to be worked out. But, because halteres sense rotatory self-motions, it seems reasonable to assume that the observed visual motion sensitivities must be interpreted in this context. Thus, although the halteres have been thought of as an extremely specialized, hardwired and purely mechanosensory system, Chan *et al.*[3] have forced us to reconsider the fly's 'gyroscopes' as sense organs that are under neural and visual control. □

Roland Hengstenberg is at the Max-Planck-Institut für Biologische Kybernetik, Spemannstrasse 38, D-72076 Tübingen, Germany, and at the Institute for Advanced Study, Wallotstrasse 19, D-14193 Berlin, Germany.
e-mail: roland.hengstenberg@tuebingen.mpg.de

1. Nalbach, G. *J. Comp. Physiol.* **165,** 321–331 (1989).
2. Lehmann, F.-O. & Dickinson, W. H. *J. Exp. Biol.* **200,** 1133–1144 (1997).
3. Chan, W. P., Prete, F. & Dickinson, W. H. *Science* **280**, 289–292 (1998).
4. Dickinson, M. H. *J. Exp. Biol.* **169,** 221–233 (1992).
5. Dickinson, M. H. & Tu, M. S. *Comp. Biochem. Physiol.* **116A,** 223–238 (1997).
6. Pringle, J. W. S. *Phil. Trans. R. Soc. Lond. B* **233,** 347–384 (1948).
7. Hengstenberg, R. *J. Comp. Physiol.* **163,** 151–165 (1988).
8. Nalbach, G. *J. Comp. Physiol.* **173,** 293–300 (1993).
9. Nalbach, G. *Neuroscience* **61,** 149–163 (1994).
10. Nalbach, G. & Hengstenberg, R. *J. Comp. Physiol.* **175,** 695–708 (1994).
11. Gnatzy, W., Grünert, U. & Bender, M. *Zoomorphology* **106,** 312–319 (1987).
12. Faust, R. *Zool. Jahrb. Physiol.* **63,** 325–366 (1952).
13. Heide, G. in *Insect Flight* (ed. Nachtigall, W.) 35–52 (G. Fischer, Stuttgart, 1983).
14. Schneider, G. *Z. Vergl. Physiol.* **35,** 416–458 (1953).

Climate change

The past as guide to the future

Gabriele Hegerl

We know that in recent years the Earth's climate has been getting warmer. But is this warming unusual relative to low-frequency variations in temperature? If it is, then how much of it has been caused by anthropogenic changes in the composition of the atmosphere?

On page 779 of this issue[1], Mann *et al.* provide a reconstruction of past temperature back to the year AD 1400, extending previous records further into the past, and deriving annual temperature anomaly patterns over large parts of the globe. As examples, the authors have produced reconstructions of the 'year without summer' (1816), which was probably influenced by the eruption of Mount Tambora in Indonesia, and of 1791 when a strong El Niño is known to have occurred. Such reconstructions are potentially useful for interpreting the warming trend in the twentieth century. For example, the reconstructed record for the Northern Hemisphere suggests that the warming is unprecedented, at least since 1400. Also, from a multivariate correlation between the reconstructed temperature time-series for the Northern Hemisphere and external climate influences, it seems that increases in greenhouse gases have been the main forcing in the twentieth century, whereas natural climate forcing by changes in solar irradiance and volcanism dominate the early part of the record.

Mann *et al.* use a quite original and promising method to produce their reconstructions, employing data from tree rings, ice cores, ice melt indices and long historical records of temperature and precipitation. The reconstruction is based on large-scale patterns of temperature fluctuations in the twentieth century as recorded by instruments. The authors derived an empirical relationship between the strength of these patterns in the twentieth century and the palaeoclimate indices, which were then used to estimate the magnitude of the same patterns in times before instruments were used to record temperature. This approach differs from that taken in producing local temperature reconstructions, on which other reconstructions of global-scale temperature are based (see, for example, refs 2 and 3), and enables use of instrumental data other than temperature and of proxy data influenced by more than temperature. For example, tree-ring data may reflect, among other influences, a combination of temperature and precipitation. Mann and colleagues attempt to use the relation of such variables with atmospheric dynamics to reconstruct large-scale temperature patterns.

Given the novelty of this approach, it is not surprising that the uncertainties need more investigation[4]. As the authors acknowledge, climate reconstructions can only be as good as the underlying data. The value of different data as temperature proxies[3] varies, which should also influence the pattern reconstructions. Similarly, problems in dating some records may decrease the quality of the reconstruction. Also, we need to know more about the influence of non-resolved patterns on global-scale averages, about the validity of the assumption that proxy and temperature data are related linearly, and about the quality of the reconstruction in the earlier part of the record where data are sparser.

Still, when Mann and colleagues' reconstruction is compared with other new recon-

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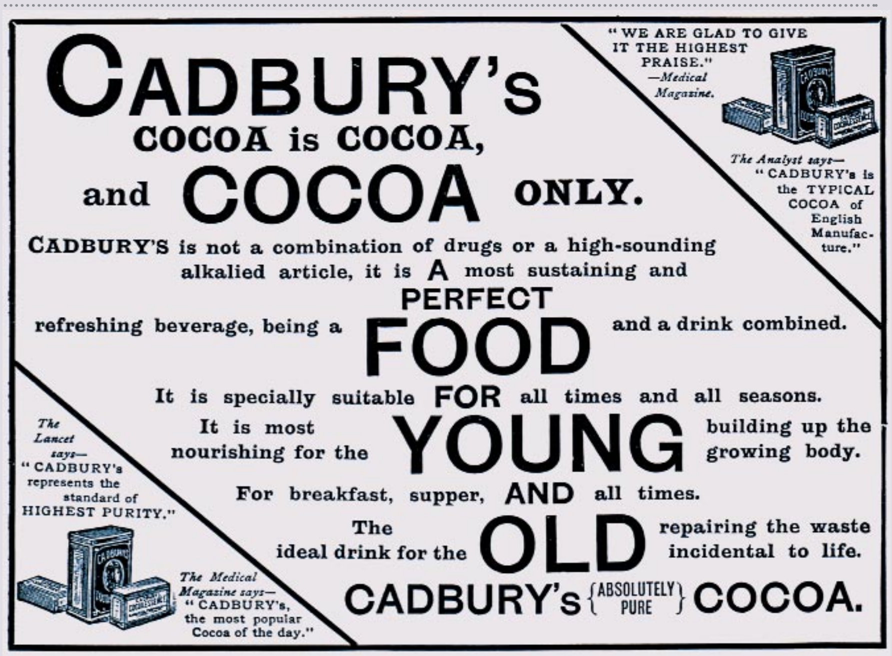


structions, as described elsewhere[4], the main features are broadly the same. Taking the record as a whole, most of the twentieth century has been unprecedentedly warm, whereas the nineteenth and the seventeenth centuries were quite cool. The comparison, however, also reveals quite substantial differences in the estimated magnitudes of the warm and cold phases, meaning that work still needs to be done to improve reconstructions of past temperature averages.

In the light of these uncertainties, Mann and colleagues' interpretation of the climate record — in terms of correlations with different forcing agents (greenhouse gases, solar radiation changes and volcanism) — should be considered primarily as a consistency check on results from more rigorous 'fingerprint detection' techniques[5–7]. In this line of research, the model-simulated evolution of the climate response to anthropogenic climate change, in both space and time, is used to detect such a change in the observations and distinguish it from internal climate variations and from the response to the naturally occurring forcing mechanisms. Thus far, the evidence from these fingerprint detection studies suggests that a significant part of climate change is indeed attributable to human activity[8]. Mann and colleagues' method uses time information only, and assumes a linear response of climate to forcing with no time lags. But their results support, independently of climate models, the conclusion that anthropogenic influences have dominated the evolution of temperature in the twentieth century.

Our incomplete understanding of natural climate variability is the largest limitation in fingerprint detection work. In most cases the internal variability of atmosphere–ocean general circulation models is used as a substitute for instrumental observations, which cover too short a time span to sample natural climate variability on the relevant timescale of several decades. Also, model simulations are used to estimate the influence of natural external forcings on climate (for example ref. 9).

A very useful application of reconstructions of past temperature variability would therefore be to verify model estimates of natural climate fluctuations[10], and of the climate's response to past changes in solar radiation and volcanism. The paper of Mann *et al.* is an important step towards reconstructing space–time records of historical temperature patterns, which could reduce the gap in our knowledge of that variability. Such work can not only provide a window on the past but it can also deliver invaluable information for a more reliable detection of anthropogenic climate change. This in turn brings us closer to glimpsing what the future may hold for a world with increasing levels of greenhouse gases. □

Gabriele Hegerl is at the Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle, Washington 98195-4235, USA.
e-mail: hegerl@atmos.washington.edu

1. Mann, M. E., Bradley, R. S. & Hughes, M. K. *Nature* **392,** 779–787 (1998).
2. Bradley, R. S. & Jones, P. D. *Holocene* **3,** 367–376 (1993).
3. Jones, P. D., Briffa, K. R., Barnett, T. P. & Tett, S. F. B. *Holocene* (in the press).
4. Jones, P. D. *Science* **280,** 544 (1998).
5. Santer, B. D. *et al. Nature* **382,** 39–46 (1996).
6. Hegerl, G. C. *et al. Clim. Dyn.* **13,** 613–634 (1997).
7. North, G. R. & Stevens, M. J. *J. Clim.* (in the press).
8. Santer, B. D., Wigley, T. M. L., Barnett, T. P. & Anyamba, E. *The IPCC Second Scientific Assessment* (eds Houghton, J. T. *et al.*) 407–444 (Cambridge Univ. Press, 1996).
9. Cubasch, U., Voss, R., Hegerl, G. C., Waszkewitz, J. & Crowley, T. J. *Clim. Dyn.* **13,** 757–767 (1997).
10. Barnett, T. P., Santer, B. D., Jones, P. D., Bradley, R. S. & Briffa, K. R. *Holocene* **6,** 255–263 (1996).

Animal behaviour

The evolution of menopause

Paul W. Sherman

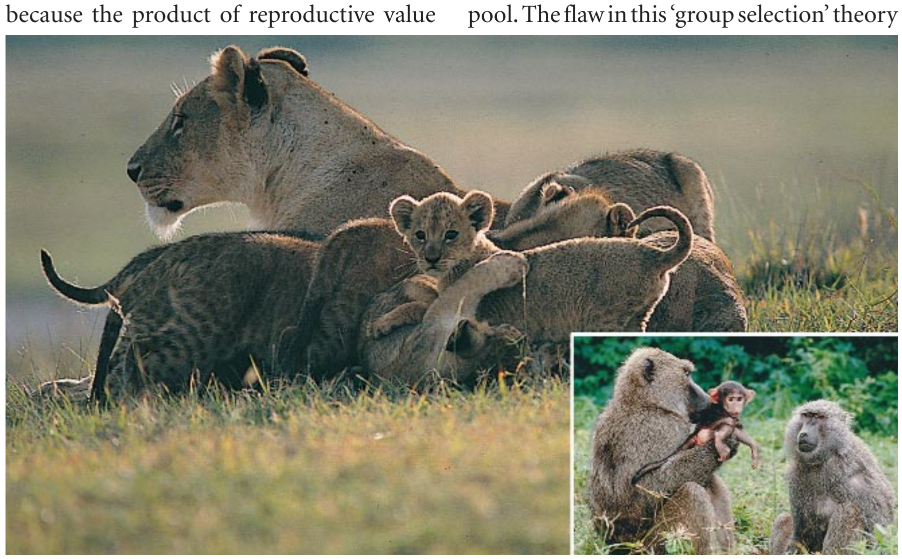
Menopause is the permanent cessation of menstruation, and it affects all women by the time they are about 50 years old. As well as raising personal, medical and social issues, menopause is an evolutionary puzzle — because natural selection favours increased reproduction, how could terminating it early be beneficial? On page 807 of this issue, Packer *et al.*[1] explore this question, using data from free-living olive baboons and lions (Fig. 1). They conclude that menopause is a non-adaptive result of senescence (ageing).

Four hypotheses have been proposed to explain menopause. Two are non-adaptive and two adaptive. First, it may simply be a cultural artefact. According to this 'blessings of modern life' theory[2], menopause occurs because women live longer now than in the past. Most animals reproduce as long as they live, but zoo specimens and pets (whose lifespans have been artificially lengthened) often stop reproducing before they die[3]. Menopause may similarly result from medically increasing the lifespan of a primate that is born with a fixed total number of gametes[4].

Second, menopause may be explained by 'senescence' theory. Senescence occurs because the product of reproductive value and survivorship of young individuals always exceeds that of old individuals[5]. Tendencies to be vigorous, healthy and fertile pile up in youth, whereas somatic and reproductive maintenance is neglected later in life. Thus, menopause may be like geriatric memory loss and failing eyesight — the uncontrolled deterioration of a physiological process that once was well regulated.

But these non-adaptive hypotheses leave some questions unanswered. Why does gamete production terminate abruptly in women, yet taper off gradually in men[6]? And why does ovulation cease so early in a woman's life? Although average life expectancy has increased due to medical advances, this results mainly from reduced juvenile mortality[7], and the maximum human lifespan (about 115 years) has changed little for centuries. Even in traditional, hunter–gatherer societies, many women live long enough to experience menopause[8]. Moreover, the complex, seemingly programmed way in which menopause occurs suggests adaptation rather than pathology[6,7,9].

The first adaptive theory proposes that, because birth defects increase with maternal age, menopause protects the human gene pool. The flaw in this 'group selection' theory



BERNARD CASTELEIN
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Figure 1 **Good mothers — lioness and female olive baboon with young. Packer *et al.*[1] have studied these animals and conclude that reproductive cessation is a non-adaptive consequence of senescence, rather than an adaptation to enable grandmothers to help rear their daughters' young.**