flow data[15]. The present-day geotherm differs little from that in the Cretaceous period[15]. The properties of minerals at depths exceeding 400 km are unfavourable for the development of significant anisotropy[16]. Hence lattice preferred orientation created during the last 150 Myr in the mantle of the Kaapvaal craton is probably located at 150–400 km depth. To obtain δt of 1 s in a 250-km-thick layer, the required difference between the split wave velocities is 2%. This difference is ~3 times lower than the maximum values found in samples of upper-mantle rocks.

Seismic observations indicate consistently that the seismic velocities underneath Precambrian shields are anomalously high in the 150–400 km depth range[5]. Apparently, the old roots of the continents extend deep into the mantle and translate coherently with the plates[6]. The evidence of relatively young (younger than 200 Myr) deformations in the same depth range does not contradict the evidence of coherent motion. Significant lattice preferred orientation develops by intracrystalline slip when $\ln(c_1/c_2)$ or $\ln(c_2/c_3)$—where c_1, c_2 and c_3 are the largest, intermediate and smallest axes of the strain ellipsoid—are around 0.3 (ref. 8). This range of strains is reached when the root at a depth of 400 km is displaced laterally by 250 km with respect to a depth of 150 km. This shift (of the order of a few hundred kilometres at 400 km depth) could easily pass unnoticed in the presently available seismic tomography data. Although silicate inclusions in diamonds from the Kaapvaal craton yield Archaean model ages[21], implying no significant displacement of the Archaean cratonic root, we do not consider this to be inconsistent with our model, as the diamonds come from depths of less than ~200 km, whereas the main part of the deformed zone is deeper than this.

Our conclusion does not mean that older deformations are absent in the subcratonic upper mantle. A strong contribution from fossil anisotropy at shallow depth can be suspected at station SLR. At other stations, small-scale frozen anisotropy in the top of the upper mantle might be a reason for the lateral variations of the estimates of α and δt. Some effects of layered anisotropic structure in the seismic wavefield can be used to infer the parameters of anisotropy in the layers[17–19], but these effects are either too weak at most of our stations, or the amount of data is insufficient to identify them. ☐

Received 25 August 1993; accepted 28 March 1995.

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ACKNOWLEDGEMENTS. We thank E. O. Kostlin, L. I. Makeyeva, R. Kind and G. Asch for their assistance. Part of this research was carried out in the Seismologisches Zentralobservatorium of Germany (Erlangen), where L.V. was supported by the Alexander-von-Humboldt-Stiftung.

Energy-saving gait mechanics with head-supported loads

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IN many areas of the world that lack a transportation infrastructure, people routinely carry extraordinary loads supported by their heads, for example the Sherpa of the Himalayas and the women of East Africa. It has previously been shown that African women from the Kikuyu and Luo tribes can carry loads substantially more cheaply than army recruits[1]; however, the mechanism for their economy has remained unknown. Here we investigate, using a force platform, the mechanics of carrying head-supported loads by Kikuyu and Luo women. The weight-specific mechanical work, required to maintain the motion of the common centre of mass of the body and load, decreases with load in the African women, whereas it increases in control subjects. The decrease in work by the African women is a result of a greater conservation of mechanical energy resulting from an improved pendulum-like transfer of energy during each step, back and forth between gravitational potential energy and kinetic energy of the centre of mass.

Luo women, from the western flatlands of Kenya, carry loads on the top of their heads in an upright posture, whereas the Kikuyu women, from the rugged central highlands, carry loads supported by a strap that is looped across their foreheads, in a forward-leaning posture, presumably so they can see where to place their feet. There are two intriguing aspects of the energetics of these women that have defied explanation[2,3]: they can carry loads of up to 20% of their body weight with no demonstrable increase in oxygen consumption rate; and they can carry loads of up to 70% of their body weight, at all but the slowest walking speeds, much more economically than either trained people using backpacks, or untrained people using their heads or backpacks[1]. Further study on West African women carrying head-supported loads has confirmed and extended these findings[4].

In this study, two women carrying loads Kikuyu style, two women using the Luo style, and one woman able to use both styles, walked at 0.8–1.6 m s^{-1} across a force platform mounted at ground level in the middle of a walkway. The gravitational potential energy and kinetic energy of the common centre of mass (body plus any load) were calculated from the measured forces[5]. For comparison, similar experiments were made on six male and six female Europeans carrying back-supported loads.

The walking gait is characterized by cyclic, out-of-phase, fluctuations in the height and forward velocity of the centre of mass of the body (as in a pendulum). This is because, during each step, the centre of mass is successively behind, or in front of, the point of contact of the foot on the ground. When the centre of mass is behind the point of contact, the link to the ground causes a forward deceleration (therefore a decrease in the kinetic energy of forward motion, $E_{\mathrm{cm,k}}$) and a vertical rise in the centre of mass (therefore an increase in gravitational potential energy, $E_{\mathrm{cm,p}}$); some of the $E_{\mathrm{cm,k}}$ is converted into $E_{\mathrm{cm,p}}$. As the centre of mass moves forward of the point of contact on the ground, the link to the ground allows a decrease in the height of the centre of mass and a concomitant increase in the forward velocity, as some of the $E_{\mathrm{cm,p}}$ is converted back into $E_{\mathrm{cm,k}}$. If the movement of the centre of mass were equal to that of an ideal, frictionless pendulum, the fluctuations of $E_{\mathrm{cm,k}}$ and $E_{\mathrm{cm,p}}$

would be equal and opposite, the total energy of the centre of mass ($E_{\mathrm{cm,tot}}$) would be constant, and no external work (W_{ext}) would be required to maintain the motion. However, people are not ideal, frictionless pendulums, the kinetic and potential energy is not perfectly conserved, and consequently the $E_{\mathrm{cm,tot}}$ fluctuates (Fig. 1). Nevertheless, the increments in $E_{\mathrm{cm,tot}}$ (W_{ext}) are less than the sum of the increments in $E_{\mathrm{cm,p}}$ (work against gravity, W_{v}) plus the increments in $E_{\mathrm{cm,k}}$ (work to accelerate forward, W_{f}), indicating that at least some energy is conserved. The recovery of mechanical energy, resulting from this transfer between potential and kinetic energy, is $R = 100(W_{\mathrm{f}} + W_{\mathrm{v}} - W_{\mathrm{ext}})/(W_{\mathrm{f}} + W_{\mathrm{v}})$. In an ideal, frictionless pendulum, R would be 100%; in normal, unloaded walking at the optimal speed, R attains a maximum of 65% (ref. 6).

The energy curves of the unloaded African women are very similar to those of the unloaded control subjects (Fig. 1, left column). However, when carrying loads, the African women are more able to transfer their potential energy into kinetic energy, and vice versa, so the total energy curve is more constant, showing that less external positive work is done (Fig. 1, right column). The recovery of mechanical energy via this pendular transfer increases with increasing load in the African women (occasionally attaining values over 80%), whereas it remains about constant or increases slightly in the controls (Fig. 2, top). As a consequence, the weight-specific external work decreases with increasing load in the African women, whereas it increases in the controls (Fig. 2, bottom).

The increase in energy expenditure of African women and control subjects can be inferred from the increase in total mechanical work done (W_{tot}), assuming that efficiency is unaffected by load. The increase in W_{tot}, in turn, can be calculated, as described in the legend of Fig. 3, from the external mechanical work, assuming that the internal mechanical work (the work required to accelerate the body segments relative to the centre of mass) is unaffected by load. Because the step frequency, which is the same in the African women and the controls, is unaffected by load, it is reasonable to assume that the internal mechanical work is also unaffected by load.

That the African women can carry loads of up to nearly 20% of their body weight with no measurable increase in energy expenditure (oxygen consumption rate) is accounted for by the finding that, over the same load range, the W_{tot} does not increase (Fig. 3, filled circles). This is in contrast to the proportional increase in W_{tot} observed in the control subjects over the same load range (Fig. 3, open circles). Further, that the increment in energy expenditure of African women is much less than that

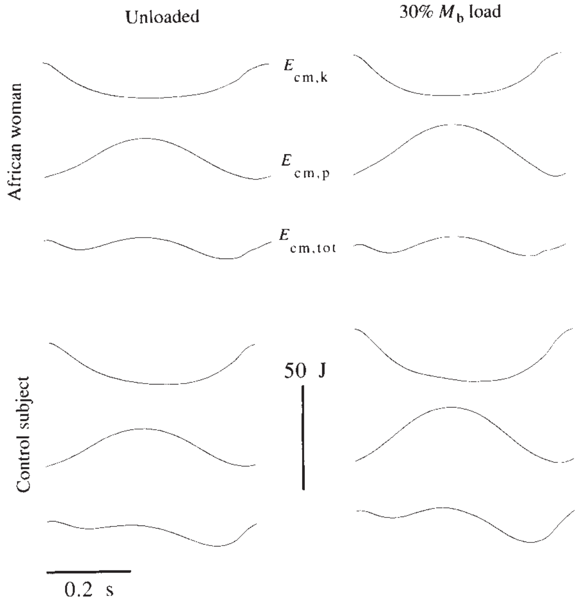

FIG. 1 Kinetic energy due to the forward velocity ($E_{\mathrm{cm,k}}$), top curve in each panel), energy due to the vertical movements ($E_{\mathrm{cm,p}}$, middle curve, mainly gravitational potential energy, but also including kinetic energy due to the vertical velocity), and total mechanical energy ($E_{\mathrm{cm,tot}}$, lower curve) of the combined centre of mass (body plus any load) for a 63.8 kg African women (top panels) and a 60.7 kg control subject (bottom panels) walking without load (left panels) and while carrying a load equivalent to about 30% of their body weight, M_{b} (right panels). Note the similarity in the shape and amplitude of the traces for the unloaded subjects, indicating that there is little difference between the unloaded gaits of the African woman and the control. The load increases the amplitude of the $E_{\mathrm{cm,k}}$ and $E_{\mathrm{cm,p}}$ curves in both subjects but, because of the increased energy recovery in the African woman, her $E_{\mathrm{cm,tot}}$ is flatter than that of the control, and her W_{ext} is relatively small as a result. The traces are original records for walking at a speed of 1.14 (upper left), 1.24 (upper right), 1.31 (lower left) and 1.33 (lower right) ms^{-1}; each trace is within ±1 s.d. of the average W_{f}, W_{v}, W_{ext}, and energy transfer in their respective experimental group. Traces were obtained by having the subjects walk across a 1.8 m × 0.4 m force platform (6.0 m × 0.4 m in the case of the controls) sensitive to the force exerted in the forward and vertical directions[7].

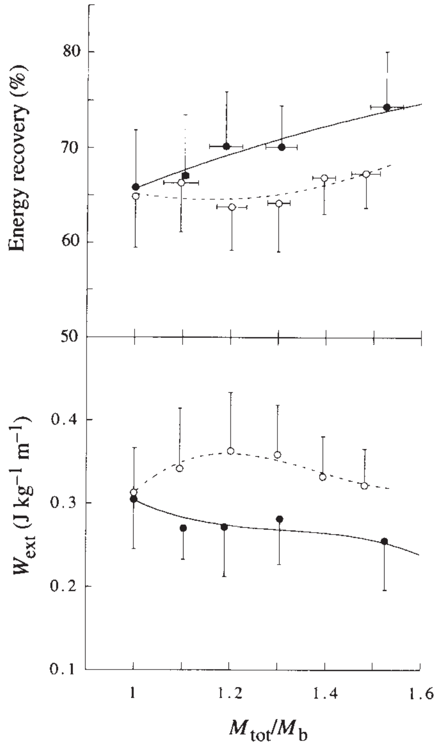

FIG. 2 Top, the energy recovered via the transfer between potential energy ($E_{\mathrm{cm,p}}$) and kinetic energy ($E_{\mathrm{cm,k}}$), about the same in all unloaded subjects, increases with increasing loads in the African women (filled circles), whereas it is nearly independent of load in the control subjects (open circles). On the abscissa, total weight (M_{tot}) is expressed as a multiple of body weight (M_{b}). Bottom, the weight-specific (body weight plus any load) external work done per unit distance decreases with loads in the African women (filled circles), whereas it increases with loads in the controls (open circles). The circles and bars represent the mean and standard deviation of the mean of the groups of trials based upon the following load ranges (loads are expressed as per cent of body weight; the numbers in parentheses represent the number of trials averaged for the African women and controls, respectively): 0% (121, 161); >0% to <15% (59, 85); 15% to <25% (73, 78); 25% to <35% (64, 73); 35% to <45% (0, 68); and 45% to 60% (25, 36). Fitting of the lines to the ungrouped data points of the African women (solid lines) or controls (broken lines) used either a second-order (top) or third-order (bottom) polynomial curve fit.

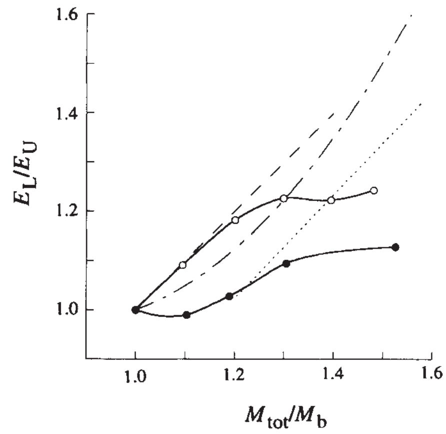

FIG. 3 The mechanical energy output and the total energy consumed when carrying loads is compared with the energy output or consumed when walking unloaded, as a function of load. The ratio of the total work done when walking with a load to the total work done when walking unloaded is shown for the African women (filled circles) and the control subjects (open circles). The dotted line is the straight line used by Maloiy *et al.*[1] to fit their Fig. 3 data of the ratio of oxygen consumption rate in African women carrying loads to their oxygen consumption rate when unloaded. Similarly, the dashed line, also from Maloiy *et al.*, is the relationship found for untrained adults carrying loads on their backs or their heads. The dot–dash line is the same ratio, calculated from Pandolf *et al.*[8], for army recruits carrying backpacks. Note that the African women can carry loads of nearly 20% of their body weight with no increase in their total work, whereas, for the same loads, the control subjects' work increases in proportion to the load. For loads greater than 30% of body weight, both the African women and the controls show little further increase in the total work, indicating that the work ratio is no longer indicative of the oxygen consumption ratio, which increases continuously with load (dotted and dashed lines). However, the work ratio of the African women at these high loads is only about half that of the controls. The work ratio on the ordinate was calculated as:

$$\frac{W_{\mathrm{tot,L}}}{W_{\mathrm{tot,U}}}=\frac{W_{\mathrm{ext,L}}+0.537W_{\mathrm{tot,U}}}{W_{\mathrm{tot,U}}}$$

$$=\frac{\frac{W_{\mathrm{ext,L}}}{W_{\mathrm{ext,U}}}0.463W_{\mathrm{tot,U}}+0.537W_{\mathrm{tot,U}}}{W_{\mathrm{tot,U}}}$$

$$=\frac{W_{\mathrm{ext,L}}}{W_{\mathrm{ext,U}}}0.463+0.537$$

on the assumption that the internal work, namely the work required to move the body segments relative to the combined centre of mass, is equal to the unloaded walking value (that is, $0.537W_{\mathrm{tot,U}}$) (ref. 9); the U and L subscripts indicate unloaded and loaded measurements, respectively. The ratio $W_{\mathrm{ext,L}}/W_{\mathrm{ext,U}}$ was calculated for each load by multiplying the data in the bottom of Fig. 2 times the total weight (body weight plus any load).

of the control subjects (Fig. 3, dotted against dashed lines) is accounted for by the finding that the increment in W_{tot} by the African women is much less than that done by the controls at all loads.

The dissociation between the increase in energy expenditure and the increase in mechanical work for loads greater than 30% of body weight may be due to factors not measured here as mechanical work, but which nevertheless increase the energy expenditure at these high loads. These factors may include a decrease in muscular efficiency, an increase in isometric contractions required to maintain posture and support the load, and increase in the internal work due to movements of the load relative to the centre of mass. Alternatively, the skill of these women in carrying head-supported loads may require muscular strength appropriate for the load. At very high loads in the African women, and at all loads in the control subjects, the required strength may not be available; this may also help explain the finding that obese African women do not exhibit the same economy of head-supported load carriage[4].

In conclusion, African women can carry head-supported loads of up to 20% of their body weight for 'free', because their total mechanical work of walking does not increase. Furthermore, they carry loads of up to 70% of their body weight for a lower metabolic cost than control subjects carrying either head- or back-supported loads because they do less mechanical work. They conserve more mechanical energy through a more complete energy transfer, back and forth between the kinetic energy of forward motion and the potential energy of their centre of mass; in effect, they become better pendulums. ☐

Received 26 September 1994; accepted 24 February 1995.

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ACKNOWLEDGEMENTS. This study was supported by the US Fulbright Scholar Program, the US Army Research Office, the Belgian FNRS, and the Italian MURST. We thank the University of Nairobi, the Concord Field Station of Harvard University, and J. D. Harry for their facilities, equipment and assistance.

Use of implicit motor imagery for visual shape discrimination as revealed by PET

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POSITRON emission tomography (PET) can be used to map brain regions that are active when a visual object (for example, a hand) is discriminated from its mirror form. Chronometric studies[1–3] suggest that viewers 'solve' this visual shape task by mentally modelling it as a reaching task, implicitly moving their left hand into the orientation of any left-hand stimulus (and conversely for a right-hand stimulus). Here we describe an experiment in which visual and somatic processing are dissociated by presenting right hands to the left visual field and vice versa. Frontal (motor), parietal (somatosensory) and cerebellar (sensorimotor) regions similar to those activated by actual[4,5] and imagined[6–8] movement are strongly activated, whereas primary somatosensory and motor cortices are not. We conclude that mental imagery is realized at intermediate-to-high order, modality-specific cortical systems, but does not require primary cortex and is not constrained to the perceptual systems of the presented stimuli.

Virtually all brain regions known to participate in the planning and execution of bodily movements (with the exception of primary sensorimotor cortex, see later) were activated