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SHORT NOTE

Two voice system found in the Australasian gannet (*Morus serrator*)

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In large and dense seabird colonies the difficulty that partners experience in finding each other may be extreme; nests can be densely packed together, and along a regular pattern with equidistant spacing, making nests in the centre of the colony especially difficult to distinguish (Aubin *et al.* 2000). Topographical cues may be critical for landing on the nest or for locating the chick before it becomes mobile (Penney 1968), but in species nesting in large colonies situated on flat terrain, it may be error-prone to use topographical cues to visually identify the nest site, the mate, or the offspring. In species with spatially homogenous nest sites and colonies, including king and emperor penguins (*Aptenodytes patagonicus* and *A. forsteri*), a 2 voice system functions to facilitate individual recognition to direct mates and parents to nest sites and young (Aubin *et al*. 2000).

The sound production organ in birds, the syrinx, is a 2 component structure, located at the junction of the bronchi (Gaunt *et al*. 1982; Stein 1968). Although the syrinx varies in complexity between species and across orders, the basic structure is essentially the same throughout most avian lineages (Greenwalt 1968). In the dual components of the syrinx, each has an independent set of muscles and membranes, which in turn are innervated separately, and so birds may be able to control these parts independently to produce 2 different voices simultaneously (Gaunt *et al*. 1982; Goller & Larsen 1997; Stein 1968). Indeed, such use of a 2 voice system is widespread, especially among oscines, or songbirds (Latimer 1977; King & West 1983; Adret-Hausberger & Jenkins 1988; Weisman *et al*. 1990) but also in other lineages (Krakauer *et al.* 2009), and it has also been found in some species of colonially breeding penguins, where double-voice calls are used in individual identification of mates (Aubin *et al*. 2000). Therefore, it is possible that the 2 voice system may also be important for individual recognition in other colonial seabirds.

The Australasian gannet (*Morus serrator*) is a sexually monomorphic seabird (Daniel *et al*. 2007), that nests on cliff tops and beaches, mainly on flat ground, with a regular inter-nest distance of approximately 0.8 m (Wodzicki & McMeekan 1947). This structurally homogeneous environment may make it difficult for an individual gannet to return to its own nest. Landing at the wrong nest in a gannet colony can result in swift pecks from the nest owner, and aggression from occupants of neighbouring nests (Matthews *et al*. 2008). Inter-neighbour aggression has also been well documented in other gannet species (Marchant *et al*. 1990; Nelson 1978; Nelson 2002; Wingham 1984). In previous

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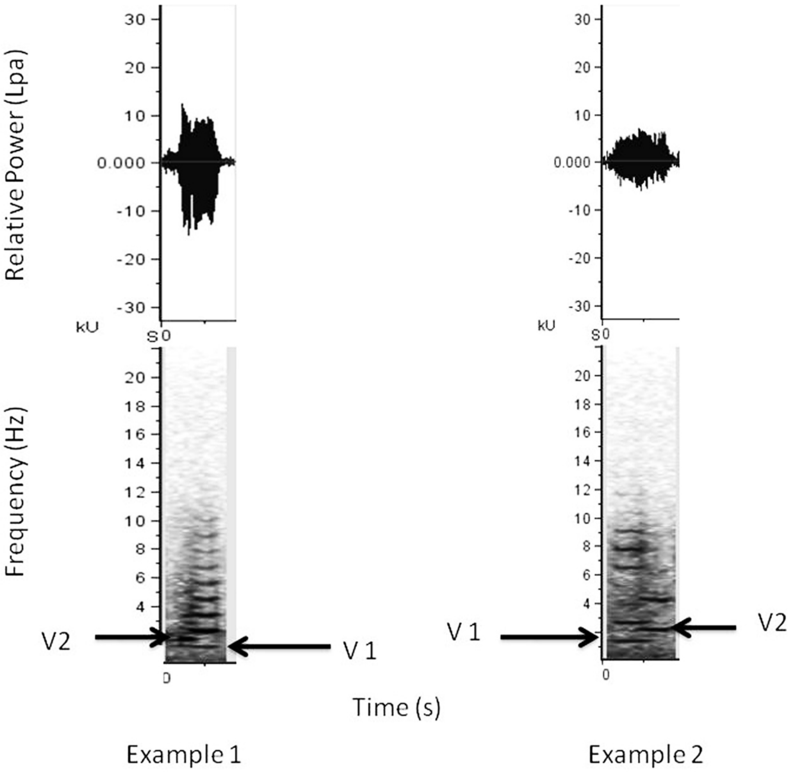

Example 1

Example 2

Fig. 1. Spectrograms showing double voicing in the Australasian gannet. Both examples are of element E2. The arrows show voice 1 (V1) and voice 2 (V2). Example 1: V1 – fundamental frequency (frequency difference between the harmonics) 1094 Hz, V2 - fundamental frequency 1178 Hz. Example 2: V1 fundamental frequency 1110 Hz, V2 fundamental frequency 2062 Hz.

works, individually distinct vocal signatures were identified through analyses of amplitude modulation and experimental playback studies in the related Atlantic gannet (*M. bassanus*) (White 1971; White *et al*. 1970), and through bioacoustic analyses of the temporal- and frequency-modulation of individually banded Australasian gannets in New Zealand (Miner-Williams 2007; Ranjard 2010); these studies also found that Australasian gannets have a large repertoire of distinctly different elements (or vocalisation types). Our study here aimed to analyse the calls of the Australasian gannet to seek evidence of double voicing in this species.

Vocalisations of the Australasian gannet (hereafter: gannet) were obtained by recording gannets at 2 "mainland" gannetries on the North I, New Zealand: Cape Kidnappers (39° 38′ S, 177° 05′ E) and Muriwai (36° 49′S, 174° 25′ E). For this study we used our data base of digital gannet calls described in Miner-Williams (2007) and Ranjard (2010). Briefly, recordings of 23 individuals from Cape Kidnappers were made on 3 consecutive days between 31 Oct and 2 Nov 2006, using a Fostex FR-2 Field Recorder with an Audio Technica Shotgun Microphone and a Rycote wind-kit (48 kHz 24 bit precision). Opportunistic recordings of 29 banded individuals were also made between 3 to 6 Sep 2007 at the Plateau colony at Cape Kidnappers using a Sony Dictaphone. These recordings were later digitised to AIFF files (with 44,100 Hz sampling rate and 16 bit precision) using the Raven sound analysis programme v1.2 (Cornell Lab of Ornithology, Bioacoustics Research Program). An additional 43 individuals were recorded at the Atlantic and Southern cliff colonies at Muriwai gannetry, during 2 consecutive weeks from 19 to 26 Aug 2007, using a Marantz portable high resolution digital audio recorder (stored as 48-bit wave files) and a handheld Sennheiser microphone (model K6 ME 66). All files were visualised using the Raven sound analysis programme v1.2. A spectrogram view of amplitude versus time was created using Fast Fourier Transform (FFT) using an overlap of 50% giving a resolution of 61.9 Hz. No filter was used in the analysis. All recordings were examined and a repertoire library was created for each different vocalisation produced. All examples of a 'type' of element were catalogued with multiple examples from each individual; this was then pooled for each site. The calls were categorized into elements (or notes), defined as any continuous production of sound. The elements were arbitrarily called by letters and numbers to distinguish one element type from another. For each recording, all the elements of the calls were highlighted in Raven using selection boxes which then analysed certain acoustic parameters of the element. These were: highest frequency, lowest frequency, element duration, number of harmonics, the maximum frequency and delta frequency (frequency range of the element).

Elements were then examined for double voicing, in which 2 separate sounds with mismatching fundamental or non-overlapping harmonic frequencies were produced by the bird at the same time (Robisson 1992; Stoddard & Beecher 1983). To remain conservative, double voicing could only be determined in very clear recordings where there were no other birds vocalising in the vicinity. It was clear when double voicing occurred because 2 separate elements were seen occurring simultaneously or overlapping in the spectrogram. To ensure that one element was not just a harmonic of the other, we required that distinct harmonics with different fundamental frequencies had to be identified for each element.

Double voicing was discovered in gannet vocalisations from both colony locations, and on both trips to Cape Kidnappers. The total number of elements recorded was 1983; 176 of these elements (8.8%) contained double voicing. Double voicing was observed in one element (named element E2 in Miner-Williams 2007), which appeared in 37 of the 45 individuals recorded (82%) of the individuals recorded recorded at both Cape Kidnappers and Muriwai (Fig. 1). For each individual an average of 43.11 elements were recorded (SD = 21.89). On average, 8.4% of an individual's total elements contained double voicing (SD = 13.64%). This may be an underestimation of double voicing in the gannet as only clear recordings could be used.

In the double voiced elements the second voice was clearly distinct by harmonics at very different, non-multiplicative frequencies from those of the first voice. The dominant frequency of the first voice appeared to be between 1178 and 1262 Hz; however, the dominant frequency for the second voice clearly occurs between 1683 and 2104 Hz. In example 1 (Fig. 1), the harmonics of voice 1 occur regularly at 1094 Hz intervals above the dominant frequency, while the harmonics of the second voice occur at regular intervals of 1178 Hz. The double voice in gannet call element E2 appeared either at the beginning of the element, as shown in example 1, or at the end of the element, as shown in example 2 (Fig. 1). Gannets at the Muriwai colony were also putatively assigned to have a second voice in a different element (named element G1), although this element was only recorded once and may not be representative of the Muriwai gannet population.

This study found evidence for double voicing in at least 1 element of the Australasian gannet's call repertoire. Notably, clear evidence was found for double voicing in the same element shared by gannets at both Cape Kidnappers and Muriwai colonies. It is possible that double voicing occurred in more elements of the calls than recorded in this study. This is because it was often difficult to make clear recordings of a single bird in a crowded colony environment, therefore making a second voice difficult to distinguish from a neighbouring bird. A thorough study of double voicing in the Australasian gannet could be better conducted with captured birds, perhaps using captive birds held for rehabilitation, in a sound proof chamber.

Aubin *et al*. (2000) found that paired individuals in emperor penguin colonies used the double voice system to recognise each other. To test this, these authors modified the calls of individuals by suppressing 1 of the 2 voices within the call. They then played back the modified call to an individual's mate and its chick and then compared the behavioural responses of mate and chick against a control call which was unmodified. In emperor penguins, both mate and chick responded to the control calls, but did not respond to the modified calls. Aubin *et al*. (2000) imply that, within the syllables of the emperor penguins call, their 2 voices (or frequency bands) and the harmonics create a beat, which is then suggested to convey information about individual identity. As this trait was not present in experimentally modified calls, individuals could not be recognised. The presence of the double voice system reported here in the Australasian gannet could also be important in individual recognition. Our field notes revealed that element E2, in which double voicing was present, was recorded during both the fly-by behaviour, in which an individual flies over the colony looking for their mate, and also with calling during the first few minutes after landing. It could be that the double voice component is required for initial vocal recognition in these behavioural contexts, and is not required in other vocalizations, i.e., after the identity of a mate or offspring has been established or individual identity confirmed through other sensory modalities.

It has also been suggested that double voicing may be a way of minimising sound degradation, and the resulting loss of signal-to-noise ratio, in a noisy colonial breeding environment (Aubin *et al*. 2000). A gannet colony, composed of several hundred (at Muriwai) to several thousand (at Cape Kidnappers) breeding individuals, is indeed a noisy environment, not only due to the vocalisations of other birds, but also the wind and wave-generated noise of the localities. Therefore, it may also be possible that the double voice in some gannet call elements allows the individual vocal cue to carry further through the environment (Patricelli & Blickley 2006).

The presence of the double voicing system in the Australasian gannet should be further confirmed by anatomical and neurophysiological studies of the syrinx (Suthers 1990; Goller & Larsen 1997, Krakauer *et al.* 2009), and additional recordings of birds in a sound-controlled environment. The function of double voicing in the Australasian gannet is speculated to be involved in individual recognition and possibly efficient sound propagation, and tests of these alternatives through experimental playback studies are still needed and may provide a basis for the study of double voicing in other sulid species.

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