One step beyond

Paul Denton describes an experiment to determine whether it's the band or the dancing that generates seismic noise at music festivals.

1: Madness, making the audience make the Earth move. (Marc Sethi)

Seismologists have often noticed increased levels of seismic noise recorded on stations close to large music festivals (Green and Bowers 2008, Erlingsson and Bodare 1996, Browitt and Walker 1993). The noise often has distinct spectral peaks in the 1–6 Hz band and amplitude variations coincide with times of day that music is being played. There has been some debate about whether the source mechanism for this seismic signal is the vibrations caused by extremely loud sound systems or tremors caused by many people dancing. Green and Bowers (2008) concluded that seismic noise observed within 10 km of an electronic dance music festival in 2006 and 2007 with distinct spectral peaks between 2 and 3 Hz was generated by vibrations in the loudspeakers at the festival site. Here we use data from the Reading Festival in 2011 to show that the seismic signals generated by rhythmic dancing were the dominant source of seismic noise in the 2–6 Hz band.

On 28 August 2011, the popular ska band Madness played at the Reading Festival in southern England. During this concert the British Geological Survey (BGS) was monitoring seismic vibrations on two seismometers near the site as part of a television science documentary. One was about 700 m from the main stage, just outside the festival boundary and by the side of the River Thames. The second was in a suburban garden about 1.5 km from the main stage. The seismometers used were Guralp CMG-6T sensors recording at 100 samples per second; this gives the sensors a bandwidth of 0.033–50 Hz. The concert was being recorded for transmission by the BBC, and a recording of the concert was made available for later viewing on the BBC website (BBC Music 2011). The opportunity to analyse coincident recordings of the seismic signal and the video and audio track of the band's performance made possible a detailed analysis of the source of this seismic noise.

Here we present a detailed analysis of the data recorded during two songs, *Our House* and *Baggy Trousers*, together with data recorded during a controlled jump made by the crowd for the BBC science show *Ask a Stupid Question* and described on its website (http://bbc.in/1laNP11).

The band Madness formed in 1976 and spent a decade as one of the most popular bands in the UK, playing a high-tempo style of music called ska which has origins in 1960s Jamaican music. Ska music is strongly associated with a style of rhythmic dancing called skanking, defined by the Urban Dictionary as "the bizarre, wild dance done to the music known as ska, skanking resembles running in place while flailing your arms". The band is currently undergoing something of a revival and is a popular live act, playing to enthusiastic audiences. During one of its biggest concerts in 1992 in Finsbury Park, London, local residents complained to the police about ground motion, thinking that an earthquake was happening! Unfortunately there were no nearby seismometers to record the vibrations; BGS explained the shaking as caused by the crowd dancing, based on circumstantial evidence (Health Protection Agency 2008).

Our House

Our House is a song with four verses interspersed with either a short or long chorus. The verses are quite gentle and melodic with rousing choruses during which the audience is seen to be dancing enthusiastically; the maximum dancing energy is seen during the first chorus, with subsequent episodes gradually declining in amplitude as the crowd tires (see table 1).

The timings and amplitudes measured on both seismometers, one 700 m from the main stage and one 1.5 km away, show an excellent correlation with the dancing observed on the video (figure 2). The song has a series of melodic verses interspersed with rousing choruses, to which the crowd responds with enthusiastic dancing. Analysis of the sound amplitude as recorded with the video shows very little variation with time for the duration of the song. This is in strong contrast to the seismic signal recorded during this song, which shows not only a strong variation between verse, chorus and instrumental sections, but also a distinct pattern of maximum energy near the beginning of the song, as the crowd recognizes the tune and starts dancing enthusiastically. There is a marked decrease in intensity throughout the course of the song, with a small increase of energy towards the end. It should be noted that the song *Our House* was first released in 1982; many of the band's keenest followers are now well into their forties and can no longer sustain high-energy dancing for the full two minutes of the song.

The tempo of this song was measured as 125 bpm (beats per minute) or 2.08 Hz. Analysis of the frequency spectrum of the seismic traces shows distinct peaks at 2.08 Hz and 4.16 Hz (figure 3); this can be interpreted as dancing in time to the music with a two-step dance, a strong right foot striking the ground on the beat and a weaker left foot striking the ground on the off-beat. The maximum amplitude signal recorded during this song at a distance of 1.5 km was $1700\,nm\,s^{-1}$ at a frequency of 2 Hz.

Baggy Trousers

The song *Baggy Trousers* has three verses with chorus and two instrumental breaks. It is a very high energy song lasting only 2 minutes and 11 seconds; both the verse and chorus parts of the song are seen to produce enthusiastic dancing in the audience. Again, the high energy and tempo of the dancing diminishes as the song progresses.

The timings and amplitudes measured on both seismometers again show an excellent correlation with the dancing observed on the video; the decline in energy in the dancing and the brief pick-up during the reprieve are especially noticeable. Analysis of the sound amplitude as recorded with the video again shows very little variation with time for the duration of the song. The tempo of this song was measured as 149 bpm or 2.48 Hz. Analysis of the frequency spectrum of the seismic traces shows distinct peaks at 2.50 Hz and 5.0 Hz. The maximum amplitude signal recorded during this song at 1.5 km distance was $2400\,nm\,s^{-1}$ at a frequency of 2 Hz, equivalent to the signal produced by an earthquake of ML = 0.4.

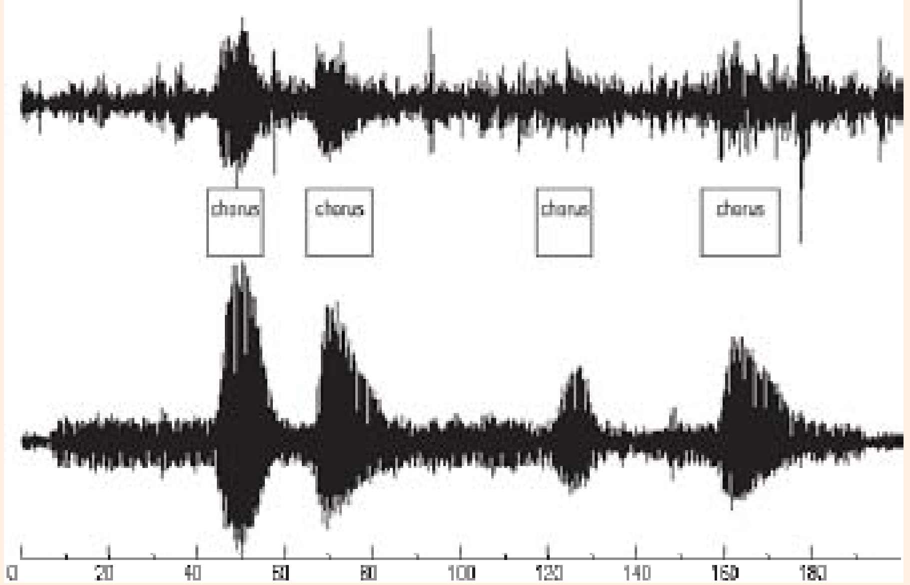
1: Timings taken during performance of *Our House*

time (min:sec)	song	audience dancing
00:00	verse 1	calm
00:40	short chorus	very enthusiastic
00:46	verse 2	calming down
01:02	long chorus	very enthusiastic
01:17	verse 3	calming down
01:57	short chorus	enthusiastic
02:03	verse 4	calming down
02:35	long chorus	enthusiastic but tiring
03:07	end	

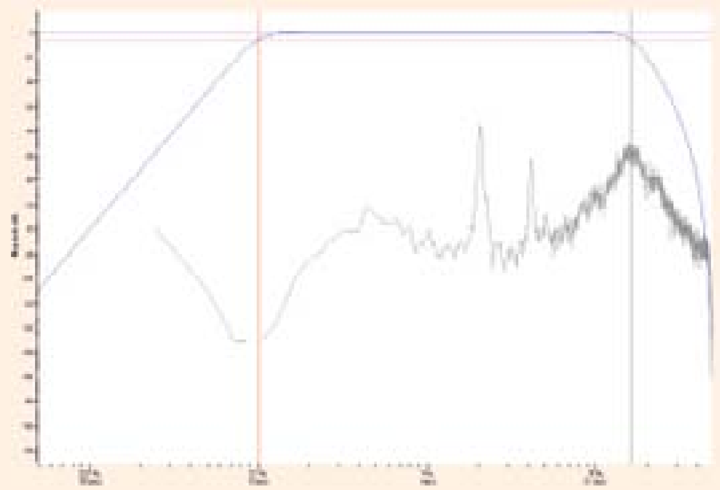
2: Comparative energy use at Reading

food energy expended dancing per second	20 MJ
gravitational potential energy released per second	5 MJ
electrical energy input to sound system per second	50 kJ
seismic energy measured over 1 second	500 kJ

2: Seismic traces recorded during *Our House* (top trace from the seismometer at 700 m, bottom trace from 1500 m).



3: The seismic signal shows frequency peaks at 2.08 Hz and 4.16 Hz. This corresponds to a musical beat of 125 bpm as measured for the song *Our House*.



The Big Jump

In an experiment to answer the question "If everyone in the world jumps at the same time, could we shift the planet?", BBC science show presenter Greg Foot came on the stage after the Madness set and asked the crowd to make a big jump, all at the same time (BBC Science 2011). The seismometer records show a clear signal; the maximum amplitude recorded at 1.5 km distance was $1000\,nm\,s^{-1}$ at 1 Hz, equivalent to the signal produced by an earthquake ML = 0.3.

Energy considerations

Vigorous dancing can be compared to high-impact aerobics as an activity and would be expected to burn around 30 kJ (7–8 calories) per minute for an average (70 kg) adult. A two-minute song with 40 000 people dancing would therefore have an energy input of approximately 2400 MJ and a power input of 20 MW. Energy dissipated by the act of jumping up and down can be estimated from potential energy conservation. For 40 000 people jumping 10 cm twice a second, this is equivalent to about 5 MW. The amplitude of the seismic waves measured was equivalent to that of an earthquake of magnitude 0.4 ML, which is equivalent to 250 kJ of energy. The typical power (input) of a large sound system at a modern rock concert by contrast is 50 kW.

The figures for energy use, summarized in table 2, show that the energy expended by a crowd dancing is many times greater than that supplied through the sound system; the energy recorded by the seismometers per second is greater than that supplied by the sound system and so is likely to come in the most part from the enthusiastic and rhythmic movement of the crowd. The Big Jump, a single, coordinated jump by the crowd, produced the equivalent of a small earthquake, but dancing made the Earth move more. ●

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References

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