how the VTA and SC coordinate the successful execution of goal-directed head movements and how target value, and the presence of reward in general, impact on head movement decisions and kinematics.

The existence of a markedly motor-related population within the VTA has interesting implications with respect to the organisation of brain circuits responsible for the execution of goal-directed behaviour. Given that such behaviour relies on the precise execution of a motor plan in three-dimensional space matched by an appropriate reward-driven motivational state, this and other recent work [10] support the idea that these two representations co-exist within the VTA and pave the way to future studies on the interaction of the neuronal populations responsible for their implementation.

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# Water Balance: Abstaining from Obtaining While Retaining

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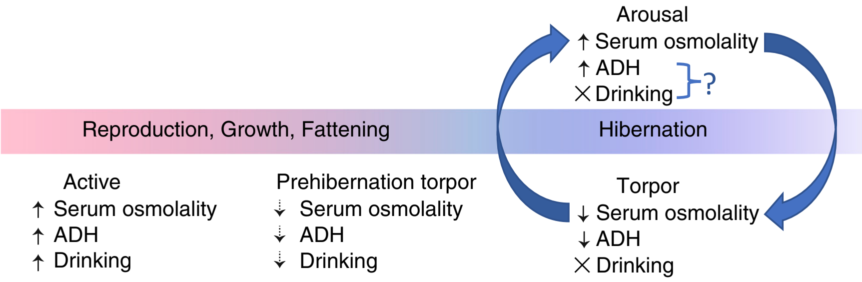
Animals tightly regulate blood volume and solute concentrations. Water balance is usually achieved by a combination of managing intake and excretion but sometimes both drinking and urination are inconvenient. Hibernators have perfected internal mechanisms to maintain water balance without either.

Thirst is a powerful drive — ask anyone who has exercised without drinking water in the heat of summer. This is because even tiny changes in our blood osmolality trigger homeostatic mechanisms [1,2]. When water is depleted, the hypothalamus region of the brain coordinates the incoming signals warning of decreased blood volume



Current Biology

**Figure 1. Hibernation and water balance.**
The annual cycle of activity (red) and hibernation (blue) in 13-lined ground squirrels is represented by the shaded bar. The blue arrows depict one of the repeating torpor–arousal cycles that characterizes hibernation. Four physiological conditions were examined [3] for serum osmolality, concentrations of the antidiuretic hormones (ADH) oxytocin and vasopressin, and drinking behavior; solid up arrows represent the greatest observed, dashed or solid down arrows less or least, and x, none observed, of the adjacent measured feature. The unexpected uncoupling of ADH release and drinking during arousal from torpor where osmolality returns to active levels is highlighted.

(baroreceptors) and increased osmolyte concentration (osmoreceptors), directing us to find and drink water by making us feel thirsty. The hypothalamus simultaneously instructs our kidneys to recover more water by releasing antidiuretic hormone, or ADH, into the circulation. A new study by Feng *et al.* [3] published in a recent issue of *Current Biology* provides evidence that hibernating ground squirrels uncouple these brain mechanisms of thirst and water retention.

What if you couldn't drink for six months? In nature, hibernating ground squirrels disappear for half the year into underground burrows where they are relatively safe from predators. They neither eat nor drink during this entire time, and spend most of it in a state of deep torpor. While torpid, their heart, respiratory and metabolic rates plummet, and body temperature hovers just above freezing. This strategy saves a tremendous amount of energy that would otherwise be needed to maintain activity at high body temperature when the environment is cold [4]. A need to drink would obviate many advantages of this energy-saving adaptation. Significantly, it would endanger the animals' survival by requiring additional fuel and by greatly increasing their chances of becoming someone else's dinner.

Ground squirrels prepare for hibernation in autumn, most conspicuously by becoming obese, and begin to use torpor even when environmental temperatures remain relatively warm [5]. Paradoxically, torpor is not continuous throughout the many months of hibernation. Instead, every week or two, the animal undergoes intense metabolic reactivation, rapidly raising its body temperature by 30°C. These arousals from torpor last less than 24hrs. While the exact purpose of this energy-consuming process is not known, it is clear that effectively all biochemical and physiological processes that were slowed or suspended during torpor resume during these brief rewarmings [6]. Hibernators cycle back and forth between these profoundly different states of torpor and arousal numerous times during each hibernation season (Figure 1).

Feng and colleagues wondered how hibernating ground squirrels manage osmolyte concentration and hydration status without drinking for such a long time. Despite their inactivity, the hibernators must be losing water to the environment simply through breathing and evaporation. They also produce small amounts of urine [7]. The authors measured serum osmolality, hormone concentrations and drinking behavior in four physiologically distinct groups of ground squirrels. The groups included three phases from hibernation — animals in between bouts of torpor (IBA), or while torpid either early in the season with body temperature 20–25°C (prehibernation), or mid-season at 5°C (hibernation). These hibernators were compared to active animals that were not prepared for hibernation. The authors also tested responsiveness to an artificial increase in serum osmolytes, which has long been known to trigger drinking behavior and water retention by the kidneys.

Intriguingly, animals in torpor were *more* hydrated than active animals. The decreased plasma osmolality was strictly correlated with simply being torpid. It did not change with the number of days spent in a bout of torpor, the number of months spent in hibernation, or the number of times the hibernating animal had aroused. Yet plasma osmolality in the IBA hibernators was restored to the level seen in active animals. Thus, as an animal cycles between torpor and arousal, plasma fluid volume increases and decreases, or the osmolyte concentration decreases and increases.

Careful monitoring confirmed the animals did not anticipate dehydration in torpor and thus did not drink water prior to entering torpor, as occurs prior to sleep [8]. Enhanced water recovery by the kidneys, signaled by elevated ADH in the blood (specifically in rodents, oxytocin and vasopressin) could also lower plasma osmolality during torpor. But circulating levels of both of these antidiuretic hormones were decreased in the torpid animals. Perhaps catabolism of fatty acids, the main fuel of hibernation, could provide enough metabolic water to increase hydration? But the authors provide a compelling argument that fat catabolism is insufficient to account for the repeating cycles of increased hydration during torpor. Moreover, not all plasma osmolytes were depleted equally, further supporting a conclusion that the decreased osmolality cannot be caused by simple dilution. From these results it appears that key plasma osmolytes including sodium, potassium and lactate are sequestered from the plasma during torpor and returned during each arousal.

Finally, the authors examined the thirst circuitry by perturbing the system and monitoring drinking behavior. As noted above, aroused hibernators naturally choose not to drink or drink very little compared to active animals, despite the similarity in their blood osmolality. However, when plasma osmolality was further increased artificially by injection of a hypertonic solution, both the active, non-hibernating ground squirrels and the aroused hibernators responded by drinking, just like the active, non-hibernating ground squirrels. This result indicates that the hypothalamic circuitry that senses and responds to dehydration is intact and functional in hibernation. There is, however, an uncoupling of the release of ADH and drinking (thirst) such that thirst is suppressed during normal arousal despite normal ADH release and only activated when blood osmolality is artificially elevated.

Further studies are needed to address several key questions that remain. How are such large swings in plasma osmolality tolerated by the ground squirrel's cells and tissues? Where exactly are the osmolytes sequestered during torpor, and how is the cyclical capture and release controlled? By what mechanism is thirst suppressed for many months of hibernation and how is the urge to drink uncoupled from the release of oxytocin and vasopressin? Uncovering the answers to these questions holds promise for improving solutions to human situations where body fluid homeostasis is challenged, including critical care medicine and space exploration.

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# Auditory Perception: Relative Universals for Musical Pitch

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**Do members of a remote Amazonian tribe and Boston-trained musicians share similarities in their mental representations of auditory pitch? According to an impressive new set of psychoacoustic evidence they do, a finding which highlights the universal importance of relative pitch patterns.**

Music is a feature of all human cultures. The bewildering diversity of musical practices can be sampled simply by flicking randomly through radio stations or, for the more adventurous, by having a sneak peek at your children's playlists. As remarked in the 19th century by Helmholtz in his seminal opus [1], music starts with completely 'shapeless' acoustic material. Music is free to use any sounds in the world, and to arrange them in any way it pleases. So, music should be a unique product of its own culture, profoundly alien to any outsider — but this is not the case [2,3]. There are statistical universals that, presumably, tell us profound truths about how sound is processed by the human brain. As they report in this issue of *Current Biology*, Jacoby *et al.* [4] travelled deep into the Amazonian forest to probe the mental representation of pitch in members of a remote tribe, the Tsimane'. What they discovered is that Tsimane' share several aspects of pitch perception with Westerners: a log-frequency representation, with the same frequency limits that do not match the audible range. However, octave relationships or even the absolute frequencies composing a musical pitch interval were largely irrelevant to the Tsimane'.

To unpack the significance of these findings, it is useful to go briefly over basic facts about sound, music, and the human auditory system. The singing voice and many musical instruments produce periodic sounds, that is, acoustic waveforms that repeat over time with a fixed period. Periodic sounds can be decomposed into harmonic