Mellifluous matures to malodorous in musth
Mood-altering secretions by excited male elephants smooth out social interactions.

Male Asian elephants in musth — an annual period of heightened sexual activity and intensified aggression — broadcast odoriferous, behaviourally influential messages from secretions of the temporal gland. From our observations in the wild, together with instantaneous chemical sampling and captive-elephant playback experiments, we have discovered that young, socially immature males in musth signal their naiveté by releasing honey-like odours to avoid conflict with adult males, whereas older musth males broadcast malodorous combinations to deter young males, facilitating the smooth functioning of male society. As elephant–human conflicts can upset this equilibrium, chemically modulating male elephant–human conflicts can upset this smooth functioning of male society. As males mature (post-moda), their periods of increased androgen hormone levels lengthen, aggressive behaviour becomes overt, and their copious secretions are chemically altered to resemble those of the adult temporal gland. We analysed the changing chemical composition of temporal-gland secretions from young post-pubertal male Asian elephants, who were exhibiting episodes of aberrant behaviour and had fluctuating hormone levels (Table 1). Combining innovative modification of solid-phase micro-extraction, capture of headspace volatiles in evacuated bottles, and chemical analysis by gas chromatography with mass spectrometry, we identified the predominant components in the mellifluous exudates as 3-hexen-1-ol, two ketones (2-heptanone and acetophenone) and various acetates (mainly isoamyl acetate) — all of which are sweet-smelling (Table 1). There is a marked chemical convergence between the temporal-gland secretions of male Asian elephants in moda musth, and honeybees and honey — honey also contains 3-hexen-1-ol and sweet-smelling acetates, and bees use pheromone blends containing 2-heptanone and acetates, including isoamyl acetate.

As males mature (post-moda), their periods of increased androgen hormone levels lengthen, aggressive behaviour becomes overt, and their copious secretions are chemically altered to resemble those of the adult temporal gland (Table 1). Concentrations of 3-hexen-1-ol and acetates are greatly reduced, and acetophenone is replaced by a foul-smelling combination of 2-nonanone, acyclic ketones and substituted cyclohexanones, including 3-methyl-2-cyclohexen-1-one and frontalyn (1,5-dimethyl-6,8-dioxybicyclo[3.2.1]octane).

These last two compounds are also secreted together as pheromones by bark beetles (Dendroctonus tenebrosus).

‘Playback’ experiments monitoring the responses of captive males to collected samples of temporal-gland secretions, together with observations of the behaviour of wild males of known chemical status, supported our idea that chemical signals change in association with maturing musth-linked behaviours. Moda males generally avoided the secretions of older males, whereas samples from moda males elicited little response from mature individuals (Table 1, and see supplementary information).

Encounters observed in the wild between a focal musth male, emitting chemically characterized adult secretions, and 12 different male conspecifics, emitting varying chemical signals, were consistent with our results from elephants in captivity. After sniffing the focal musth male from distances of 3–100 metres, three juveniles showed little reaction, five young males acquiesced, and four were apprehensive, choosing to avoid the senior male.

When the smell of a chemically defined moda male was assessed from a distance by...
the focal male, it was ignored, suggesting that the honey odour conveys a non-threatening message. However, the focal male stalked and attacked a different, slightly secreting young adult in a dominance interaction (see supplementary information). It is evidently advantageous to be able to recognize the ontogenic degree of musth in conspecífics before initiating physical encounters.¹²,¹³

Unravelling this medley of chemical signals helps to clarify the behavioural and physiological mechanisms that underlie the phenomenon of musth and its influence on other males. This knowledge should help in the formulation of deterrence programmes in southern India against crop-raiding wild elephants, most of which are male and are often in musth. Moreover, the modus-musth emanations of young maturing elephants, as poetically observed by the ancient Hindus, have now been substantiated by modern scientific techniques.¹⁴

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7. Kashiwaya et al. reply — The most important issue in the dating of the long Baikal core (600 m) is whether the segment between the base of C3An.2n and the top of C3Bn (267.67–375.48 m) is distorted. Changes in y-ray intensity (H. Tsukahara et al., personal communication), which reflects the structure of the cores, indicate that this part is different from the rest (strictly speaking, the upper and lower shifting points seem to be around 262 m and 362 m, respectively, from the fluctuation). To investigate this difference, we carried out spectral analyses of the upper section of the core (163–261 m), and of the middle (263–361 m) and lower (363–673 m) parts. Prevailing periods for each part are different, particularly in the middle one. There is a distinct common prevailing period of around 4.5–4.9 m in the upper and lower parts, whereas a period of 18 m prevails in the middle part, suggesting that the structure of the middle is different from the upper and lower parts of the core.

We are therefore reluctant to propose an age model that includes the middle part without further information on this section. Another recent age model⁶ omits any discussion of this point, although the structure cannot be explained without further information.

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Figure 1 Progressive change of facies at the BDP-98 drill site, indicating that average sedimentation rates cannot be almost uniform throughout the section, as suggested by the age model of Kashiwaya et al. The lithology of the section also shows that there is no justification for the excision of the shaded interval in order to fit the age model. All of the components, apart from diatom abundance and sand laminae, are expressed as occurrences per 1-m interval in the split core.

 logical results indicate that there is a need to revise the age model and the signal-processing results of Kashiwaya et al.¹⁴

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⁶Tsukahara et al., personal communication.

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