ACOUSTICS 2025
JOONDALUP
SOUNDS OF THE SUNSET COAST

Humpback whales change their songs in response to seismic air guns

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ABSTRACT

Seismic air guns, used in offshore exploration, generate impulsive noise that may change how marine mammals acoustically communicate. For example, male humpback whales (*Megaptera novaeangliae*) produce complex, but structurally constrained, songs likely as a breeding display, yet the impacts of seismic air guns on song structure is unknown. This study investigated how the structure of humpback whale songs changed in the presence of air gun pulses. Five variables for song organisation and rate, two frequency variables, and song unit source levels, were measured in singing whales exposed to air gun activity and compared to singing whales that were not exposed. Preliminary results suggest that there were changes to variables of organisation and rate, and the frequency of some units of song. However, there was no indication that unit source levels significantly changed. Interestingly, the structural changes here are similar to changes in response to nearby conspecifics. It is unclear if air guns are perceived as a noise source, or misinterpreted as a nearby conspecific, and how this perception affects song structure. These results demonstrate that more research is required on how and why singers change their song in different social contexts as well as how biologically important acoustic communication signals are affected by anthropogenic noise sources.

1 INTRODUCTION

Anthropogenic noise is increasing in marine environments and poses a growing threat to species that rely on acoustic signalling such as baleen whales (Richardson et al., 1995; Southall et al., 2007). For these animals, noise can disrupt essential behaviours, including migration, feeding, and reproduction (Ferrari et al., 2018; Rabin et al., 2006). Seismic air guns, commonly used for offshore exploration, produce loud broadband pulses at frequencies that overlap with baleen whale vocalisations (Barger & Hamblen, 1980). Air gun surveys often overlap with humpback whale migratory routes, and their signals can propagate long distances (Gordon et al., 2003). Air guns can elicit behavioural responses in marine mammals, including avoidance (Dunlop et al., 2015, 2016; Malme et al.,1984) and changes in feeding (Johnson 2002; Johnson et al., 2007; Sarnocinska et al., 2020). However, their effect on acoustic signalling in large marine mammals is not well understood.

Humpback whale (*Megaptera novaeangliae)* song is a complex, structured vocalisation believed to serve as a breeding display (Payne & McVay, 1971). Song is composed of various structural elements organised in a hierarchy. For example, units compose phrases, which are repeated to make up themes which together compose a song. Within a population, song structure is consistent between individuals in the same year, however, research demonstrates that males can adjust components of their song in response to various stimuli. For example, Smith (2009) found male humpback whales escorting a female, reduced the number of phrases within a particular theme compared to lone singers. The response is likely a way to increase the display rate of phrases that are more useful for intersexual communication. Furthermore, various studies show that singers increase the source level of some song units in response to environmental noise (Girola et al., 2023; Guazzo et al., 2020). This is an example of a Lombard response, where an animal adjusts their vocalisation to maintain its detectability in response to signal masking (Lombard 1911). Masking occurs when noise is received at a similar level and frequency to the signal of interest, making it difficult for receivers to detect the signal amid the noise. It is unclear if short, intense sounds such as air gun pulses, that pose less risk of masking, also illicit a change in humpback whale song structure (Southall et al., 2007).

Most studies assume that air gun sound is perceived by whales as a source of noise. However, in some cases, anthropogenic signals may be incorrectly perceived as biologically relevant signals. Air gun pulses share acoustic features with the sounds of a breaching whale, a known social signal in humpback whales (McCauley et al., 2000). In addition, Dunlop and Noad (2024) reported an increase in singing during air gun activity, suggesting that whales may interpret the pulses as cues from nearby conspecifics. The current study investigates whether male humpback whales alter the structure, rate, frequency or source level of their songs in response to seismic air gun exposure.

2 METHODS

Data for this study were collected as part of the Behavioural Response of Australian Humpback whales to Seismic Survey (BRAHSS) project (2010–2015). Fieldwork occurred off Peregian Beach, Queensland, Australia (26°29′S, 153°06′E), during the southward migration of eastern Australian humpback whales. An array of five moored hydrophones (~500–700 m apart) recorded and tracked singing whales acoustically. Trials involved an active array of air guns towed behind a source vessel, either perpendicular or parallel to the migratory path. Baseline data were also collected on migrating whales in the absence of air gun activity. The received level of the air gun sounds at the whale's location was estimated based on measurements made across the study area during trials (see, Dunlop et al., 2015).

Five variables for song rate and organisation are being measured using Raven Pro (Cornell Lab of Ornithology, 2024): inter-call interval, phrase duration, theme duration, phrases per theme, and song duration. To assess structural changes in song, models are using treatment (Baseline vs. Airguns), period (Before vs. During), and their interaction as fixed effects, with singer ID as a random effect. The before and after period for baseline is a superficial differentiation for modelling purposes. Variables are modelled using either linear mixed models (LMMs; Bates et al., 2015) or generalised LMMs (Brooks et al., 2015) in R (R core team 2024), depending on their distribution. To evaluate changes in unit frequency and level, the peak frequency, 5th-percentile frequency and source level of units were measured. Unit frequency and received level were extracted in Raven Pro and source level was calculated in MATLAB (MathWorks 2023) using standardised transmission loss corrections from the site (Dunlop et al., 2013a). Statistical modelling followed the same structure as above, with unit type also included as a random effect for source level analyses. Estimated marginal means (EMMs; Lenth R 2025) were computed to aid interpretation for frequency.

3 RESULTS

Preliminary results suggest that humpback whale song duration (i.e. the time it took to cycle through all themes), was shorter in singers exposed to air guns compared to unexposed singers. This is most likely achieved by singers reducing the number of phrases within some themes. Preliminary results also suggest that there was no obvious increase in source level of song units in response to air guns, however, there is some indication that the frequency of some song units decreased.

4 DISCUSSION

This study demonstrates that singing humpback whales may change structural features of their song in response to seismic air guns. While baleen whales often modify vocal behaviour to overcome acoustic masking (Dunlop et al., 2014; Girola et al., 2023; Guazzo et al., 2020; Parks et al., 2007), the brief and transient nature of air gun pulses makes them unlikely to interfere with song in this way. If masking were occurring, one would expect an increase in signal redundancy and SL to maintain detectability in noisy conditions. Instead, singers seemed to reduce the duration of their songs by singing fewer phrases in some themes, thus reducing redundancy. In addition, preliminary analysis found no significant change in source level suggesting no obvious Lombard response. Alternatively, whales may not interpret air gun pulses as environmental noise, but instead as socially meaningful cues. Air gun pulses share acoustic similarities with surface generated sounds of a breaching whale (McCauley et al., 2000), which are known to serve communicative and social functions (Baker et al., 1985; Darling & Bérubé, 2001; Dunlop et al., 2008). It is therefore possible that singers perceive air guns as resembling the acoustic signature of a nearby conspecific.

Song structure in humpback whales also varies by social context. Simple and complex themes are thought to serve different communicative roles, with simple themes, usually short and comprising low-frequency units, suited for long-range signalling, and complex themes used in close-range courtship (Murray et al., 2016). Smith (2009) found that males escorting females reduced phrase repetition in a specific simple theme, possibly to increase display rate when in close proximity. Future research will determine if the change in structural features of their song is more similar to changes in response to nearby conspecifics than changes in response to a noise source. Not only will this help better understand the consequences of anthropogenic noise but also aid in the understanding of the functional role of song in humpback whale communication.

5 CONCLUSION

This study provides preliminary evidence that humpback whales change the rate and some structural and spectral features of their song in response to nearby air guns. Future work aims to establish if this is likely a response to a perceived noise source, or a perceived conspecific. Overall, this research highlights that the effects of anthropogenic noise extend beyond acoustic masking, emphasising that the impacts of noise can be complex and further research is needed to understand how noise can affect animals.

6 ACKNOWLEDGMENTS

We would like to thank Kelsey Stone for her helpful feedback, and the BRAHSS team and volunteers for data collection. BRAHSS was funded by the Sound and Marine Life Joint Industry Program (JIP). We gratefully acknowledge the Queensland Division of the Australian Acoustical Society for their 2024 bursary support of Liam Johnson.

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