Arnon, A, Koyama, N and Wronski, T

Vocalisation in wild-living mountain gazelles (Gazella gazella): structure and context of acoustical signals

Vocalisation in wild-living mountain gazelles (*Gazella gazella*): structure and context of acoustical signals

Amir Arnon[1,2], Nicola F. Koyama[3] & Torsten Wronski[3,4]

([1] Department of Evolutionary and Environmental Biology, University of Haifa, Mt Carmel, Haifa 3498838, Israel; [2] Ramat Hanadiv Nature Park, Zikhron Yaakov 30900, Israel; [3] Faculty of Science, School of Biological and Environmental Sciences, Liverpool John Moores University, Liverpool L3 3AF, UK) [4] corresponding author's email address: t_wronski@gmx.de

Summary

Describing vocalisations of species in the wild is an important step to understanding their function. A wild-living population of mountain gazelles (*Gazella gazella*) was monitored in Israel, using camera traps, thereby providing a first detailed description of the acoustic repertoire. We described six acoustical signals that were either reported by previous authors or that were hitherto not reported. Acoustic signals were categorised according to behavioural context as alarm calls, courtship calls or threat calls and—if possible—characterised by four acoustic variables, i.e., duration, maximum amplitude frequency, three power quartiles and fundamental frequency. Vocalisations were illustrated as spectrograms supplemented by full video sequences to show the acoustical signal in its environmental, social, and behavioural context. Given the rather inconspicuous character of many acoustic signals, we proposed further in-depth studies of vocalisation in mountain gazelles and other Antilopine species to unravel new insights into their behaviour and social organisation.

Keywords: agonistic behaviour, vigilance, courtship behaviour, nasal/oral calls, Antilopini

Short title: Vocalisation in mountain gazelles

Introduction

Describing the vocalisations produced by animals in the wild is an important initial step in understanding their function and can aid the conservation of endangered species through acoustic population monitoring (Browning et al., 2017). In social, group living mammals, acoustic communication plays an essential role. Acoustic signals are widely used in different social contexts such as courtship, mother-infant relations, or agonistic interactions (Fitch & Hauser, 2003; Fitch, 2006). Factors controlling the structure of acoustic signals are numerous, including the anatomy and morphology of the larynx and the oral and nasal cavities (Frey et al., 2008a; 2011), but also environmental and functional factors such as the species' habitat, its sociability, and the type of social organisation (Fitch, 2006; Charlton et al., 2019; Stein & Rachlow, 2023). Ungulates represent an interesting group with a comparatively wide repertoire of acoustic signals (Kiley, 1972; Walther, 1984; Vannoni et al., 2005; Volodina et al., 2018; Blank, 2021). Vocalisation in bovids and cervids was studied in many species, including the oral and nasal alarm and courtship calls of deer (Vannoni et al., 2005) and many antelopes (Estes 1991, Bro-Jørgensen 2010), but also locomotion-induced sounds, such as the knee-klicks of male eland antelopes (Bro-Jørgensen & Dabelsteen, 2008). According to Kiley (1972), and more recently Blank (2021), the bovine acoustic repertoire is characterised by five types of vocal communications, mainly of nasal, but also of oral origin: i) contact calls, i.e., mainly mother-infant communications, ii) advertisement calls, iii) threat calls, iv) courtship calls (including mating, herding and driving calls), and most common v) alarm calls.

For the Antilopini tribe (*sensu* Bärmann et al., 2013), some early studies summarised acoustic communications mainly referring to the alarm and courtship calls of gerenuk (*Litocranius walleri*; Schomber 1966), blackbuck (*Antilope cervicapra*; Walther, 1959), Thomson's gazelle (*Eudorcas thomsonii*), dorcas gazelle (*Gazella dorcas*), Speke's gazelle (*G. spekei*), Grant's gazelle (*Nanger granti*; Walther, 1968) and springbok (*Antidorcas marsupialis*; Walther, 1981). More recently, several studies have explored the vocalisation of goitered gazelles (*Gazella subgutturosa*), Mongolian gazelles (*Procapra guttorosa*), impala (*Aepyceros melampus*), and saigas (*Saiga tatarica*), focusing on the anatomy and function of the larynx, which is used to produce the sonorous roaring of adult males (Frey et al., 2007; 2008a, b; 2011, Blank et al., 2014; Frey et al., 2020, Volodin et al., 2021). Other studies were centred on contact calls between mothers and their calves (Volodin et al., 2011, Volodin et al., 2014), on neonate distress and discomfort calls (Volodin et al., 2017a, b), or on the development and ontogeny of acoustic signals (Efremova et al., 2010; 2011a, b) and their individuality (Lapshina et al., 2012; Volodin et al., 2017c).

The only references addressing acoustic communication in mountain gazelles (*Gazella gazella*) come from Fritz Walther and colleagues (Grau & Walther, 1976; Walther, 1968; Walther et al., 1983), describing distress and alarm calls, snort-like threat calls, and a driving call that is either produced when a territorial male chases an oestrous female or another adult male. Mendelssohn et al. (1995) described a sneeze-like call serving as a warning call, a low snoring call produced by females to call their fawn, and a strong bleating distress call. These authors further emphasised that most vocalisations produced by male gazelles during agonistic encounters are rather soft, only audible in captivity when a human is taking up the role of an opponent (Walther et al., 1983).

In our descriptive study, we present a selection of nasal, and presumably oral, call samples arbitrarily recorded from wild-living mountain gazelles in Israel, using camera traps. We provide a first description of the acoustic features of six call types that were either reported by previous studies (see above) or that were hitherto not observed. Acoustic signals were categorised, depending on behavioural context, as alarm calls, courtship calls or threat calls and—if possible—characterised by four acoustic variables, i.e., duration, maximum amplitude frequency (fpeak), three power quartiles (q25, q50 and q75) and the range (f0(min) and f0(max)) of the fundamental frequency (f0). Furthermore, vocalisations were illustrated as spectrograms, supplemented by full video sequences to show acoustical signals in their environmental, social, and behavioural context.

Methods

Study location and species

Acoustical signals of mountain gazelles were recorded in Ramat Hanadiv Nature Park (RHNP) in north-central Israel (32°30′N; 34°57′E). For details regarding geography, climate, and vegetation see Geffen et al. (1999). The mountain gazelle occurs predominantly in Israel (Yom-Tov et al., 2020), but small populations are reported from Jordan and Turkey (Amr, 2012; Kankiliç et al., 2012). Mountain gazelles reproduce throughout the year, with a strong peak in late spring (May to June; Baharav, 1983; Geffen, 1999). They are most active at dusk and dawn but shift their active phase towards night-time if predation pressure is high (Arnon et al., unpublished data). The social structure encompasses territorial males holding territories of about 50 ha (Grau & Walther, 1976), and matrilineal female groups with an average home range size of 16.5 ± 0.51 ha (Geffen et al., 1999). Both sexes show a strong site fidelity (Grau & Walther, 1976). In addition, non-territorial, solitary males are organized in small, loose bachelor groups, trying to displace a territorial male. Adult territorial males vigorously defend their territories against such intruders and mark territorial boundaries through the deposition of excreta at localised defecation sites (Wronski & Plath, 2010) or by object horning, i.e., the deposition of glandular secretions from the frontal gland (Walther et al., 1983).

Data collection

Camera traps (Spec Ops Edge: Browning Trail Cameras Inc., ATC 128X: A.T.C. Trail Camera Technologies Ltd.) were employed at 10 locations known to be frequently visited by gazelles, i.e., localised defecation sites, day- and night-time bedding sites as well as preferred feeding sites. Camera trapping was carried out from March 2018 to July 2021 for consecutive periods of one to 20 days, resulting into a total of about 80 trapping days. Vocalisations were recorded at seven camera trapping locations during 14 events (site visits with vocalisation) at four to six meters from the recorder, including six males and four females (individuals were recorded in different years and at different points of recording). Typically, individuals could not be reliably distinguished, however, at one location where cameras captured an ongoing territorial dispute it was possible to individually distinguish the two males involved (horn size and shape, body stature). Cameras recorded short video sequences lasting either 10, 20, 30, 60 or 120 seconds with audio sampling rates of either 32 kHz or 48 kHz and resolution ranging from 115 to 770 kbps.

Data processing and spectrograms

Vocalisations were coincidentally detected while repeatedly screening the video footage for other purposes (i.e., calibration of drive count data; Arnon et al. unpublished data). From the calls identified in the recordings, those that were not superimposed with other noises and where the acoustic structure was visible were selected for analysis. Calls were analysed in Raven Pro 1.6 (Cornell Lab of Ornithology, Cornell University), using a sampling frequency of 44.1 kHz, Hamming window, a FFT length of 512, and an overlap of 50%. The following variables were measured for each call: duration, the peak frequency at maximum amplitude (fpeak) and three quartiles (q25, q50 and q75) representing 25%, 50% and 75% of the energy within call respectively, and where visible, the fundamental frequency (f0(min) and f0(max)) using the standard marker cursor. At this point, it should be noted that in audio recordings of camera traps the filter for low frequencies might be turned on by default, and thus values of peak frequency and quartiles could be enhanced relative to those which could be obtained using professional audio equipment. For the threat calls which were an exchange between two males, we also calculated mean call interval. In cases with more than one call in a video recording, mean measurements per individual were taken. Because of the quality of recordings, we used visually guided analyses to measure all variables in each recording. For example, we did not use an automatic algorithm to detect the maximum or minimum f0 but used placement of the cursor by human eye. All measurements calculated in Raven Pro 1.6 were visually checked with reference to the power spectra. To analyse for differences in the acoustic structure of calls between identifiable males, call duration, fpeak, f0(min) and f0(max) were compared using an independent samples permutation test (R package *coin*) in R statistical software version 4.1.2 (R core team, 2020), except for threat calls or when only one sample was available. Permutation or randomisation tests make no assumptions about the underlying distribution of the dependent variable and are relatively robust when applied to data sets with small sample sizes (e.g., Craig and Fisher, 2019). Only for representative audio files, the calls were amplified in Audacity 2.4.2 by normalising to zero decibels relative to full scale (dBFS), i.e., the maximum peak level. Based on the social and behavioural context, calls were categorised as i) threat calls (male-to-male), ii) courtship calls (male-to-female), and iii) alarm calls (both sexes; Kiley, 1972; Blank, 2021).

Results and discussion

Threat calls

The most frequently recorded call type was the male threat call that was captured a total of 72 times from two males, in five recordings on three days from one camera trapping location. Of these 72 threat calls, 52 calls (9 and 43 calls for each male, respectively) were analysed for peak frequency and quartiles (Table 1; ESM: S1, S2, S3, S4, and S5), and additionally, it was possible to extract fundamental frequency for 24 calls (ESM: S1).

Threat calls were short, sharp nasal calls lasting around one tenth of a second. The 52 analysed vocalisations were obtained from three recordings of territorial border conflicts between two adult males (Figure 1a; ESM S1, S2, S3). One male produced audibly lower frequency threats (9 calls) than the other (43 calls) and we therefore analysed the two males' calls separately (Table 1). The mean ± SD call interval was 3.7 ± 1.3 seconds. The calls of male B (seen e.g., in ESM S1 as the left male producing the second call) were significantly lower frequency calls than those of male C (fpeak: $z = 3.48$, $p < 0.001$). Male B had a maximum call amplitude at 1699 ± 416 Hz (Figure 1b), ranging from 1723 to 2210 Hz, whilst the calls of male C (seen e.g., in video 5 as the right male who produced the first call), were emitted at higher frequencies with a maximum amplitude at 3206 ± 369 Hz (Figure 1c), ranging from 1852 to 4565 Hz. The duration of the calls of male C (0.095 ± 0.011 seconds) was longer than those of male B (0.083 ± 0.008 seconds; $z = 2.5$, $p < 0.02$). As in most ruminants (for review see Volodina et al., 2018), snorts were explosive, short and sharp expirations without visible fundamental frequency (Figure 1b, c), and thus f0(min) and f0(max) were not established.

(Figure 1 here)

The recorded threat calls largely correspond to the nasal snorts described by Walther et al. (1983) as a repeated 'pshorre', mostly performed when taking an erect posture with the nose levelled (*sensu* Estes, 1991) or slightly raised (Nase nach vorne oben heben, *sensu* Walther, 1968). Hereby, both males show a lateral presentation of the body, turning the heads away, or performing nodding motions such as headshaking or vegetation-horning (see ESM S1, S2, S3). The encounter continued with high horn presentation, attack, clash-fighting, front-pressing, and aircushion fighting (Schlagwechselkampf *sensu* Walther, 1968).

Alarm calls

Twenty-two alarm calls were recorded (three from females and 19 from males) in six videos (ESM S6, S7, S8, S9, S10, and S11) obtained at four camera trapping locations. Of all calls captured, 16 could be analysed, three from females and 13 from males (Table 1). Female alarm calls (Figure 2; ESM S7 and S11) were short calls lasting around one fifth of a second (mean ± SD = 0.21 ± 0.18 seconds), with maximum call amplitude (fpeak) at 3919 ± 61 Hz. The fundamental frequency of female calls was f0(min) = 297 ± 176 Hz and f0(max) = 612 ± 84 Hz. Male alarm calls (Figure 3; ESM S6, S8, S9 and S10) were similarly short calls (mean ± SD = 0.18 ± 0.06 seconds; $z = 1.06$, $p = 0.3$), with a maximum call amplitude (fpeak) at 2428 ± 1190 Hz, that was not significantly different from that produced by females ($z = 0.95$, $p = 0.3$). The fundamental frequency of male calls was also similar to that of females (f0(min) = 264 ± 22 Hz and f0(max) = 635 ± 55 Hz) with no significant difference in f0(min) ($z = -0.41$, $p = 0.7$) or f0(max) ($z = -1.57$, $p = 0.1$) when compared to females.

(Figure 2 & 3 here)

Alarm calls were expected to be of nasal origin since they were accompanied by strong flank twitching (pressing large amounts of air off the lungs) whilst having the mouth closed. These alarm calls correspond to snorting calls described by Estes (1991) for the Antilopini tribe as well as the 'kwueff' sound mentioned by Walther (1968) for Thomson gazelle (*Gazella thomsoni*). However, spectrograms and call measurements were comparable to those reported from klipspringer (*Oreotragus oreotragus*; Tilson & Norton, 1981) and goitered gazelle (Efremova et al., 2011). Contextually, these snorts are similar to snorts produced by male topi (*Damaliscus lunatus*) in both, courtship and alarm situations (Bro-Jorgensen & Pangle, 2010). In topi, rutting and alarm snorts are acoustically identical and snorts aim to capture the attention of receptive females. By contrast, rutting snorts of male impalas were longer and had higher upper quartile values than alarm snorts (Volodin et al., 2021). Although we did not observe rutting snorts in mountain gazelles, the use of snorts across different contexts is intriguing and may represent another example of mate guarding through sensory exploitation.

Apart from these 'normal' alarm calls, another stage of arousal could be distinguished in alerted mountain gazelles, i.e., a series of short calls, whereby each call corresponds to a single jump whilst performing stotting (or pronking *sensu* Walther, 1968; ESM S6, S9). As the male in ESM S9 is moving rapidly away from the camera with increasing distance as he emits these calls, only the first call was analysed.

Courtship calls

Courtship calls are usually produced by males, directed towards a female (Figure 4a). A total of 15 calls were recorded from eight video samples obtained from four camera trapping locations. However, of all calls captured, only three could be analysed (one from ESM S12 and two from ESM S13), mainly because of poor sound quality, strong back-ground noise, and the remarkably soft and inconspicuous nature of the calls. Three call types appearing in a courtship context were distinguished (Table 1), one short and sharp call lasting only 0.04 seconds with fpeak = 1494 Hz (Figure 4b) and two calls lasting 0.09 ± 0.01 seconds with fpeak = 1895 ± 244 Hz and a staccato-like structure (Figure 4c). Prior to the actual call, the male makes a chewing movement with his lower jaw (ESM S13), suggesting an oral output. Therefore, this call seems to be different to the sputtering, nasal sound described by Estes (1991) for the Antilopini tribe. However, with respect to the behavioural context, the recorded calls occur during the demonstrative driving phase, a part of courtship during which the male makes the female stand up (hoch-machen, *sensu* Walther, 1968) and performs repeated foreleg-lifting (Laufschlag, *sensu* Walther, 1968; Estes, 1991).

(Figure 4 here)

In one case, a yet undescribed courtship call could be documented (ESM S14). This weeping call was the longest call recorded (0.65 seconds; Figure 5). It appeared to be produced at a much lower fundamental frequency (f0(min) = 288 and f0(max) = 442) than those of the short (f0(min) = 895 and f0(max) = 1211), and long (f0(min) = 1378 ± 318 and f0(max) = 2246 ± 227; Table 1) courtship calls. The weeping call was produced while an adult male was advancing a camera trap, performing a low stretch approach. The low stretch approach is usually directed towards a female, signalling that the approaching male wants to test the reproductive status of the female (genital testing *sensu* Estes, 1991), and is therefore characteristic for the initial contact and testing phase of Antilopine courtship (Walther, 1968; Walther et al., 1983; Estes, 1991). Although the male's head was out of sight when producing the call (ESM S14), there is confidence that this call was produced by the gazelle since the timing of the call is perfectly synchronised with its abdominal flank movement. However, since this call was recorded only on one occasion the origin and analysis is preliminary and should be viewed with caution.

(Figure 5 here)

Conclusion and limitations

Since the call repertoire presented in our study was entirely based on arbitrary observations recorded by camera traps, poor sound quality, strong back-ground noise, and remarkably soft calls, a detailed analysis of acoustic signals was often difficult, if not completely impossible. We were thus only able to analyse and/or describe six types of vocalisations, a threat call associated with agonistic interactions between adult, territorial males, male and female alarm calls, and three calls relating to courtship behaviour. Except for the threat and alarm calls, sample sizes were extremely low, meaning that only one or two samples could be analysed for each type of vocalisation. Two calls were previously mentioned (or roughly described) by previous authors (Grau & Walther, 1976; Walther, 1968; Walther et al., 1983), including the threat calls produced by two displaying adult males (Figure 1) and the short, sharp alarm call produced by both, vigilant males, and females (Figure 2, 3). Thus, the reliability of our vocalisation measurements is limited, and further recordings are needed to obtain better measurements and confirm our findings. .

The frequency of greatest amplitude (fpeak) and the fundamental frequency (both f0(min) and f0(max)) were similar in both sexes, indicating no difference between male and female alarm calls. Not unexpected was the discovery of individual threat calls produced by adult, territorial males as the fundamental frequency (f0(min)) was significantly lower for one male than for the other. Several studies on various mammal species have provided evidence that acoustic signals can provide the receiver of a signal with a plethora of socially and physiologically relevant information such as the senders reproductive ability, hormonal state, or body size (ungulates: Clutton-Brock & Albon, 1979; Reby & McComb, 2003; Reby et al., 2005; primates: Fitch, 1997; carnivores: Pfefferle et al., 2007; Charlton et al., 2010). To empirically prove this theory in mountain gazelles, repeated recordings of threat calls from individually known territorial adult males in captivity would be needed and related to the hormone concentration and body size of the respective male.

Another three acoustic signals were completely unknown from mountain gazelles and were here described for the first time, including the pronking snorts (Figure 3), and the short and long courtship call (Figure 4c). In particular, the courtship calls were extremely unobtrusive and future studies may unravel more yet unobserved and undescribed signals. Interesting is the observation of the staccato-like structure of the long courtship call that was observed in conjunction with foreleg-lifting. Here, the male made a characteristic chewing movement with the lower jaw, suggesting that this sound was of oral, rather than of nasal origin. Several studies have highlighted the importance of oral sounds in Antilopines, especially for the group-living and migrative goitered and Mongolian gazelle (Frey et al., 2008a, b; 2011; Blank et al., 2014). Our study provides the first indication that oral signals produced by the larynx also play an important role in the communication of sedentary, territorial gazelles, although to a much lower extent than that observed in *Procapra* or the vagrant species of *Gazella* such as *G. subgutturosa* or *G. marica* (Kingswood & Blank, 1996).

Finally, a word of caution regarding the pros and cons of using camera traps in acoustic analysis: An evident advantage of using camera traps, is the opportunity to view the acoustic signals in the social and behavioural context. The main limitation, on the other hand, is the non-calibrated recording of audio signals, often with cruel filtration of lower frequencies, resulting in the incomparability with recordings obtained from professional sound recording equipment. Comparison of camera trapping footage is further complicated by different brands and models with differing audio settings. Despite these shortcomings, we believe that our preliminary results make a substantial contribution to the understanding of gazelle behaviour and thus the *in situ* and *ex situ* conservation of gazelles. Given the remarkably soft and inconspicuous calls coincidentally obtained during this study, we propose further in-depth studies of vocalisation in wild and captive mountain gazelles (and other Antilopine species), using high-end camera trapping technology in combination with directional microphones (e.g., in the mountain gazelle breeding enclosure at Hai-Bar Carmel Nature Reserve in northern Israel).

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Ethical approval

Ethical approval was obtained from the Review Group for the Use of Non-regulated Animals of Liverpool John Moores University (approval number: TW/2023-8).

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Tables

Table 1. Mean ± SD values for acoustic measurements of threat, alarm, and courtship calls: duration (seconds), fpeak – maximum amplitude (Hz), q25, q50, q75 – lower, medium and upper quartiles (Hz), and f0(min) and f0(max) (Hz).

Call type	**Number of calls**	**Duration**	**fpeak (Hz)**	**q25 (Hz)**	**q50 (Hz)**	**q75 (Hz)**	**f0(min) (Hz)**	**f0(max) (Hz)**	**Video number**
Threat (Male B)	9	0.07+0.01	1699±416	1640±204	2045±159	2889±541	n/a	n/a	ESM: S1-5
Threat (Male C)	43	0.08±0.01	3206±369	1977±128	2737±154	3918±35	n/a	n/a	ESM: S1-5
Female alarm	3	0.21±0.18	3919±61	1357±1370	2885±1523	5168±1340	297±176	612±84	ESM: S7, S11
Male alarm	18	0.18±0.06	2428±1190	1994±799	2629±1205	3587±1010	264±22	635±55	ESM: S6, S8, S9, S10
Courtship - short	1	0.04	1464	1205	1378	1550	895	1211	ESM: S12
Courtship - long	2	0.09±0.01	1895±244	1895±244	1895±244	2067±244	1378 ±318	2246 ±227	ESM: S13
Courtship - weeping	1	0.65	430	344	430	430	288	442	ESM: S14

Figure legends

Figure 1. a) Two adult male mountain gazelles displaying lateral presentation and turning heads away while each producing an individual threat call type (ESM S1), b) spectrogram illustrating call type 1 (the second call in ESM S1 produced by the left male), c) spectrogram illustrating call type 2 (the first call in ESM S1 produced by the right male). Spectrograms were created with the settings: Hamming window, 22,050 Hz sampling rate, FFT 512 points, frame 50% and overlap 50%. Annotations show maximum amplitude (fpeak).

Figure 2. a) An adult female mountain gazelle in alert posture producing two single alarm calls, b) spectrogram showing two single alarm calls produced by an adult female in ESM S11. The spectrogram was created with the settings: Hamming window, 22,050 Hz sampling rate, FFT 512 points, frame 50% and overlap 50%. Annotations show maximum amplitude (fpeak) as well as minimum and maximum fundamental frequencies (f0(min) and f0(max)).

Figure 3. a) An adult male mountain gazelle producing a series of short calls, whereby each call corresponds to a single jump whilst stotting, b) spectrogram showing the series of calls performed during stotting (ESM S6) The spectrogram was created with the settings: Hamming window, 22,050 Hz sampling rate, FFT 512 points, frame 50% and overlap 50%. Annotations show maximum amplitude (fpeak) as well as minimum and maximum fundamental frequencies (f0min and f0max).

Figure 4. a) An adult male mountain gazelle prompts a female to stand up by performing foreleg-lifting, b) spectrogram showing a single courtship call and c) two courtship calls produced by the male while performing foreleg-lifting with a staccato-like structure (ESM S13). The spectrogram was created with the settings: Hamming window, 22,050 Hz sampling rate, FFT 256 points, frame 50% and overlap 50%. Annotations show maximum amplitude (fpeak) as well as minimum and maximum fundamental frequencies (f0(min) and f0(max)).

Figure 5. a) An adult male mountain gazelle performing a low-stretch approach while producing a long weeping call, b) spectrogram illustrating the long courtship call in ESM S14. The spectrogram was created with the settings: Hamming window, 22,050 Hz sampling rate, FFT 512 points, frame 50% and overlap 50%. Annotations show maximum amplitude (fpeak) as well as minimum and maximum fundamental frequencies (f0(min) and f0(max)).

Video captions

ESM S1. Two adult male mountain gazelles (*Gazella gazella*) engaged in a territorial border conflict near a localised defecation site. Both males produce a series of short, sharp nasal threat calls whilst taking an erect posture with the nose levelled or slightly raised. Both males show a lateral presentation of the body, turning the heads away, and performing nodding motions such as headshaking. The encounter continues with high horn presentation, attack, clash-fighting, front-pressing, and aircushion fighting. Ramat Hanadiv Nature Park, Israel, 12.11.2020, AVI format, 363 MB.

ESM S2. The same two adult male mountain gazelles (*Gazella gazella*) as in ESM S1 engaged in a territorial border conflict. Both males produce a series of short, sharp nasal threat calls whilst showing lateral presentation of the body, turning the heads away, and performing vegetation-horning. Ramat Hanadiv Nature Park, Israel, 01.07.2021, AVI format, 369 MB.

ESM S3. The same two adult male mountain gazelles (*Gazella gazella*) as in ESM S1 engaged in a territorial border conflict. While producing a series of short, sharp nasal threat calls, the male on the right is performing nodding motions such as headshaking and vegetation-horning. The encounter continues with high horn presentation, attack, clash-fighting, front-pressing, and aircushion fighting. Ramat Hanadiv Nature Park, Israel, 01.07.2021, AVI format, 369 MB.

ESM S4. An adult male mountain gazelle (*Gazella gazella;* presumably one of the two males in ESM S1) producing a series of short, sharp nasal threat calls whilst performing nodding motions or taking an erect posture with the nose levelled or slightly raised. The behaviour and call were performed near a localised defecation site at the boundary between two adult males' territories. Ramat Hanadiv Nature Park, Israel, 12.09.2020, AVI format, 185 MB.

ESM S5. The same two adult male mountain gazelles (*Gazella gazella*) as in ESM S1 engaged in a territorial border conflict (out of sight). Short, sharp nasal threat calls are clearly audible, and accompanied by strong flank twitching (pressing large amounts of air off the lungs) whilst having the mouth closed. Ramat Hanadiv Nature Park, Israel, 12.09.2020, AVI format, 185 MB.

ESM S6. An adult male mountain gazelle (*Gazella gazella*) producing a series of short alarm calls, whereby each call corresponds to a single jump whilst performing stotting or pronking behaviour (jumping into the air, lifting all four feet off the ground simultaneously, whereby the legs are held in a relatively stiff position). Ramat Hanadiv Nature Park, Israel, 01.10.2021, AVI format, 369 MB.

ESM S7. An adult female mountain gazelle (*Gazella gazella*) producing a single alarm call (in second 30) after being alerted by an approaching golden jackal (*Canis aureus*). Ramat Hanadiv Nature Park, Israel, 10.09.2019, MP4 format, 59.5 MB.

ESM S8. An adult male mountain gazelle (*Gazella gazella*) producing a series of alarm calls, which appears to be in triggered by a conspecific male (or another strange object or noise) rather than by a predator. Ramat Hanadiv Nature Park, Israel, 12.07.2020, AVI format, 185 MB.

ESM S9. An adult male mountain gazelle (*Gazella gazella*) producing a series of short alarm calls, whereby each call corresponds to a single jump whilst performing stotting or pronking behaviour (see ESM S7). Ramat Hanadiv Nature Park, Israel, 12.08.2020, AVI format, 61.8 MB.

ESM S10. An adult male mountain gazelle (*Gazella gazella*) producing a strong, single alarm call before fleeing. Ramat Hanadiv Nature Park, Israel, 02.12.2021, AVI format, 40 MB.

ESM S11. An adult female mountain gazelle (*Gazella gazella*) producing two alarm call (in seconds 27 and 31) whilst taking the alert posture. Note that alarm calls are accompanied by strong flank twitching (pressing large amounts of air off the lungs) while having the mouth closed, suggesting that alarm calls are of nasal output. Ramat Hanadiv Nature Park, Israel, 31.03.2022, MP4 format, 229 MB.

ESM S12. An adult male mountain gazelle (*Gazella gazella*) performing a low-stretch approach towards a female. Prior to genital testing the male produces a courtship call (in second 3), barely audible due to the soft and inconspicuous nature of the vocalisation. Ramat Hanadiv Nature Park, Israel, 20.12.2019, MOV format, 5.25 MB.

ESM S13. An adult male mountain gazelle (*Gazella gazella*) during the demonstrative driving phase, a part of courtship during which the male makes the female stand up while performing repeated foreleg-lifting and producing courtship calls (in seconds 21 and 28). Ramat Hanadiv Nature Park, Israel, 19.10.2018, MP4 format, 66 MB.

ESM S14. An adult male mountain gazelle (*Gazella gazella*) advancing the camera whilst performing a low stretch approach. The low stretch approach is usually directed towards a female, signalling that the approaching male wants to test the reproductive status of the female (genital testing). A courtship call (weeping call) was produced in second 8, just after the male passed the camera. Ramat Hanadiv Nature Park, Israel, 20.12.2019, MOV format, 5.25 MB.