

consider a point on the attractor, and ask how long it will be before a trajectory starting at that point returns, not exactly to that point (as in the periodic trajectory calculation), but to within some certain distance of that point. Although a method was developed in the mid-1980s to find multifractal properties based on the properties of the recurrence times³, this method had not been applied to strange attractors, and had not been verified against more rigorous methods (an important step, given the unfortunate history of box-counting).

These gaps have now been filled by Gratrix and Elgin¹, by developing the recurrence-time method for the Lorenz attractor and by verifying it against the periodic trajectory method. Because calculations based on recurrence times should be relatively straightforward for experimentalists, and as we now have reason to believe that they will be more reliable than box-counting results, we can confidently await a new series of experimental demonstrations of the chaotic properties of a variety of natural systems.

But will this solve the problem of the butterfly and the hurricane? The Lorenz attractor lives in a three-dimensional phase space; a hurricane lives in a phase space with an enormous number of dimensions. After several decades of work on chaos, we still do not understand the extent to which systems with such large numbers of degrees of freedom (typically turbulent systems) can be understood using the same concepts as for chaotic systems, which are relatively simple in comparison. So if a hurricane destroys your beach house, the verdict against the butterfly is: not proven. ■

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Human longevity

The grandmother effect

Kristen Hawkes

Why do women live long past the age of child-bearing? Contrary to common wisdom, this phenomenon is not new, and is not due to support for the elderly. Rather, grannies have a lot to offer their grandchildren.

Those who think postmenopausal women make little difference in the story of human populations will be surprised by the report of Lahdenperä and colleagues on page 178 of this issue¹. The authors have unearthed firm evidence in support of the ‘grandmother hypothesis’, according to which a grandmother has a decidedly beneficial effect on the reproductive success of her children and the survival of her grandchildren.

The question of human longevity has deeper evolutionary importance than many think. It is often assumed that the steady increase in life expectancy over the past century and a half² has resulted in a larger proportion of older people than ever before. But, until the past few decades, increases in life expectancy reflected reductions in infant and juvenile mortality, and made little difference to the fraction of women past child-bearing age. As shown in Fig. 1, it is levels of fertility, not life expectancy (mortality), that shift the proportion of elders in a population. Even when life expectancy is well below 40 years, most girls who survive childhood live past their child-bearing years. In both historical and hunter-gatherer populations, a third or more of women are usually beyond the age of 45.

This large proportion of older people has fundamental implications for all human social organizations. Its unusual character is highlighted by comparisons with other primates. For example, among our closest living relatives, chimpanzees, female fertility declines at about the same age as in people, from a peak before age 30 to virtually zero at age 45 (ref. 3). But chimpanzee survival rates fall along with fertility, so that in the wild less than 3% of the adults are over 45 (ref. 4).

We might assume that the large fraction of elders in human populations reflects a characteristically human social safety net. But natural selection generally favours the flow of help from older to younger kin (Fig. 2), so we should be sceptical that a species-wide pattern of care for older people explains human longevity⁵. Developments in evolutionary life-history theory suggest that, instead of help for older members of the population, it is help from postmenopausal grandmothers that accounts for the age structures of human societies.

Mammalian life histories fall along a fast–slow continuum⁶. At one end, maturation is quick, fertility is high and adults die young. At the other, maturity is delayed, reproduction is slow, and adults usually live long enough to grow old⁷. The most

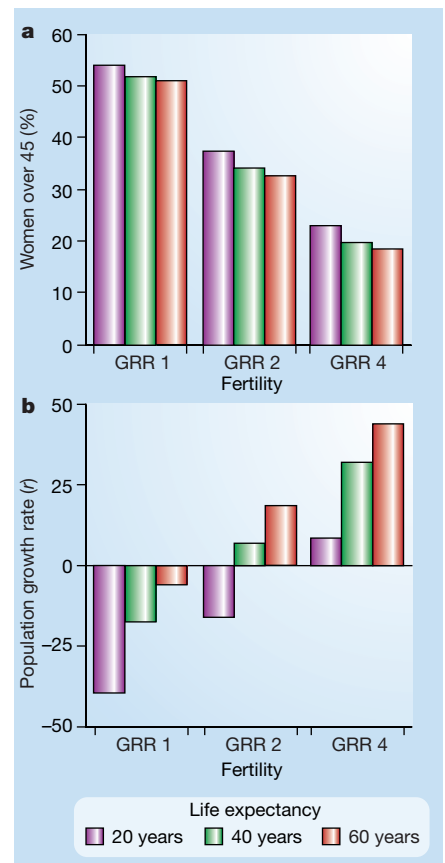


Figure 1 Population profiles for women — females over 15 years of age — for different variables. a, The proportion of women over 45 for different life expectancies (20, 40 and 60 years) and fertility levels (expressed as gross reproduction rate, GRR, which is equivalent to the average number of daughters for women who survive the fertile years). When life expectancies are the same, higher fertilities make younger cohorts larger and the proportion of elders smaller (compare all the purple bars, all the green bars, all the orange bars). When fertility levels are the same (each cluster of bars), the fraction of elders varies little even across a tripling of life expectancies. Life expectancies vary widely with differing levels of infant and juvenile mortality. The point to stress is that, at the same fertility level, populations with shorter life expectancies do not have fewer elders: in fact, they have slightly more women past fertile ages. b, Population growth rate (r = annual rate of growth/1,000) accompanying each combination of fertility and life expectancy. The very high proportions (> 50%) of women past 45 occur in sharply declining populations, and the very small proportions (< 20%) in swiftly growing populations. Growth rates that differ from zero cannot be sustained for long. (Data from ref. 17.)

successful model for explaining this cross-species variation⁸ shows that adult lifespans can determine the other life-history traits. The relationship between average adult lifespan and average age at maturity is much the same across the living primates, including humans⁹. Chimpanzees are at the slow

extreme; humans are even slower. From this perspective, the question to ask is, what caused the extension of lifespan in human evolution?

The answer may lie in grandmothers' contribution to childcare. Unlike other primates, including chimpanzees¹⁰, human children are unable to feed themselves when they reach weaning age. The foods we rely on are too difficult for young children to handle. This gives women whose fertility is ending (so they have no newborns of their own) an opportunity to influence the reproductive success of their daughters and survival of their grandchildren through assistance in food provisioning. In an ancestral population that was shifting from chimpanzee-like feeding to hard-to-handle foods¹¹, the more vigorous elder females could help more, thereby increasing the representation of their vigour in descendant generations, shifting rates of ageing¹², and lengthening average adult lifespans¹³.

This 'grandmother hypothesis' accounts for various similarities and differences between the life histories of human females and those of our nearest living relatives. We live longer, mature later and space births more closely during the child-bearing years, whereas our fertility declines and we reach menopause at similar ages¹⁴. But does the hypothesis stand up to scrutiny?

A few studies have hinted at the relationship between postmenopausal longevity and the welfare of a woman's descendants, but most have been concerned about the timing of menopause. Lahdenperä and colleagues¹ focus squarely on the longevity question. They have analysed multi-generation records from two eighteenth- and nineteenth-century populations, Finnish (slow-growing) and Canadian (fast-growing). They show that in both of these populations the duration of a woman's postmenopausal survival affects both the reproductive success of her children and the survival of her grandchildren.

In neither the Finnish nor Canadian populations are these effects due to secular changes in both family size and longevity, or geographical differences that might give the same relationship independent of grandmother effects. Other studies have sometimes identified associations between postmenopausal longevity and numbers of children¹⁵, and different grandmother effects through sons and daughters. Lahdenperä *et al.* find neither.

Finer-grained data for the Finnish population allow them to go further. Both sons and daughters who had a living mother past menopause had children sooner and at shorter intervals, and raised more of them to adulthood. These differences are independent of differences in wealth, and increased the longer the mothers lived. Fewer grandchildren were born if the grandmother was not living in the same village. Because post-



Figure 2 Helping hands for the young — Granny provides assistance.

menopausal mothers were at different ages when each of their children had children, Lahdenperä *et al.* could compare the success of children of the same mother depending on whether she was alive or dead, improving the likelihood that differences are due to her help. Grandmothers' effect on the survival of grandchildren did not begin until the children reached weaning age, another detail indicating that the investigators were directly measuring her help. By controlling so many of the likely confounding factors, Lahdenperä and colleagues show that the family assistance provided by grandmothers is a central determinant of our longevity.

We age slowly. Physiological mechanisms must underlie that¹⁶. Accumulating evidence (referenced in ref. 13) shows that humans

allocate more to cell and molecular maintenance and repair than do our nearest primate relatives. The grandmother hypothesis attributes our slow ageing to the help that older females can give their descendants¹²; females ageing more slowly in physiological systems other than their ovaries could help more. Questions about male life histories involve different trade-offs, but this hypothesis about shifting rates of ageing has implications for longevity in both sexes. Daughters and sons both inherit genes affecting levels of cellular maintenance and repair from their mothers. While others work to unravel these mechanisms, Lahdenperä and colleagues have found evidence that can help to explain why they are set differently in us than in our nearest non-human kin. ■

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Quantum information

Flight of the qubit

Eugene Polzik

A trapped ion emits a photon. Ion and photon are entangled, so the photon carries away information on the state of the ion. Now realized, this system could become a communication link in a quantum network.

A quantum computer would be capable of performing certain operations, such as factoring large numbers, exponentially faster than its classical counterpart. It could also efficiently model processes that are excessively difficult to model using existing technology. Building such a computer is a formidable task, but spectacular progress has been made in the past few years. It is now widely acknowledged

that one of the most promising systems for quantum computation is an array of ions, trapped and controlled inside an electric field. The initial proposal¹ by Ignacio Cirac and Peter Zoller in 1995 has since been followed up by a train of theoretical and experimental breakthroughs, which last year arrived at the demonstration of elementary quantum logic gates using trapped ions^{2,3}. Now (page 153 of this issue), Blinov