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

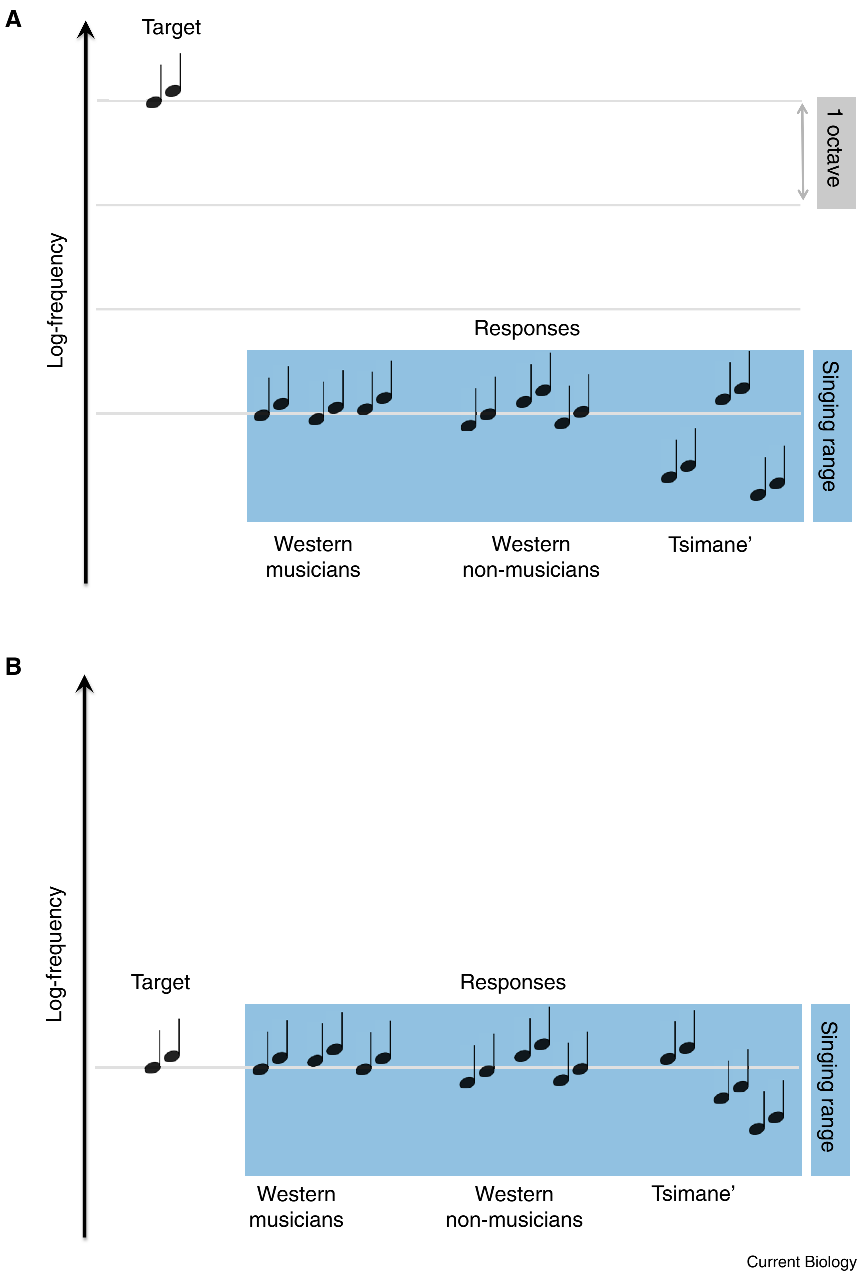

Figure 1. Illustration of the experimental paradigm and main results.
Participants heard a target pitch interval played over headphones, and were asked to sing it back. (A) When the target interval was too high in frequency to be sung comfortably, participants had no choice but to transpose, that is, to change the pitches composing the intervals. For all groups of participants, transpositions preserved log-frequency patterns. For Western musicians and non-musicians, the transpositions also clustered around octaves of the target intervals, but not for Tsimane' participants. (B) When the target interval was presented within singing range, Western listeners attempted to match the exact target frequencies. Tsimane' generally did not, even if a small effect was observed.

series: a set of pure tones with frequencies that are integer multiples of a low, fundamental frequency (and hence, share a common periodicity). In the Western tradition, notes (labeled C, D, E, and so on) are defined by their fundamental frequencies. Scales are discrete sets of notes used as structural elements. A central feature of Western scales is that they are logarithmic: they are built on frequency *ratios*. To move from C to G, a musical fifth, a ratio of 3:2 is applied to the fundamental frequency of C (ignoring the small variations between tuning systems).

Throughout the human auditory system, from the cochlea up to at least primary auditory cortex, most neurons respond only to a restricted frequency range. They are arranged in 'tonotopic maps', with neurons responding to low frequencies at one end and those responding to high frequencies at the other end. Thus, cues to the absolute frequency of a tone are ubiquitous. Remarkably, however, there is up to now no uncontroversial evidence for the existence of precisely logarithmic maps. From this point of view, the fact that the Western musical scale is precisely logarithmic is intriguing. This mathematical property has fascinated an astonishing range of thinkers, such as Pythagoras, Galileo, Kepler, Newton, Leibniz, Rameau, and Helmholtz. The proposed interpretations have ranged from a philosophical belief in the underlying numerical nature of the universe, to the physics of harmonics that contain simple frequency ratios, to peculiarities of the auditory system. Its musical use could also be dismissed as purely arbitrary. So, are logarithmic scales a product of culture, physics, or biology?

Jacoby *et al.* [4] used a cross-cultural comparison to revisit this enduring issue. They enrolled Western musicians, Western non-musicians, and members of the Tsimane' tribe. Tsimane' have had minimal exposure to Western music, as their territory is remote and hard to access. The comparison between the three groups should thus titrate the influence of exposure to Western music on musical pitch perception. The same approach has already produced key results renewing the nature/nurture debate about musical consonance [5] or rhythm [6].

Of course, probing mental representations of pitch using psychophysical methods in listeners from vastly different cultural backgrounds is a big ask. Jacoby *et al.* [4] introduce a novel paradigm, which is both ecologically valid and experimentally efficient. Pitch intervals were played to participants, who were simply asked to sing them back. The clever trick was that, in most cases, the target intervals to match were too high to fit within an adult's comfortable singing range (Figure 1A). Participants thus had to transpose the notes (change the pitch) in their sung response. How they would do this revealed their underlying pitch representations.

In Western participants, it was assumed that transpositions would preserve log-frequency distances. This sounds scary, but it is exactly what happens when one gets ready to sing "Happy Birthday". Before a courageous person in the group starts singing, no one is quite sure of what the first note will be. However, whatever the starting note, the tune retains its identity as long as its log-frequency pattern is preserved (and/or a cake appears). Log-frequency transpositions were indeed observed, for Western musicians and non-musicians alike.

This turned out to be also the case for the Tsimane': they conclusively produced precise log-frequency transpositions. Thus, Jacoby *et al.* [4] provide evidence that the logarithmic character of the Western musical scale (and, to be fair, many other scales around the world) stems from physics or biology rather than culture.

Another, perhaps more specific observation was made by Jacoby *et al.* [4]. For all groups, the accuracy of the transposition was degraded when the target tones had fundamental frequencies above about 4000 Hz, even though sounds remained clearly audible. This suggests that this musical pitch limit is also not due to cultural exposure, nor even physics, but rather reflects hard-wired biological processes.

However, a previously assumed universal seemed to be lacking in the Tsimane'. For most of the scales known around the world, notes separated by one octave receive the same name; they form a single *pitch class*. This suggests some form of 'octave equivalence'. Past evidence has shown that perceptual sensitivity to octave equivalence may have inborn roots [7] but depends on musical practice or exposure in Western adult listeners [8,9]. In the Jacoby *et al.* [4] study, Western listeners, especially musicians, tended to preserve pitch class in their sung responses: for instance, if the interval to sing back was C–D, a whole tone, not only did participants sing back a whole tone (D–E, G–A, and so on) but they were statistically more likely to sing back C–D. The Tsimane' participants, by contrast, used any pitch class to reproduce the target interval, showing no preference for octave relationships.

This is remarkable, but could be explained by a further fascinating finding of Jacoby *et al.* [4]. When the target intervals were presented *within* comfortable singing range, Tsimane' participants most often did not match the exact frequencies of the target interval, even though this would have been physically possible. Rather, they transposed the (correct) interval in their sung responses (Figure 1B), even if instructions were varied to encourage exact matches. This indicates that, for some cultures, reproducing pitch intervals is really about preserving log-frequency patterns, the actual frequencies involved mattering very little.

The latter finding brings further support to a proposal that pitch intervals *per se* may be represented explicitly by the auditory system, in addition to a representation of single pitches [10–12]. The loss of octave equivalence may then be a by-product of an emphasis on relative pitch representations. In fact, the Tsimane' data expose beautifully one of the most vexing puzzles about pitch perception: throughout the auditory system, cues to absolute frequency abound; however, discarding such cues is essential for effective pitch transposition. For the Tsimane', it seems that such relative pitch representations totally supersede the first-order representations of absolute frequency. Where these 'relativist' computations take place in the brain remains largely mysterious.

So, this unique, precious and extensive dataset demonstrates both striking similarities and unexpected differences in how Tsimane' and Western listeners perceive or conceive musical pitch. The new study by Jacoby *et al.* [4] contributes to the age-long debate about the interplays between culture and biological constraints in music. This is a very important debate. If music is part of what makes us uniquely human, what uniquely makes music should be of interest to all of us.

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