theory, commonly used in fluid mechanics and engineering to estimate diffusion by turbulence in pipes and channels. The turbulent transport of a quantity, for example, heat, is parameterized as a mixing coefficient times the average gradient of, in the case of heat, temperature. The theory provides an estimate of the mixing coefficient in terms of certain gross statistics of the turbulence — the root-mean-square (r.m.s.) velocity and the size (mixing length) of the eddies. The difference in the oceanic context lies in the large scales (10–100 km) of the turbulent eddies and the dynamics, involving the Coriolis force associated with Earth's rotation, that sustains them. The mixing coefficient is proportional to the r.m.s. sea-surface height, which serves for pressure in the ocean and hence for velocity, and which can be measured globally to sufficient accuracy (several centimetres) with radar altimeters on satellites. Just such an instrument was carried by the short-lived Seasat mission[8] in 1978, the data from which Keffer and Holloway use to test their theory. Other altimeters are now in space or planned.

Keffer and Holloway's model is not flawless. The basic theory is worked out for geostrophic turbulence in a homogeneous layer of fluid on a curved, rotating Earth. The real ocean is certainly not homogeneous, and density stratification influences the vertical structure of large-scale eddies, which are invariably more intense near the ocean surface. The authors allow for this by arbitrarily halving the theoretical mixing coefficients. On the other hand, the Seasat data they used spanned only a 28-day period, which does not cover the range of eddy timescales (10–100 days) thought to be responsible for turbulent heat flux. Keffer and Holloway compensate for this by doubling their mixing coefficient estimate. Although these corrections cancel, their arbitrariness introduces uncertainty. Also, the theory does not allow for the dynamical effects of buoyancy forces associated with temperature variations in eddies but instead treats temperature as a passive quantity. The large-scale temperature gradients associated with the Antarctic Circumpolar Current can produce eddies of the requsite time and space scales by 'baroclinic' instability[9], which is absent from Keffer and Holloway's model.

Still, the new calculations give estimates for eddy heat flux across the Southern Ocean of the same magnitude as the heat lost by high-latitude waters. Although the theory is not watertight, it shows how satellite-borne instruments can yield ocean-wide data useful for computing the parameters, like eddy heat flux, of vital geophysical importance. *In situ* field experiments will test the details of theories and parameterizations such as Keffer and Holloway's, so that reliable methods of remote sensing with satellites can be developed. □

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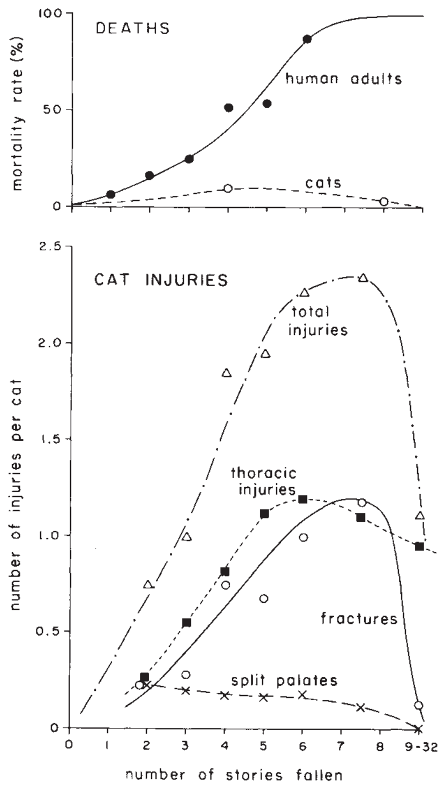
Animal behaviour

Why cats have nine lives

Jared M. Diamond



Mortality rates for falling adult humans and cats (above), and number of total injuries and various types of injury per falling cat (below), as a function of number of stories fallen. (Based on the work by Waring and Demling and by Whitney and Mehlhoff.)

THE famous adage that cats have nine lives stems in part from their ability to survive falls lethal to most people. This phenomenon has not received the scientific attention that it deserves. Filling this lacuna, a new study by W.O. Whitney and C.J. Mehlhoff (*J. Am. Vet. Med. Assoc.* **191**, 1399–1403; 1987) applies principles of anatomy, physics and evolutionary biology to falling cats.

The authors were veterinarians at an animal hospital in New York City, where skyscrapers, open windows and paved ground combined to generate a database of 132 cats injured by falls of 2 or more stories, with a maximum of 32 stories and a mean of 5.5 ± 0.3 (s.e.m.) (1 storey = 15 feet). Most victims landed on concrete after a free-fall. Omitting 17 cats that were euthanatized by owners unable to afford treatment, 90 per cent of the cats (104 of 115) survived, whereas 11 died (mainly because of thoracic injuries and shock). The most remarkable feature of the results (see figure) is that incidence both of injuries and of mortality peaked for falls of around seven stories and decreased for falls from greater heights. For instance, the cat that free-fell 32 stories onto concrete was released after 2 days of observation in the hospital, having suffered nothing worse than a chipped tooth and mild pneumothorax.

Falling adult humans differ from falling cats in their much higher mortality rate, monotonic mortality/height relation, different causes of death, and different sublethal injuries (Warner, K.G. & Demling, R.H. *Ann. emerg. Med.* **15**, 1088–1093; 1986). As illustrated in the figure, higher falls are increasingly lethal for humans, and few adults survive falls of more than six stories onto concrete. The principal causes of death are head injuries and haemorrhage from visceral injuries. Although forelimb fractures are slightly commoner than hindlimb fractures in falling cats, falling adult humans most often break their legs, and falling children their arms (Smith, M.D. *et al. J. Trauma* **15**, 987–991; 1975).

Straightforward theory relates injuries from falls to three sets of variables, as shown by Warner and Demling. First, the height of the fall determines the impact velocity. Second, the softness of the surface of impact affects the stopping distance and hence the impact force. Those people surviving falls from aeroplanes have landed on mud or snow, not concrete. And third, at least five properties of the falling body itself are relevant: its mass, which determines impact force (F) and energy; its cross-sectional area A, determining frictional drag during fall and also stress on impact (F/A); cross-sectional areas of bone, determining bone strength; cushioning of vital parts by fat and other soft tissue; and dissipation of impact forces through flexing of muscles and use of joints.

These theoretical considerations provide several reasons why cats survive falls that kill adult humans. First, because mass increases as the cube but surface area as the square of linear dimensions, falling large animals are in general more injury-prone than small ones, as they suffer greater impact stress, their bones experience greater stress, and they reach higher terminal velocities in free-fall because of a less favourable area/mass ratio. Even a small drop breaks an elephant's leg, but falling mice reach terminal velocity in the atmosphere much sooner and at a much lower value than do falling elephants.

Second, falling cats have a superb vestibular system and make gyroscopic turns such that all four feet are soon pointing downwards, regardless of the cat's orientation at the start of the fall. Hence cats dissipate the impact force over all four limbs. Falling human adults tend to tumble uncontrollably but land most often on two feet, next most often on their heads. Falling babies, because their relatively large heads shift their centre of gravity towards the head, tend to land head-first with arms reflexly extended to break the fall. These facts contribute not only to the lower mortality of falling cats but also to the tendencies of falling babies, adults and cats to broken arms, broken legs and breaks distributed over all four limbs, respectively.

Third, a cat falling in the atmosphere reaches a terminal velocity of about 60 m.p.h. (compared with 120 m.p.h. for adult humans) after only about 100 feet. As long as it experiences acceleration, the cat probably extends its limbs reflexly, but on reaching terminal velocity it may relax and extend the limbs more horizontally in flying-squirrel fashion, thus not only reducing the velocity of fall but also absorbing the impact over a greater area of its body. This may explain the paradoxical decrease of mortality and injury in cats that fall more than 100 feet.

Finally, cats that land with their limbs flexed dissipate much of the impact force through soft tissue. Parachutists are trained to dissipate impact forces by landing with knees and hips flexed, then rolling.

Evidently, falling cats have some advantages shared with any small animal of similar mass and shape but also have unique advantages of their own, notably their gyroscopic righting reflex and their limb flexing on landing. Small dogs that fall from buildings are prone to more serious injuries than cats. The cat-specific advantages have undoubtedly evolved through natural selection: most felid but few canid species are arboreal, so that millions of years of springing or falling from trees have favoured those felids with the best vestibular systems. Thus, the nine lives of cats are a product of their evolutionary history. □

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Indian maize in the twelfth century BC

GODDESSES and gods in sculptured soapstone friezes in Hoysala temples of the twelfth and thirteenth centuries BC near Mysore, India hold in their hands representations of maize ears. There are more than 63 of these large ears at Somnanthpur, and maize is represented at three other temples I have visited.

In the Hoysala tradition, worshippers must have used maize as a golden coloured and a many-seeded fertility symbol in their religious rites. That the ears are modelled on maize is shown by the ear length-to-diameter ratio, the ear sizes in relation to parts of human figures, and the wide variation of anatomical detail in the carvings that all belong to maize: the ears have either parallel, highly tapered or bulging sides, their tips are pointed, and their axes may be straight or warped, depending on the moisture at the time of picking and the way maize dries.

Normally, the husks are removed from religious offerings of maize to show perfection. Only part of the husks have been removed on a few ears in the sculptures, showing three to seven rows of kernels. Occasionally, husks are left whole with an etched curl of silk signifying that the smoothed object, with the several shapes of ears inside, is maize.

Kernels generally have a rounded, rectilinear outline with a width-to-thickness ratio that is found in modern maize, though it is more typical of ancient maize. The kernels get smaller near the tips, and kernels are larger next to a gap in the row as the adjacent kernel tends to fill in the space. Kernels are arranged generally in pairs, in parallel rows that nest together on the cob, and they shift relative arrangements up and down the ear the way the pairs of modern maize kernels do. The most definitive evidence is that a few ears illustrate that the maize models had a jumbled or tessellate arrangement at the butt of the ear.

No other plant or object has the extensive intricacy and variation of highly segregated maize that could serve as a model for the sculptures. No other fruits have the same number and shape of the closely packed kernels that are arranged in parallel rows in the sculptures.

The existence of maize in twelth-century India appears to contradict the widely-held view that no evidence exists for trans-oceanic contact between civilizations at this period.

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