1A) but no significant effect of faecal type (Table S1). Once the first mongoose had approached the faeces, subsequent behaviour by the group was significantly influenced by the interaction between sound treatment and faecal type. During ambient-noise playback, mongooses were more likely to approach (interaction term, LMM: $\chi^2_1 = 6.910$, p = 0.009; Table S1b; Figure 1B), sniff (GLMM: $\chi^2_1 = 5.487$, p = 0.019; Table S1; Figure 1C) and over-mark ($\chi^2_1 = 5.675$, p = 0.017; Table S1; Figure 1D) predator faeces compared with herbivore faeces; these differences were not seen during road-noise playback. While approaching behaviour could result from visual or olfactory cues, sniffing and over-marking are most likely responses to the olfactory information [5].

One previous study has shown how anthropogenic noise can affect signalling in another sensory modality: common cuttlefish (*Sepia officinalis*) adjusted their visual displays by colour changing more frequently during ship-noise playback compared with before and after playback [7]. Recent research using looming

stimuli has suggested that noise could also potentially disrupt the use of visual information [8,9]. However, those latter experimental paradigms cannot generally rule out the possibility that the stimulus had some associated auditory cue that was masked. By using faecal samples, which definitely do not provide an acoustic cue, we offer strong evidence that additional noise can negatively influence responses to information from other sensory modalities.

In our experiment, vigilance behaviour following faecal detection (LMM: χ^2_1 = 5.733, p = 0.017; Table S1) and time spent at the burrow before commencing foraging (χ^2_1 = 8.517, p = 0.004; Table S1) were also significantly affected by the interaction between sound treatment and faecal type. In ambient-noise trials, mongooses were more vigilant in response to predator compared with herbivore faeces, but this was not the case during road-noise playback when vigilance levels were elevated in both faecal treatments (Figure S1A). Anthropogenic noise has previously been shown to increase vigilance, either because it is viewed as a threat or because the likelihood of masking acoustic cues leads to an increased reliance on visual information [10].

In ambient-noise trials, mongooses spent longer near the burrow in response to predator compared with herbivore faeces, but this response was reversed during road-noise playback (Figure S1B). It is possible that predator faeces and road-traffic playback individually represent sufficient threat to cause increased time spent near the safety of the burrow, but that their combination is even more stressful and causes fleeing from the area; these complementary stresses may induce a classic flight-or-fight response. Increased interaction with predator faeces, increased vigilance following their detection and longer spent near the burrow in response to predator cues likely result in greater information gathering about the current risk level, likelihood of detecting any nearby predator, and chances of fleeing safely to a refuge if an attack occurred [5]. The disruption of this adaptive anti-predator behaviour means that anthropogenic noise therefore has the potential to increase predation risk, although it is important to point out that the effects of additional noise on predators must also be considered to assess fully the fitness and community-level consequences [8].

Distraction may explain at least some of our results, such as the longer latency until first approach of the faeces and the decreased subsequent levels of interaction with the predatory faeces when there is additional noise. While distraction is often proposed as a potential mechanism for an impact of anthropogenic noise, masking can only be convincingly ruled out if there are definitely no acoustic cues associated with the relevant stimulus [9]. Faecal cues do not have associated sounds, and the dwarf mongooses did not produce vocalisations on discovering predator faeces (data not shown). Distraction is unlikely to explain some of our results, such as the decreased time spent near the safety of the burrow. Instead, it is possible that noise leads to increased stress (see [8] and references therein), which in turn affects the collection and processing of information and subsequent decision-making.

In summary, our experiment adds to a small body of research indicating that anthropogenic noise can negatively affect behaviours fundamental to survival [8,9]. Our current work represents the first step in understanding the impacts of anthropogenic noise on individual fitness in dwarf mongooses, offering a rare experimental investigation of mammalian responses in this regard (see [1,2] for taxonomic biases in anthropogenic-noise research). What needs to be studied next is whether mongoose responses to anthropogenic noise change over time, since their territoriality makes it unlikely they will move away from the source [6]; consideration of alterations in tolerance with repeated exposure are generally needed.

Our study also suggests that noise pollution can have cross-modal effects in terms of information use [3]; in this case, a negative impact on responses to olfactory cues, a common information source in mammals [5]. That is, a cross-modal effect from a behavioural perspective, rather than a neurobiological one which would imply that the noise had somehow altered the way the faeces smelled. Given the demonstrated effects, considering the interactions among multiple sensory channels is critically important if we are to understand fully the consequences of human-induced environmental change.

SUPPLEMENTAL INFORMATION

Supplemental Information including one figure, one table, supplemental experimental procedures and supplemental references can be found with this article online at http://dx.doi.org/10.1016/j.cub.2016.08.064.

ACKNOWLEDGEMENTS

We thank B. Rouwhorst and H. Yeates for granting us access to their land, E. Ackerley, F. Carr, K. Collier, B. Davison, and K. Rapson for invaluable assistance in the field, and Hansjoerg Kunc and two anonymous referees for useful comments on the manuscript. This work was supported by a University of Bristol Science Faculty Studentship to J.M.K.

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