embodies the details of the fragmentation mechanism and the assumptions and simplifications concerning magma rheology and degassing. As η and γ are predicted to increase very rapidly in a narrow conduit region in response to magma degassing (Fig. 1), relatively large variations in the value of η do not lead to significant displacements of the calculated fragmentation level, and the two mechanisms show good agreement in the predicted fragmentation conditions.

The model reported here makes predictions that are in line with experiments and observations, as follows: the consistency between the experimental conditions for brittle magma fragmentation and the fluid dynamic of magma ascent; the calculated range of gas volume fraction at fragmentation in close agreement with measured pumice vesi- cularities; the inverse relationship between pumice vesicularity and magma viscosity (which is observed in natural samples and suggested by the modelling results); and the discrimination between high-viscosity (mainly explosive) and low-viscosity (mainly effusive) eruptions. This suggests that the proposed criterion for magma fragmentation could be operating during sustained explosive eruptions.

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<table>
<thead>
<tr>
<th>Table 1 Number of neurons in the different response categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactile response on back of head</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>Unresponsive</td>
</tr>
<tr>
<td>Velcro</td>
</tr>
<tr>
<td>Auditory</td>
</tr>
<tr>
<td>Tactile</td>
</tr>
<tr>
<td>Tactile + visual</td>
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<tr>
<td>Tactile + visual + auditory</td>
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<tr>
<td>Total</td>
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Humans can accurately perceive the location of a sound source—not only the direction, but also the distance exact. Sounds near the head, within ducking or reaching distance, have a special saliency. However, little is known about this perception of auditory distance. The direction to a sound source can be determined by interaural differences, and the mechanisms of direction perception have been studied intensively; but except for studies on echolocation in the bat, little is known about how neurons encode information on auditory distance. Here we describe neurons in the brain of macaque monkeys (Macaca fascicularis) that represent the auditory space surrounding the head, within roughly 30 cm. These neurons, which are located in the ventral premotor cortex, have spatial receptive fields that extend a limited distance outward from the head.

The ventral premotor cortex (PMv) is a multimodal, sensory-motor area located in the frontal lobe just anterior to primary motor cortex. Most PMv neurons respond to touch, and about 40% also respond to visual stimuli 11–14. For these bimodal neurons, the visual receptive field extends from the region of the tactile receptive field into the space immediately adjacent (Fig. 1a). These neurons usually do not respond to distant visual stimuli, more than 30 cm from the tactile receptive field. That is, they represent the space near the body, within the monkey’s reach. Here we studied neurons in PMv whose tactile receptive fields included the back of the monkey’s head, and found that 53% were trimodal, responding to tactile, visual and auditory stimuli (Table 1). The mean auditory response latency was 46 ms (s.d. = 10.9 ms).

Figure 1b shows the responses of a typical trimodal neuron. The tactile receptive field (stippled) covered the contralateral side of the head. The neuron responded to visual stimuli within about 20 cm of the contralateral side of the face. In addition to these tactile and visual responses, the neuron also responded to sounds produced near the contralateral side of the head. Jingling keys, claps, crinkling paper, and bursts of white noise all gave strong responses. Simultaneous sounds were also non-Newtonian melt rheology in geologic processes. Phys. Chem. Miner. 16, 506–518 (1989).

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represents the preferred auditory direction for one neuron. The auditory responses in PMv clearly span the entire contralateral space, and seem to represent the space in front of the head (31 neurons) more densely than the space behind the head (12 neurons; \( \chi^2 = 8.4, P < 0.01 \)). Almost all neurons with an auditory response also responded to a touch on the ears or back of the head (Table 1). Yet the tactile receptive fields of these trimodal neurons were rarely restricted to the back of the head (9/91, 10%); most also included parts of the cheek, eyebrow, snout or jaw (82/91, 90%). Likewise, the visual receptive fields were sometimes located in the periphery and sometimes extended into the centre of the visual field. That is, the trimodal neurons in PMv do not form a back-of-the-head representation, but instead form a complete representation of the space around the head. As already described, the visual representation in PMv emphasizes the space within reaching distance. Do the auditory receptive fields have a similar spatial limit?

Figure 1 shows data from four trimodal neurons. We manipulated both the amplitude of the sound and the distance between the speaker and the head. In Fig. 2a, the neuron responded to sounds presented 10 cm from the head. Sounds presented 30 or 50 cm away did not elicit a response, even though they covered the same range of amplitudes measured at the head. The effect of distance on the response of the neuron was statistically significant, but there was no significant overall effect of the amplitude of the sound on the response of the neuron (see regression analysis in legend of Fig. 2).

Data from another neuron are shown in Fig. 2b. Like the cell in Fig. 2a, this neuron responded significantly better to closer stimuli, but unlike that cell, it responded significantly better to higher-amplitude stimuli as well. The neuron in Fig. 2c had an inhibitory response to auditory stimuli and an excitatory response to tactile stimuli. It responded best, that is, had the lowest firing rate, to sounds presented 10 cm away, and responded less well to sounds at 30 or 50 cm. Again the effect both of distance and of amplitude was significant. We often found trimodal neurons with an inhibitory auditory response and an excitatory tactile response, or vice versa (17 of 91 trimodal neurons, 19%). This result demonstrates that the response to nearby sounds is not caused by the sound mechanically stimulating the tactile receptive field. Finally, for the neuron in Fig. 2d, the response showed no significant dependence on the distance to the sound source, and instead depended on the amplitude of the sound.

In total, 44 neurons (34 in monkey 1, 10 in monkey 2) were tested for dependence on stimulus amplitude and distance. Of these, 15

Figure 1 Responses of bimodal and trimodal neurons in PMv. a, Receptive fields of a typical bimodal, visual-tactile neuron. The tactile receptive field (shaded) is on the front of the face contralateral to the recording electrode (indicated by the arrowhead). The visual receptive field (boxed) is confined to a region of space within about 10 cm of the tactile receptive field. b, Responses of a typical trimodal, visual-tactile-auditory neuron. The tactile receptive field is contralateral to the recording electrode (indicated by the black spot) and includes the ear and back of the head. The visual receptive field (not shown) extends about 20 cm into the space near the contralateral side of the face. The histograms show the response, summed over ten trials, to a burst of white noise presented 10 cm away at the indicated azimuth angles. c, The calculated preferred direction of the auditory response for 43 trimodal neurons. Each arrow shows the result for one neuron. Preferred direction is given by \( (\phi_s - \phi) / \Delta \phi \), where \( \phi_s \) = the angular position of speaker \( n \), and \( \phi \) = the neuron’s response to speaker \( n \) (mean number of spikes per s in the stimulus period).
transient bursts of activity in PMv associated with eye movement, whereas most of the auditory responses in PMv were transient, short-latency bursts (Fig. 1b).

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Methods

Two adult M. fascicularis were trained to sit in a primate chair; they did not perform any task. (For details of the experimental procedures, see ref. 16.) During daily recording sessions, a microdrive was used to lower an electrode into PMv. Once a neuron was isolated, it was tested for somatosenory, visual and auditory responses. Somatosenory receptive fields were plotted by manipulating the joints and stroking the skin. Visual receptive fields were plotted with objects presented on a wand. Auditory stimuli included tones, clicks, claps, jangling keys and other sounds. Controlled tests were done using white noise (20–22,000 Hz) presented over Cambridge Soundworks 3-inch (76.2 mm) speakers mounted in a circular array around the monkey's head at ear level. The angular position and distance of the speakers to the head was adjustable. The sound pressure level of the stimuli was measured at the monkey's head using a Radio Shack sound level meter, repeatedly calibrated with a 0.25-inch (6.35 mm) Bruel and Kjaer microphone. Neurons were tested either with the speaker behind the head, or in the dark, so that the monkey could not see the distance to the sound source. Eye position was not controlled during the presentation of auditory stimuli. Some PMv neurons are influenced by eye position10,18,25. However, the short latency of the auditory response eliminates the possibility that it was caused by a change in eye position elicited by the presentation of the stimulus. In addition, there are no reports of

Perception's shadow: long-distance synchrononization of human brain activity

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Transient periods of synchrononization of oscillating neuronal discharges in the frequency range 30–80 Hz (gamma oscillations) have been proposed to act as an integrative mechanism that may bring a widely distributed set of neurons together into a coherent ensemble that underlies a cognitive act1–4. Results of several experiments in animals provide support for this idea (see, for example, refs 4–10). In humans, gamma oscillations have been