Comment on "How Cats Lap: Water Uptake by *Felis catus*"

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Reis *et al*. (Reports, 26 November 2010, p. 1231) reported on the mechanism by which cats lap and gave a theoretical and experimental analysis of their observations. Their explanation for the cat's lapping frequency, however, is based on an incorrect application of the principles of fluid dynamics. The revised analysis given here agrees with their observations and predicts a similar lapping frequency for cats and dogs.

Reis *et al*. (*1*) showed the remarkable way by which cats lap fluids. A cat extends its tongue to the surface of the fluid and lifts a slender column to its mouth by adhering the tip of the column to the dorsal side of its tongue. Afterward, without shifting its head, the cat rapidly closes its mouth, enabling it to capture a portion of the fluid column, and then repeats this cycle with a lapping frequency $f = 3.5 \pm 0.4\ s^{-1}$. To understand this mechanism, and to explain this lapping frequency, Reis *et al*. performed a fluid dynamics experiment that simulated the cat's mechanism and provided a scaling analysis, explaining that "the column dynamics are set by a competition between inertia and gravity." Their scaling relations, however, are based on an incorrect application of the principles of fluid dynamics, and, as expected, it does not provide a quantitative agreement with their observations. For example, their theoretical prediction for the lapping frequency is $f \sim (gH)^{1/2}/R$, where H is the length, R is the radius of the cat's tongue, and g is the acceleration of gravity. But for $H = 3$ cm and $R = 0.5$ cm, corresponding to their cat's tongue dimensions, $f \sim 108\ s^{-1}$, which is a factor 31 times larger than their observation. An analysis that does agree with their observations is given here. Although dogs lap by a more elaborate mechanism, curling the tongue backward to scoop some of the fluid, my analysis shows that their lapping frequency is similar to that of cats.

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The scaling analysis of Reis *et al*. is based on two incorrect premises about the physics governing the flow in the fluid column under consideration: (i) that the fluid pressure is the hydrostatic pressure $p = \rho g z$ at height z, corresponding to the pressure of a confined column of fluid of density ρ, where g is the acceleration constant of gravity, and (ii) that the balance between fluid inertia and gravity is determined by the relation $\rho v^2_R \sim p$, where v_R is the radial speed at z. The fluid in this column, however, is not static but instead flows freely under the action of gravity, and, therefore, in a first approximation, the difference of fluid and atmospheric pressure can be neglected. Hence, the relevant time that determines the lapping frequency is the characteristic time t_G for the fluid in the column to descend back into the bowl. The mean axial velocity of the fluid in a column of height H is $v_z = (gH/2)^{1/2}$, and $t_G = H/v_z = (2H/g)^{1/2}$, which is the Galilean time for an object to fall from height H. For a lapping height $H = 3$ cm, $t_G = 78$ ms, which is close to the observed 70 ms taken by Reis *et al*.'s cat to lift the milk by its tongue. Also, the predicted cat's tongue mean velocity, $H/t_G = 38\ cm\ s^{-1}$, corresponds to the observed value $U_{MAX}/2 = 39\ cm\ s^{-1}$. Finally, the predicted lapping frequency $f = 1/(4t_G) = 3.2\ s^{-1}$ is in good agreement with their observation [an additional factor of 2 in the time between laps is based on the data of Reis *et al*. in figure 2 in (*1*) that shows that the tongue rests for a time of order $2t_G$].

It should be pointed out, however, that a column of fluid confined only by surface tension is unstable. This instability, which was ignored by Reis *et al*. in their analysis, was first studied experimentally by Joseph Plateau (*2*) and later described theoretically by Lord Rayleigh (*3*) who determined the characteristic time scale t_R for collapse of the column. Neglecting the effect of gravity, Rayleigh found that $t_R \sim 3(\rho/\sigma)^{1/2}R^{3/2}$, where ρ is the density, σ is the surface tension of the fluid, and R is the radius of the column. Initially, R decreases with time, as can be seen also in Reis *et al*.'s simulation, and after $t_R < t_G$, corresponding to $R < R_o = [(2H\sigma)/(9\ g\rho)]^{1/3}$, the Plateau-Raleigh instability takes over, leading to the break-up of the fluid column observed by Reis *et al*. For milk at room temperature, $\sigma = 44\ g\ s^{-2}$ (*4*), $\rho = 1\ g\ cm^{-2}$, and $R_o = 0.311$ cm.

Assuming that the lapping height H scales approximately with the size or mass M of the animal according to the relation $H \propto M^{1/3}$, it also follows from my analysis that the lapping frequency $f \propto H^{-1/2} \propto M^{-1/6}$. This dependence appears to be in agreement with Reis *et al*.'s observations for the lapping frequency of large felines. After the first submission of this article, Crompton and Musinski presented a high-speed x-ray video demonstrating how a dog ingests a column of liquid adhering to its tongue (*5*). They found that it took their dog 110 ms to trap the liquid, in excellent agreement with my own observations and prediction that for $H = 6$ cm, $t_G = 111$ ms.

References and Notes

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