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Classifying elephant behaviour through seismic vibrations

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Seismic waves — vibrations within and along the Earth's surface — are ubiquitous sources of information. During propagation, physical factors can obscure information transfer via vibrations and influence propagation range [1]. Here, we explore how terrain type and background seismic noise influence the propagation of seismic vibrations generated by African elephants. In Kenya, we recorded the ground-based vibrations of different wild elephant behaviours, such as locomotion and infrasonic vocalisations [2], as well as natural and anthropogenic seismic noise. We employed techniques from seismology to transform the geophone recordings into source functions — the time-varying seismic signature generated at the source. We used computer modelling to constrain the propagation ranges of elephant seismic vibrations for different terrains and noise levels. Behaviours that generate a high force on a sandy terrain with low noise propagate the furthest, over the kilometre scale. Our modelling also predicts that specific elephant behaviours can be distinguished and monitored over a range of propagation distances and noise levels. We conclude that seismic cues have considerable potential for both behavioural classification and remote monitoring of wildlife. In particular, classifying the seismic signatures of specific behaviours of large mammals remotely in real time, such as elephant running, could inform on poaching threats.

The propagation of seismic information is affected by the vibration source, which in this study is elephant behaviour. Seismic vibrations generated by wild elephants were recorded in Kenya (Supplemental Information). We selected a few examples of each observed behaviour type, as well as car noise, which were processed to determine the corresponding source function — the force strength and pattern generated by the elephant 'at the source' (Supplemental Information). Differences in elephant behaviour caused detectable changes in source function properties, which remained distinguishable during modelled seismic wave propagation up to 1000 metres regardless of the noise level and terrain type (Figure 1; Supplemental Information). Recordings of seismic vibrations can therefore be used to classify elephant behaviours.

Besides vibration generation behaviour, seismic information transfer is also affected by physical factors during propagation, such as background seismic noise and terrain type [1]. We employed modelling software used in modern seismology [3], which provides benefits over previous modelling approaches [2,4] as it computes realistic and accurate frequency-dependent wave propagation, using source functions and local geological information for the elephants' home range as model inputs (sand or weathered gneiss (a type of solid rock) in the top 25 metre layer; Supplemental Information).

Using the set of source functions and a seismological detectability technique, we determined the maximum propagation range where cues could be detected above recorded background noise levels. For our set of source functions, vocalisation behaviours gave higher input forces and hence larger propagation ranges compared to locomotion (Supplemental Information). Maximum propagation range estimates

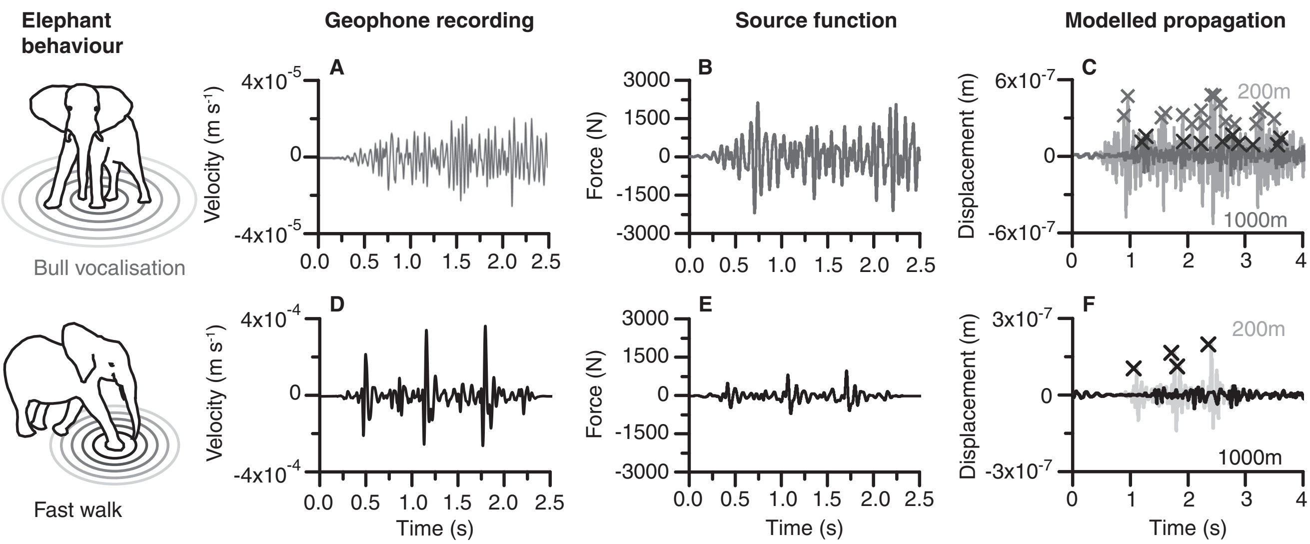

Figure 1. Determining the propagation of seismic forces produced by elephant behaviours.
A rumble from a bull (A, B, C) versus each footfall in a fast walk (D, E, F) differs in recorded vertical ground velocity versus time (A, D), determined source function force versus time (B, E) and modelled propagation sampled at 200 m and 1000 m from the source (modelled with high noise on sandy terrain; C, F). Scatter points in C (lighter for 200 m and darker for 1000 m) and F indicate points that are higher than half the maximum peak amplitude. Only fast walk at 1000 m is not detectable over background noise (Supplemental Information). Note different axes scales between A and D and C and F.

were 6.4 km for cow rumble versus 3.6 km for fast elephant walk (maximum seismological force 2546 N versus 946 N, respectively). Faster gaits of larger elephants will generate higher forces [5,6], thus leading to a larger propagation range. A sand top layer increases the propagation range for each behaviour compared to a gneiss top layer, so is best suited for long-range information transfer (Supplemental Information). However, superimposing ambient noise that was high relative to other noise recordings in the field (mixture of natural and anthropogenic sources) significantly decreased the detectable propagation range (84 ± 16% lower under higher noise on average) and thus limits information transfer (Supplemental Information).

Our findings have implications for the study of seismic information transfer between elephants. Firstly, our results suggest that elephants have the option of using the seismic component of rumbles for long-range communication (over 3 km) [2,7]. Long-range information transfer is also possible through high-force locomotion behaviours. Rapid running in elephants is a sign of distress or aggression [8], and we estimate that these high-force behaviours will propagate over many kilometres, potentially providing useful information to promote vigilance in spatially-separated elephant groups. In addition, we found an added benefit of river sand, as background noise is reduced (Supplemental Information), and seismic cues propagate with less energy loss compared to other terrains in the elephants' home range. Whether this applies to kilometre-range scales in the field remains to be quantified.

The last step in the information transfer process, seismic vibration detection, requires more research in elephants and other animals. Elephants have been shown to discriminate between the seismic components of vocalisations [7], but more research is required on the ability to discriminate between sources (behaviour, identity and single/multiple) in different physical contexts (distance from source, noise level, substrate properties). Additionally, more organisms are likely to be sensitive to seismic vibrations than are currently reported. If so, seismic vibrations can be used as biological information during ecosystem interactions. However, the strong limiting effect of noise raises concerns over the implications of close-range anthropogenic seismic sources on this mode of information transfer, for example car noise in the 20–25 Hz range (Supplemental Information).

Finally, our results support the notion that seismic recording is an intriguing, non-intrusive option for remote monitoring of wildlife, particularly large mammals [9]. Real-time monitoring of poacher threat in remote landscapes is important for species conservation [10], and we suggest that detection of rapid runs could be used in this context. In particular, utilising multiple geophones with algorithms for detection and discrimination of seismic cues could be implemented for real-time monitoring (Supplemental Information). This technique can distinguish spatially-separated seismic sources by determining their locations. The chosen geophone number and spatial separation will depend on the range and spatial resolution required, where higher geophone sensitivity, lower ambient noise level and variance, and higher force magnitude of the behaviour will lead to a greater detection range and discrimination accuracy. More data are required to develop and robustly test these methods in practice, which has potential applications within a range of wildlife monitoring contexts.

SUPPLEMENTAL INFORMATION

Supplemental Information including experimental procedures, one figure and one table can be found with this article online at https://doi.org/10.1016/j.cub.2018.03.062.

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AUTHOR CONTRIBUTIONS

B.M. and T.N.M. initiated the project and T.N.M., P.K. and B.M. designed field experiments. B.M. and W.L.R. collected field data. T.N.M., P.K. and W.L.R. analysed seismic recordings and implemented computer models. B.M. wrote the manuscript and all authors edited the manuscript.

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