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HAIR DISTRIBUTION, IMMUNO-RESISTANCE AND ADAPTATIONS TO THE FIRST BABY SLINGS

ABSTRACT: This essay contains two hypotheses: the first postulates that infectious and parasitic conditions in the first baby-carrying devices or "slings" selected for changes in juvenile hair distribution and immuno-resistance, and that a convergence of datable mutations and osteological changes indicate that infants in our lineage adapted to the microenvironment between 1.2 and 2.8 million years ago – with evidence converging towards the older end of that range. Such slings, which might have been first used to carry gleanings, would have surrounded offspring in dangerous pathogens and parasites. Babies whose foetal body baldness had not disappeared would have had an advantage over infants with previously normal body fur, because adults could clean them better – probably resulting in the neotenic extension of the foetal trait. The microenvironment might have selected for the elimination of infectious pathways as well. The inactivation of the CMAH gene, which could have provided a pathway for pathogens associated with ungulate and proboscidean hides to infect infants with diarrhea, is explored as a candidate, and multiple ways of testing the hypothesis are described. The related hypothesis, which is based partly on avian comparisons and milk chemistry, postulates that slings gradually forced adults to focus on the kind of nutrition needed by more slowly maturing infant brains by making their babies more altricial. This might have triggered more scavenging, hunting, and feedback mechanisms that slowly extended the new juvenile hair distribution to adults as part of a whole-body cooling system based on sweat and body baldness while contributing to speciation.

KEY WORDS: Human evolution – Hominins – Neoteny – Parasites – Hair distribution – Baby slings – Mirror neurons – Motherese

INTRODUCTION

This essay contains two related, falsifiable hypotheses. The first is that the original baby-carrying devices formed a microenvironment that subjected hominin infants, who are more immunologically susceptible than adults, to sustained contact with a somewhat different set of pathogens and parasites from their previous

environments, thereby unleashing selection pressures that affected immuno-resistance and the reduction of juvenile body hair by the neotenic prolongation of foetal body baldness – which would have permitted easier cleansing.

Its second hypothesis is that carrying infants in slings ended the need for newborns to have brains that were mature enough soon after birth to provide them with strong clinging reflexes – and that infants gradually became more altricial once the constraint was lifted, affecting nutritional requirements. Baby slings would have eliminated a roadblock to existing pressures for achieving larger brains through postnatal brain maturation and growth, which had been blocked by the combination of a need for a certain maturity at birth and an upward limit on the diameter of birth canals – given the engineering constraints of bipedalism. Any new pressures for encephalization would have increased selection for postnatal brain development still further, leading once again to less mature brains among newborns.

After exploring several of the pressures that probably selected for larger brains, the secondary hypothesis postulates that having such babies, whose brains reached previously neonate levels of maturity later, gave parents a greater appetite for nutrients like cystine, which were required by altricial brain development. This would have increased their appetite for fats and proteins, encouraging them to scavenge and hunt even more avidly (as is shown in the paper through parallels among birds), which would have selected, in turn, for new thermoregulatory solutions to the problems of heat stress. The evolution of a full-body cooling system based on sweating would have built on body baldness, which had first appeared in juveniles as a neotenic adaptation to infectious slings, extending it for entirely different reasons to adults.

Most importantly, the paper suggests ways of testing these hypotheses while arguing that fossil and genetic clues already indicate that babies in our lineage had begun to adapt to such infested microenvironments by 1.2 Ma, with the evidence converging on the speciation that gave rise to the oldest member of our genus, a species of *Homo*, around 2.5 Ma. For the purposes of shorthand, we shall refer to the species that arose because of the hypothesized speciation triggered by baby slings as habilines and *Homo* sp.

DIFFERENCES BETWEEN THIS AND PREVIOUS PUBLICATIONS

The hypotheses that are most relevant to this article are ones made by:

A) Markus Rantala, in "Human Nakedness: Adaptation against Ectoparasites?" (Rantala 1999), who focused on the effects of parasites on the first hominins to use other types of microenvironments, nests and bedding, repeatedly;

B) Nancy Tanner and Adrienne Zihlman, who suggested that baby slings had been among the oldest and most influential hominin inventions (Tanner, Zihlman 1976, Zihlman 1981) – an idea that was later developed by Lori Hager (1997) and Timothy Taylor (1996, 2010);

C) and Dean Falk (2004a, b, 2009), who sparked a debate by asking what mothers did with their infants while foraging between the development of bipedalism, which Falk felt made it more difficult for infants to ride on their mothers' now vertical and (in her estimation) hairless backs, and the adoption of baby slings. Falk argued that females responded to the need to put their children down and keep them calm, while foraging, by developing rhythmic, soothing calls, which became an affective substitute for touching. Although her paper was devoted to showing how such communication at short distances could have led from ape-like calls to the emergence of *motherese* and proto-languages (and only mentioned slings in passing), it elicited critiques (Rosenberg *et al.* 2004, Sokol, Thompson 2004), which argued that babies in our lineage were typically carried in slings, rather than set on the ground, by foraging mothers 2 Ma.

None of these publications about the possible effects of microenvironments such as re-used bedding and baby-carrying devices have argued, however, as this paper will, that slings:

1) triggered a neotenic event whose most obvious impact is our hair distribution, which is unique among medium-size mammals;

2) affected the immunological defences of the first users (and ourselves), especially against diarrheal diseases carried by ungulates, suids, and elephants;

3) triggered a drift toward altriciality among newborns that increased parental appetites for the kinds of fats and proteins which are needed for postnatal brain maturation, forcing adults to engage in more planned hunting and scavenging, since the most effective way to satisfy their new nutritional requirements and cravings in grasslands (Plummer *et al*. 2009) was to seek more meat, internal organs, and eggs;

4) and possibly led first to the speciation at the root of our genus, and then indirectly to the speciation that led to *Homo ergaster*.

Like all articles on the evolution of human hair distribution (Amaral 1996, Belt 1874, Bolk 1929, Carrier

1984, Glass 1966, Hardy 1960, Kushlan 1985, Montagna 1976, Montagu 1964, Robertshaw 1985, Wheeler 1984) and the impact of the slings, previous publications were based on indirect evidence, because:

A) the oldest directly observed bedding, which might have contained similar pathogens and parasites to slings, is "only" 77,000 BP (Wadley *et al.* 2011);

B) the advent of body baldness can only be inferred by the spread of skin pigment over 1.2 Ma (Jablonski 2010, Jablonski, Chaplin 2002);

C) and the failure of slings, which probably would have been made of such perishable materials as hides or vegetable matter, to be found in pre-Holocene contexts, although the preservation of bark, fruits, seeds and nuts in a 790,000-year-old layer in Gesher Benot Ya'aqov, Israel (Alperson-Afil *et al.* 2009) holds out hope for the discovery of some early examples. Even if they are found, though, it is questionable whether they will be identifiable.

Despite the failure to find ancient slings, their effects on the requirements for successful motherhood and child development might have left enough fossil and genetic clues to indicate when they appeared.

THE IMPLICATIONS OF BIPEDALISM

To know what to look for, we must examine the implications of the shift from quadrupedal to bipedal locomotion, which changed the ways mothers carried their babies. The development of bipedalism forced the pelvis to grow shorter and more rigid, limiting the potential diameter of the pelvic opening (Taylor 1996: 44–49, 2010: 105–109). That, in turn, limited how big newborn heads could be and blocked the evolution of bigger brains (when and if selective pressures for encephalization came into play) as long as hominins had to be born with brains that were already mature enough to provide them with the kind of reflexes which can support a baby's weight.

If the human brain just expanded by a factor of 2.5 after birth like the typical chimp's (DeSilva, Lesnik 2006), a baby's brain would have to be 540 cc at birth to reach 1350 cc when complete – when, in fact, neonate brains average 385 cc. But 385 cc is already so much bigger than any newborn ape's brain, despite women's rigid birth canals, that humans cannot be born with heads that are any bigger without making childbirth suicidal for mother – and child. So the only way for human brains to reach their full size is for them to expand by a factor of 3.3 after birth (DeSilva, Lesnik 2006). Humans

achieve this largely by having a higher rate of postnatal brain growth than apes, rather than by extending the period of postnatal brain growth significantly, but the result is the same: being born with a brain so far from its final size means that a modern human's brain is too incomplete at birth to provide the motor skills (Bogin 1997, Falk 2009) seen in newborn apes and, given their close relationship, in all probability, australopithecines.

To keep their hands free for myriad tasks, parents today depend on a wide range of baby-carrying devices to transport infants who cannot otherwise hold on. So, if the period of helplessness experienced by newborns lengthened gradually over human evolution, at what point would it have become an untenable encumbrance for mothers without slings? After a month of forfeiting the use of her arms by carrying her offspring? After two months of depending almost entirely on others to feed herself and her child?

Although such questions seem reasonable, they are probably flawed. Better questions might be: were babies even born in increasingly helpless states before the invention of slings? And did the human lineage have bald bodies before such devices existed? Although an inspired mother might have solved the problem posed by a baby who could not hold her either because of its cerebral immaturity or her own lack of body hair by inventing the first baby sling, it is far more probable that carrying slings were precursors that not only made the births of increasingly helpless babies viable but likely. To understand why, one must visualize the first band of hominins to use them.

THE HISTORY AND IMPLICATIONS OF BABY-CARRYING METHODS IN HOMINIDS

Clinging reflexes

First, all ape infants can cling tightly enough to their mothers within a few days of birth (*Figure 1*) to help support their own weight, allowing mothers to keep their hands and arms largely free for brachiating and foraging. Our closest relatives, chimpanzees, represent a partial exception to this, since they cannot cling for long without any support for the first two to three weeks (Falk 2009: 6), forcing mothers to support them from time to time with one hand against their chests as they move quadrupedally (Plooij 1984). Although some mothers respond to their infants' whimpering, which signals that they are losing hold of the chest fur, by consistently providing such support, others offer as little help as possible, short of losing their babies, and allow them to

dangle from just one or two of their four limbs (Plooij 1984: 45). After their first two months, chimp infants tend to ride their mothers' backs, where they hold on without support (Ross 2001) (*Figure 1*).

The appearance of developmental benchmarks involving locomotion and posture (pushing off, sitting and standing without support, creeping on all fours, and walking bipedally) occur much later in baby humans than chimps, despite the fact that some psychological landmarks (i.e. distress at separation from mother, disappearance of blind rooting responses, production of social faces, and fear of strangers) follow similar time-lines (Falk 2004a, Plooij 1984).

Modern human babies have several types of clinging reflexes, the earliest of which seem to be vestiges of early and strong grasping reflexes in our ancestors. These neonate reflexes include vestigial hand-and-foot-grasping reflexes – none of which are strong enough to hold on for long and disappear within a few weeks, as

FIGURE 2. Once humans acquire tenacious clinging reflexes at least 6 months after birth, they can hold onto adults' neck, scalp, or carrying gear. This permits women like this Pygmy mother to use their carrying devices for other things than carrying infants. Hominins probably had to develop particularly strong reflexes within weeks of birth before the invention of slings, because they had to defy gravity more than baby chimps, who not only have grasping hands, but clasping feet, and can ride adults' horizontal backs. The need for such strong reflexes probably forced bipedal hominins to be born with particularly mature brains until the invention of slings. This cerebral maturity probably prevented brains from growing as much post-natally as those of later hominins, who used slings. Photo by P. Schebesta, adopted from Severin (1973: 82).

FIGURE 1. Baby chimpanzees can support their own weight by clinging to their mothers' ventral sides within 2 or 3 weeks, and only need occasional support before that. They usually ride on their mothers' backs once they reach two months old. Flo is carrying her son, Flint, on her back and her daughter, Flame, on her chest. Adopted from Van Lawick-Goodall (1971), courtesy of The Jane Goodall Institute/Patrick McGinnis.

well as spreading the arms and then clinching them across the chest (Eibl-Eibesfeldt 1989: 26–28, *Figure 2:1–2*). The first sign of a clinging reflex that is almost strong enough to support a child's weight – the ability to grasp an object held to the backs or tips of the fingers – typically appears in modern humans at 4 months (Eisenberg *et al.* 1989) while clinging with the hands – as opposed to the arms – now appears 6 months after birth (Leach 2000: 289–291) – both much later than in ape infants (Allport 2000: 171, 187).

The odd thing, one might think, is that clinging reflexes develop at all in infants whose parents have carrying devices, but they probably still appear for two reasons. First, because human and chimpanzee development recapitulates that of a common ancestor, which leads to the appearance of similar landmarks in their infants as their brains reach comparable degrees of maturity, albeit at different rates, and, two, because strong clinging reflexes become useful to older infants for holding onto an adult's neck or carrying gear, which allows the carrier to finally use a sling for other things than carrying the infant (*Figure 2*).

Although humans, chimps (Falk 2004a: 494, Goodall 1986: 582) and bonobos (Falk 2004a: 493, Kano 1992: 164) carry their young for about the same time – four years – hominins do not have the horizontal backs that baby chimps and bonobos ride after two months (*Figure 1*). The loss of this platform, which allows apes to carry their young with little effort, was exacerbated by another consequence of bipedalism, the rigidification of hominin feet, which reduced the grasping ability of two of the limbs that baby chimps rely on (Alemseged *et al.* 2006). The combination of these factors would have made it harder for juveniles to hold on even if their elders retained body hair. This probably made it all the more important for baby australopithecines to maintain and even strengthen the kind of clinging reflexes seen in newborn chimps to help their mothers support them, until the invention of slings. This, in turn, would probably have forced them to be born with fairly mature brains.

Carrying a baby in one's arms or on one's hips

The two main ways for a bipedal mother to carry her infant without a baby-carrying device are to carry it in her arms and to brace it with an arm as it rides her hip (*Figure 3*). Both methods deny the mother the use of at least one arm for other purposes, unless the infant has strong clinging reflexes, including with its legs, and is provided with attachment points, which in the absence of garments or other devices, would probably have to be maternal fur. Despite the usefulness of such hair for this

purpose and others (including avoiding abrasions) between the rise of bipedalism and invention of slings, many reflections on the earliest baby-carrying devices, including those which have studied the energy savings of using slings (Wall-Scheffler *et al.* 2007), have accepted the notion that hominins developed functionally bald bodies soon after becoming bipedal (Wheeler 1985), and have failed to model hip-riding with such anchor points and strong clinging reflexes.

Despite this lacuna, an experimental study by Wall-Scheffler *et al.* (2007) showed that:
1) the use of a sling provided a 13–25% increase in energy efficiency (with an average of 16%) over carrying a baby in one's arms, and
2) the kind of pelvic widening seen in *Australopithecus afarensis* might be linked to reducing the deficit incurred by manual carrying by allowing longer strides while providing infants with ledges in the form of wider hips for easier riding.

The study also demonstrated that carrying an infant without a sling for more than a few minutes at a fast walk was energetically unreasonable, and that mothers lose so much energy when carrying heavier juveniles at such speeds that the costs approach those of lactation

FIGURE 3. Carrying children in the arms or on a hip with the use of an arm takes much more energy than carrying a child in a sling and denies the carrier the use of at least one arm for other purposes, such as foraging. This photo, which shows a woman carrying a heavy child after a school collapsed in Moore, Oklahoma in May 2013, demonstrates how crucial carrying children can be, regardless of their weight and the lack of easier ways of transporting them, when adults have to take children very far during moves or emergencies. AP Photo S. Ogrocki.

(a subject we will come back to). The authors concluded that the huge energy savings provided by slings would have "reward(ed) the development of carrying tools rapidly following the advent of bipedalism" (Wall-Scheffler *et al.* 2007: 845).

We will argue, on the contrary, that body-baldness and the potential energy savings of slings did not happen for more than 3 million years after the rise of bipedalism and that hominin mothers kept or acquired adaptations such as hair and wider hips that allowed infants with tenacious clinging reflexes (and relatively mature brains) to cling to them up to – and for dozens of generations after – the sling's invention.

Motivation for putting infants in the first baby slings

The antecedents for the first carrying devices and motives of the first hominin to put an infant into one cannot be proven but some scenarios come to mind. One precursor could have been scalloped sunscreens like the ones which Andaman Islanders used to make for their babies out of fibrous fronds (Rossbach 1973: Pl. 27). San children are also known to pull babies and toddlers on hide sleds (Severin 1973: 177) (*Figure 4*). These and other devices could have easily led to the creation of carrying devices from skins that predators, scavengers, maggots and even microbes left nearly intact on large carcasses (Beard 1978: 235–273). An example of such natural and apparently clean sacks, which are rarely

FIGURE 4. San boys pulling smaller children on a kaross, which is a rug or blanket made of animal skins. Such uses of blanket-or-hide sleds for play or transport are common around the world and may have inspired carrying devices. Photo by L. K. Marshall as it appeared in Severin (1973: 177). © President and Fellows of Harvard College, Peabody Museum of Archaeology and Ethnology, PM# 2001.29.802 (digital file# 99080112).

deteriorated, because of their "leathery" consistency, is elephant ears (Beard 1978: 235–273).

The first infant to be confined in a hide sling might have been too weak from illness or premature birth to hold on. But it is more likely that the first babies to encounter sacks either rode food containers that were used to make foraging easier, as is the case with older San and Pygmy children today (*Figure 2*) (Severin 1973: 82, 164), or were hanging onto their mothers' hair next to such slings. In either case, their proximity with the devices, whose folds might have provided them with shade and protection from biting insects, probably led females to the idea of putting infants in the bundles.

Consequences of putting infants in slings

Once females started using slings increasingly to carry babies as well as gleanings (Tanner, Zihlman 1976), their offspring would no longer have needed to be born with the kinds of early motor control associated with strong persistent clinging. Like modern incubators for the premature, the first slings would have eliminated the need for infants to be so developmentally mature, hence allowing a drift towards motor altriciality. Any existing or new pressures towards encephalization via postnatal brain development would have amplified this effect.

Furthermore, the first mothers to use baby slings would no longer have required significant body hair for their infants to cling to – so biological investment in hair would have become increasingly unnecessary. But having such hair would have become an actual handicap to infants once they had to survive in enclosed baby-carrying devices, even if such containers were made of tanned leather and were highly sanitary – which is unlikely, since the first hide tools were probably stripped off eviscerated kills. This means that the skins probably came into contact with faeces that had been spread from dead animal intestines during butchering or feeding frenzies by predators and scavengers. Although such hides are often left bare by maggots, as can be seen in Peter Beard's (1978) remarkable photographs, and could have been further cleaned or even partially cured with some chewing and urine, they would actually have remained polluted with zoonoses, making them vectors for disease.

To which one might retort: what if they were made of vegetable matter like the Andamanese sunscreens? Although the existence of baskets made of plaited leaves (Rossbach 1973: Pl. 18) and bark by the Ojibwa (*Figure 5*), Australian aborigines, and many other groups proves that such containers can be made, there are several reasons

to think that the first slings were often made of untanned skins. The first is that the "simplest" ethnographically observed baskets are usually more complex than a simply folded sheet of vegetable material, and often include cordage, separate handles, drilled holes, and rigid frameworks, making them compound tools that were probably beyond the mental and technological abilities of hominins until they began assembling multiple elements and technologies.

The second is Andamanese and Australian leaf devices are often simpler, despite their complexity, than baskets from areas that experienced greater technological innovation in basketry and a variety of related crafts, including working clay, metal and cordage. This technological discrepancy suggests that basketry was even more primitive millions of years ago and that the first sling makers would have had difficulty turning plant

materials, which tend to be weaker than hides, into effective or durable carrying devices.

The third reason is that humans retain a variety of genetic and dermatological traits, which we will come to, that suggest that some of the first slings were made of uncured ungulate, suid or elephant hides.

Contemporary and archaeological parallels for the first (unsanitary) slings

Could there be ethnographic evidence for the supposition that the first baby containers were often made of unsanitary skins? Probably not for two reasons. The first is that so many ethnographic examples are made out of a recent invention, cloth (Blois 2005: 30–31), which breathes better and is lighter than hides, while modern hide slings, like ones used by the San (Falk 2009: 34), are usually made of true leather (*Figure 6*).

FIGURE 5. Even the simplest ethnographically known plaited baskets like this Ojibwa specimen made of elmbark or similar ones made of leaves by Australian Aborigines (Rossbach 1973: 22, Fig. 18) are complex, since they often include drilled holes, cordage, rigid frameworks, and multiple parts, such as separate containers and handles, which make them compound tools. These complications show how many innovations had to be mastered to make most of the sturdy plaited containers known today. It also suggests that it would have been harder for the first makers of baby-carrying devices to make strong ones from plants than to make them out of hides with either natural or artificial holes. Photo by the author. American Museum of Natural History, New York.

FIGURE 6. San/Bushman women, like this one near Ghanzi, Botswana, use leather slings for transporting food and infants. Older infants can ride on top of the slings, with the support of a maternal arm, when the flexible containers are stuffed with gleanings (Severin 1973: 164). Courtesy of P. Kosina.

Although it is doubtful that diapers, which are another type of baby container, were invented as far back as slings, it is worth noting that Eskimos made them out of fawn skins packed with moss (Fejes 1966: 232) and had to deal with the same Candida yeast and bacterial infections, not to mention allergies, caused by confinement in wet sacks, with or without excrement, as mothers with disposable diapers dealing with diaper rash.

It is also noteworthy that diapers are rarely used in Africa, where heat and humidity make them even more effective microbial incubators than in the Arctic. One alternative to diapers in Africa, which is used by Beng and Fulani mothers, is to give infants enemas to prevent them from soiling slings (Falk 2009: 34). The extremity of this practice is a reminder of how insalubrious such devices can be. Another reminder is the change that used to occur when indigenous women entered heated cinemas in Anchorage, Alaska in the 1940s and 50s with babies in the hoods of their skin coats. The grandmother of one of this paper's referees remembered that the smell of the wastes, which the babies excreted and urinated directly into the hoods on their mothers' backs, only became apparent in the warm cinemas, suggesting that the wastes were nearly inert, and therefore less infectious in the cold.

Despite the fact that there might not be any exact equivalents for the first slings among modern baby containers, there is considerable evidence for the antiquity of baby-carrying devices since the invention of compound tools, weaving and leather. The oldest fairly clear evidence is a Magdalenian engraving from

FIGURE 7. This Magdalenian engraving from Gönnersdorf, which shows a female anthropomorph with a smaller one linked to her back, probably represents a woman with an infant in a papoose-like device. Courtesy of G. Bosinski.

Gönnersdorf of a female anthropomorph with a smaller one linked to her back, which probably represents a woman with an infant in a papoose (Bosinski 2011: 110, Bosinski *et al.* 2001) (*Figure 7*).

More recently, rules imposed at Disneyworld, after a man working as a costumed character died of meningitis in 1998, are instructive. One of the actors (Sophie Spence, née Albouy) in such enclosed costumes informed us that the company grew so concerned, after the death, that the warm humid microenvironments might provide a vector for contagion that each actor's period in a costume was shortened to 15 minutes, whereupon he would have to take it off so it could be fumigated.

In 2010, baby slings, themselves, were cited as the cause of three infants' deaths, forcing their manufacturer to recall over a million of them (Associated Press 2010).

Conditions in the first baby slings and their consequences

Despite the technological distance between the microenvironments formed, on the one hand, by modern slings and their equivalents as far back as the Upper Palaeolithic, and, on the other, by the first baby pouches, the probable conditions in the oldest examples can be readily duplicated – and are even warmer, wetter, and richer in nutrients for fungi and bacteria than historically known slings or diapers, which would have caused them to be lined with rich microbial colonies – when they are not made even more insalubrious with body fluids from small prey captured by hunter-gatherers and wastes from infants themselves. The natural selection of traits that enhance the chance of an organism's survival in a new environment does not depend on that environment's size, so the effects of the encompassing microenvironments within such slings could have been just as dramatic as any climate change. The diversification of finches in the small niches on the already small islands of the Galapagos archipelago provides a classic example of how the isolation of organisms in tight environments with new selective pressures (Darwin 1859: 388–406) can create bottlenecks and founder's effects (Mayr 1942).

Although babies' heads would usually have protruded from the sacks for respiration, infants' bodies would have had to adapt quickly to confinement in the microbial and parasite ridden conditions inside them. A baby, whose hair was so thick that it provided a haven for ectoparasites and became clotted with the body fluids, faeces, and microbes in the pouches, would have been harder to clean and dry than an infant with thinner fur.

Babies whose foetal hair distribution had not entirely disappeared would have been selected for in short order,

encouraging the extension of foetal body baldness, while infants whose body hair grew to previously normal lengths often died because of parasites and infections caught in the sacks. The prolongation of such a foetal trait would have involved retardation of a developmental rate while the selective pressure for infants with brains that were mature enough to provide strong clinging reflexes was simultaneously lifted. When infants without such reflexes eventually reproduced, they would actually have been passing on their slower brain maturation – leading towards the increasing viability – and, therefore, likelihood – of more helpless babies. It is possible that the retardation in the appearance of body hair might have delayed the appearance of other traits as well, including cerebral ones, in which case slings may have even accelerated this shift towards altriciality.

Zoological analogies for early baby slings and body-baldness

The most obvious analogy for hominin babies after they adapted to slings is kangaroo joeys. A kangaroo mother has to clean both her pouch and baby (while it remains attached to a teat in the pouch for 70 days) by licking away its urine and excrement (Claiborne Ray 2012). If these wastes were left to fester in the pouch's warm humid interior, they would endanger both the mother and joey. Baby red kangaroos, to give but one example, have adapted to such potentially infectious conditions by remaining absolutely bald for over 4 months (Zooborns 2009) (*Figure 8*), which makes them easier to clean.

FIGURE 8. A 4-month old red kangaroo is completely bald. This makes it easier for its mother to clean it by sticking her snout into her pouch and licking off its urine and excrement. Courtesy of the Global Wildlife Center.

Domestic ovicaprids, which have been bred for wool, provide another analogy – this time for the conditions experienced by hairy hominin babies carried in slings. Unlike wild goats and sheep, which have short coats, wooly ones must wear the equivalent of an unnatural jacket, which can put the animals into sustained contact with moisture. This humidity can damage the skin of such sheep and goats within two days during heavy rains and flooding, causing it to release proteins that trigger bacterial blooms, which makes the fleece even more attractive to blowflies (Suter *et al.* 2011). Not surprisingly, the main remedy for dermatophilosis, fleece rot, and flystrike is emergency shearing, which removes most of the animal's now dangerously long hair.

Naked mole-rats provide yet another parallel, since they have become bald and lick their babies clean partly to free themselves of parasites in colonies subject to epidemics (Jarvis, Sherman 1996: 16, 40, 2002, Porter 1953, Sherman *et al.* 1991, Thigpen 1940) (as opposed to their furry, but solitary cousins).

The reduction of juvenile body hair also resembled the loss of head and neck feathers in vultures and marabou storks (*Leptoptilos crumeniferus*). Unlike predatory birds that eat their own freshly killed prey, which tends to be smaller than they are, scavengers like vultures and marabou storks stick their heads into carcasses that are much bigger than they are and anything but fresh, because they have been killed by big carnivores (Viscardi 2010), which often prevent access to their kills until their prey has become bloated with parasites and pathogens. Baldness has evolved repeatedly in such birds (Lerner, Mindell 2005) not only to help with thermoregulation in vultures (Ward *et al.* 2008), but to prevent the clotting of the germ-infested gore in such fecally polluted bodies, which can lead to infection, in their feathers (Viscardi 2010).

Later, we will come to even more avian parallels, when we examine the similarities between hominin adaptations to slings and those of passerine birds, which have adapted to high parasite loads in nests by developing their own functionally bald, altricial infants (Møller *et al.* 1990, Rothschild, Clay 1961).

Defining hair loss

But what is meant by body hair loss? Even in areas where human bodies do not have much apparent hair, they are not hairless. *Homo sapiens* even shares similar body hair densities with the great apes (Schultz 1931). The real difference between human and ape body hair is simply that most follicles on human bodies produce vellus hairs – which are short, fine, unpigmented and

unsheathed – whereas most of those on people's scalps or apes' bodies produce terminal hairs, which are usually longer, thicker, pigmented and sheathed (Schwartz, Rosenblum 1981). But, in the light of processes to be outlined below, one should note that follicles can switch between making vellus and terminal hair under various influences, including that of hormones at puberty or with the onset of androgenic alopecia – the main type of scalp baldness in humans – when hair is not so much lost, as changed – from terminal to vellus hair (Montagna 1976, 1985) under the influence of an androgen hormone, dihydrotestosterone (DHT).

This does not mean that the shift from hairy bodies to bald ones was purely hormonal, since, as we will see in a moment, there are several ways it could have happened, but is a reminder of how simple a modification of hair length can be.

Mechanisms for rapid adaptive change
Several overlapping mechanisms have been identified which can account for rapid, broad-spectrum, adaptive change – let alone such a simple change as the switching of hair types on hominin bodies. These include:
1) the prolongation of a neonate or juvenile trait into later phases (neoteny);
2) changes in the timing, level and pattern of gene expression as it affects such regulatory proteins as hormones; and
3) loss-of-function mutations (Olson 1999), which can have major post-genomic effects, since the action of one set of genes on the products of other genes can result in new biological entities or functions (Varki 2001).

Each of these rapid pathways to broad adaptive change might be relevant to the body baldness-sling hypothesis.

Neoteny
Let us start with neoteny. When foxes were bred for docility, they underwent juvenilization in under 40 generations (Trut 1999, Trut *et al.* 2004). If the numerous new traits seen in mature foxes in the end had been achieved independently, the change probably would have required hundreds of mutations and generations. Instead, tame and non-tame farm-raised foxes only differed at the conclusion by 40 mutations (Lindberg *et al.* 2005), which had inhibited the maturation of certain traits, prolonging some juvenile features.

In the case of the first hominins to use slings for transporting babies, the quickest evolutionary fix to the problem of survival in pouches would have been the

prolongation of foetal body baldness as expressed in chimpanzee and probably australopithecine foetuses through the three-to-four years when both ape and human mothers must typically carry their offspring while walking fast.

The similarity of the human hair pattern to that of foetal chimpanzees, which only have terminal hair on their scalps and chins, is highly suggestive that the pattern exhibited by *Homo sapiens* is neotenic (Bednarik 2008). But a neotenic adaptation, such as the prolongation of foetal hair distribution, tends to affect a variety of features. This is intriguing in view of a long list of resemblances between humans and foetal or juvenile primates collected by Louis Bolk in support of his "fetalization theory" (Bolk 1929), which has remained largely anecdotal and controversial – in part, because many of the traits might not be neotenic at all, since some could have evolved through separate processes.

Indeed an ontogenetic study of modern human and common chimpanzee skulls, using a three-dimensional Procrustes analysis, led to this very conclusion: suggesting that the reduced prognathism, flexed cranial base, reduced glabella and anterior portion of the face, and prominent nose of modern humans "...mainly correspond to functional innovations which have nothing to do with a neotenic process in human evolution" (Penin *et al.* 2002). But the same study confirmed the neotenic theory of our skulls as defined by Alberch, Gould, and their colleagues (Alberch *et al.* 1979) while modifying it slightly (Penin *et al.* 2002).

This, taken together with Gould's analysis in *Ontogeny and Phylogeny* (Gould 1977) and subsequent work by others, puts the argument for human neoteny on firmer ground than Bolk's simplistic theory that hormonal changes underlie all neoteny. But Gould (1980) pointed out that proving neoteny requires more than a list of supposed features and must be linked to processes affecting human evolution. Most importantly, he pointed out that the retention of foetal or juvenile features through strongly retarded development provides a storehouse of easily available adaptations in case of selective pressures. The word "easy" is crucial, since it emphasizes that neoteny linked to retardation can provide a quick fix during such evolutionary emergencies as a sudden environmental change to confinement in unsanitary sacks.

Although Gould understandably dismissed Bolk's notion that a "mere chemical brake placed upon (an ape's) glandular development" (Gould 1980) underlay all the apparently neotenic traits observed in humans, he

also elucidated the roles that hormones often play in neoteny (Gould 1977). Molecular studies of such developmental systems as the homeotic genes of *Drosophila* have also proven that relatively minor genetic changes can radically shape developmental effects by influencing the timing or level of expression of such regulatory proteins as hormones (Lewis 1998, Olson, Varki 2003), so it is quite possible that "minor genetic changes" could affect the glandular system, thereby playing a role in hominin neoteny. For example, the lower level of transthyretin expression in humans compared with chimpanzees (Gagneux *et al.* 2001) might correlate with altered thyroid hormone metabolism, which probably affects such diverse phenotypes as brain development and function, skull shape and metabolic activity (Olson, Varki 2003). Given the fact that hormones might have a strong impact on hair follicle production, some "glandular" involvement in a neotenic response to unsanitary slings is highly likely.

Whether hormones are involved or not, Gould, Alberch and their colleagues noted that neoteny caused by minor genetic mutations can produce both delays in the appearance of structures and a cascade of side-effects, that might seem unrelated to simple changes in developmental timing (Alberch *et al.* 1979).

So the modern appreciation of neoteny is both more complex than Bolk's theory – focusing on more causes and consequences – and a partial rehabilitation of both his observations and mechanism.

INDIRECT EVIDENCE FOR THE ADOPTION OF BABY SLINGS

The invention of stone cutting tools and the means to make slings

The role, if any, of the sling in hominin encephalization, and most especially of the sharp rise, between long plateaus, in cranial capacities starting around 2 Ma (De Miguel, Henneberg 2001, Taylor 2010: 195–198, Fig. 19) is unclear. But overlapping indicators suggest that it might be partly due to the impact of slings. Hominins certainly had the opportunity, means and motive to make carrying devices out of hides once they began cutting meat with stone flakes as much as 3.4 Ma (McPherron *et al.* 2010), and especially by the time such tools had achieved some sophistication around 2.5 Ma (Semaw 2000). But what evidence, if any, is there that they actually did so?

The implications of birth canal sizes

When these hypotheses were first sent to advance readers in 2008, extrapolations from the pelvis of 1.53 Ma juvenile male *Homo ergaster* skeleton (KNM-WT 15000) were central in assessing the birth canal dimensions of female erectines (Ruff, Walker 1993a, 1993b) – and, by extension, the cranial capacities of their newborns. The ratio between an erectine's newborn and mature brain seemed to be about 275 cc to 900 cc – the same as for modern humans, rather than apes (Leakey, Lewin 1992: 159–162, 191–198). This suggested that infants were already being born without strong clinging reflexes during the lifetime of KNM-WT 15000.

But that perception had to be adjusted when a female pelvis (BSN49/P27), which appears to be around 0.9 to 1.4 million years old, was found in Ethiopia and described as being from a *Homo erectus* (Simpson *et al.* 2008), although its birth canal was much larger than the dimensions that had been extrapolated from the male pelvis of KNM-WT 15000. Previous estimates had suggested that *Homo erectus*'s small birth canal limited the size of newborn brains to ~230 ml and that this resulted in the birth of developmentally immature infants, who underwent the same kind of rapid postnatal brain growth that forces modern humans to invest so much in child-rearing (Ruff 1995, Ruff, Walker 1993a, Simpson *et al.* 2008). But the new discovery revealed that the BSN49/P27 pelvis was capable of giving birth to an infant with a brain of 315 ml, which is over 30% greater than predicted from the KNM-WT 15000 pelvis.

If one assumes that:
1) the BSN49/P27 erectus had a baby;
2) the baby survived; and
3) the mother survived childbirth to raise her infant;

then the new pelvis might indicate that at least one early Pleistocene *Homo erectus* could give birth to babies whose brains were 34 to 36% the size of an adult's, which ranged from ~600 to 1067 ml (mean = 880 ml) (Holloway *et al.* 2004). This value falls between those of chimps (~40%) and modern humans (~28%) (DeSilva, Lesnik 2006) and suggests that prenatal *Homo erectus* brain growth rates were similar to those of humans while their postnatal rate was between those of chimps and humans (Dean *et al.* 2001, Simpson *et al.* 2008).

The discovery of BSN49/P27 shows that pressures for encephalization exploited two paths simultaneously, both expanding the birth canal to allow for greater prenatal brain growth, and continuing the high rate of prenatal brain growth into more of the postnatal period. But the exploitation of the first path reached a practical limit when the expansion of the birth canal began to

interfere with efficient bipedalism (Taylor 1996: 46), at which point greater postnatal brain growth became the only way for encephalization to continue.

The question for proponents of early slings is whether slings were introduced during this initial, mixed encephalization process, given the tentative evidence that erectines had more mature brains when born than modern humans. If BSN49/P27 is an *erectus*, is its birth canal so large that *erectus* infants were still born with brains that were mature enough to give them the kind of early and strong clinging reflexes that would have allowed them to support themselves on vertical mothers with just two hands, instead of a chimp's four? The shift from the intermediate ratio of chimps' neonatal-to-adult brain size (~40%) to a mean ratio is 34 to 36% in *Homo erectus* shows that erectines were already being born with brains that were both smaller in relation to their adult size and less mature than a newborn chimp's, making it unlikely that they developed sufficient motor control to hold on without support as early as a chimp, which, as we have seen, must be partially supported for the first two or three weeks (Falk 2009: 6), and sometimes up to two months (Plooij 1984). Baby erectines would not have had to wait nearly as long as modern children to acquire strong clinging reflexes, but they might still have been quite helpless for weeks, or rather months – in which case, creches, which we will come to, or carrying devices would have been essential to maintain their mothers' safety and efficiency as foragers.

In summary, the fossil evidence provided by cranial capacities and pelvic openings demonstrates that hominins close to our lineage began to be born with increasingly immature brains by 0.9 to 1.4 Ma (Simpson *et al.* 2008) and perhaps as far back as 1.53 Ma (Ruff, Walker 1993a, 1993b). Although a combination of factors suggest that baby slings might be associated with the surge in cranial capacities among members of our genus during the early Pleistocene, a tantalizing possibility also exists that the sling's impact was gradual and began by triggering neotenic, dietary and behavioral changes around 2.5 Ma.

Encephalization quotients

The clues are subtle and tentative. The cranial capacities of fossils classified as being members of our genus, *Homo*, which date to the period before 2 Ma, are not much bigger than contemporary australopithecines (De Miguel, Henneberg 2001). But the fact that the encephalization quotient (EQ), which is the ratio of actual brain size to expected brain size, taking body weight into consideration, is the same for *Homo habilis* and *Homo erectus* (Aiello, Dean 1990, Martin 1982, 1983) and so different from australopithecines, shows that a departure took place when *habilis* evolved between 2.5 and 2.3 Ma.

Thinner crania

Another clue might lie in the strikingly thin cranial bones of such early human fossils as OH 16 and KNM-ER 1470, since the analysis by Penin *et al.* (2002) cited above showed that the thinner crania of modern humans, and, by extension, the particularly thin crania of such early *Homo* individuals, relative to australopithecines, indicates the type of neoteny that one would expect from the prolongation of a foetal developmental stage of the brain and its housing into postnatal brain growth. While the lack of sufficiently intact crania of *habilis* and its *Homo* cousins from the period when our genus arose makes it difficult to fully apply the insights of the Procrustes analyses of recent skulls to the first members of our genus, it is also generally agreed, from fragmentary remains, that *Homo habilis* appeared between 2.5 and 2.3 Ma, and it is indisputable that sufficiently intact human crania exist from slightly more recent sediments. The techniques applied by Neubauer *et al.* (2010), which demonstrated that the shape changes associated with the "globularization phase" of a human baby's skull, which takes place in its first postnatal year, when the brain growth rate is high, are unique to modern humans, and do not occur in chimpanzees before or after birth, show great promise for establishing what aspects (if any) of such early human skulls are neotenic.

Genetic evidence for hominin adaptations against diarrhea

The inactivation of the CMP-N-acetylneuraminic acid (CMP-Neu5Ac) hydroxylase gene (CMAH) in the human lineage around 2.7 Ma (Varki 2001) or 2.8 Ma (Chou *et al.* 2002) might provide another clue. According to Ajit Varki and his team, the loss of the cell-surface sugar encoded by CMAH, Neu5Gc, affects our susceptibility and resistance to pathogens, immune response, brain development, and the consequences of eating animal foods (Varki 2001). One of the main reasons the loss has such sweeping effects is that Neu5Gc provides attachment sites for many pathogens to infect cells. What is so amazing about the deactivation of the CMAH gene in humans is that the versions found in great apes are not very different from those in mice and pigs. This suggests that the gene has been so useful to mammals that only a radical selective pressure could

have turned it off. Varki and his colleagues speculated that a pathogen which gained access to hominin cells through Neu5Gc became so lethal after a random mutation that hominins with deactivated CMAH genes were selected for. They also noted that humans are "immune" to microbes that use Neu5Gc to infect farm animals like cows and pigs with serious diarrhea (Delorme *et al.* 2001, Kyogashima *et al.* 1989, Lanne *et al.* 1995, Ouadia *et al.* 1992, Schwegmann *et al.* 2001, Varki 2001, Willemsen, de Graaf 1993).

Or, rather, we are almost immune: although our lineage can no longer make Neu5Gc, human cells can still be attacked by an AB_5 bacterial toxin that causes serious gastroenteritis – Subtilase cytotoxin, which is secreted by Shiga toxigenic *Escherichia coli* (STEC), when humans eat the two foods which are the most common source of both Neu5Gc and STEC contamination: raw meat and dairy products (Byres *et al.* 2008). This demonstrates how vulnerable hominins, who still made their own Neu5Gc, would have been once they came into sustained contact with unprocessed animal products, including those from many wild species (Caprioli *et al.* 2005) – the worst, in terms of being the most important reservoir of zoonotic STEC, being ruminants (Fairbrother, Nadeau 2006). It is worth remembering that the sub-order Ruminantia include such common prey species in Africa as buffalos, wildebeest, antelopes and giraffes.

The other main cause of contemporary human diarrhea is rotaviruses which kill about 453,000 children under five each year (Tate *et al.* 2012). It is also worth noting that rotaviruses are:

1) one of the major causes of diarrhea in young domestic and wild animals (Dubovi, MacLachlan 2010);
2) a potential reservoir in wild animals such as African antelopes, zebras and elephants (Petric *et al.* 1981) for genetic exchange with human rotaviruses (Martella *et al*. 2010); and
3) seem to be able to infect humans either directly or by contributing one or several RNA segments to reassortants with human strains (Cook *et al*. 2004, Müller, Johne 2007).

These factors make it clear that any causes of diarrhea, whether they were bacteria, parasites or viruses – all of which can cause severe dysentery (World Health Organization 2013) – could have caused rapid selective mortality among the first hominins to be in sustained contact with materials polluted with animal faeces.

What change in the environment could have required such a radical response to pathogens that it resulted in the loss of a gene that had been conserved for tens of millions of years? The increasing exploitation of ungulates – the main savannah prey species – in the form of disemboweled carcasses, killed by large predators, and baby antelope, hidden by their mothers, could easily explain how hominins came into greater contact with herbivore pathogens. But would that have been sufficient to inactivate such a highly conserved gene as CMAH? After all, baboons (Richard 1985: 135, Fig. 4:4), chimps (Teleki 1973, Goodall 1986), (and, in all probability, gracile australopithecines) also hunt antelope when the opportunity arises without sacrificing it.

The difference might be the sling, rather than a random mutation in a microbe. Its use in conjunction with increased scavenging and planned, as opposed to opportunistic, hunting would have exacerbated the contact with ungulate pathogens because slings would have placed hominin infants, whose immunological systems were weaker than their elders', in even more sustained contact with animal hides, parts and wastes. There is increasing evidence that early *Homo* groups were engaged in such hunting and scavenging by 2 Ma. Researchers at Kanjera, Kenya, for example, concluded that the cracked skulls of large antelopes had probably been scavenged by hominins who had extracted their brains. The presence of complete bone collections from dozens of small antelope, with tool-marks to remove their meat, bone marrow and internal organs, suggested, on the other hand, that the carcasses had been brought whole to the site by hunters, since primary predators, such as lions and hyenas, consume such prey entirely, leaving nothing for scavengers (Ferraro *et al.* 2013).

Regardless of when baby slings were first used, their first residents must have adapted quickly to the increased risk of infection from any germs inside the pouches that triggered the deadliest illness for small-bodied infants, who can dehydrate so quickly – diarrhea. Other forms of dysentery still contaminate slings and are the second leading cause of death in children under five, killing around 760,000 of them a year (World Health Organization 2013), emphasizing how strong the selective pressure would have been for any mutation that reduced susceptibility to this illness, which would have made primitive, untanned slings even deadlier.

The evidence of milk

A further suggestion that the CMAH deactivation was linked to infancy can be found in the difference between the milk or colostrums of great apes, which contain oligosaccharides bearing both N-glycolylneuraminic acid and N-acetylneuraminic acid, and human milk, which only contains the latter (Urashima *et al*. 2009).

This means that ape milk/colostrum contains Neu5Gc, the chemical linked above to susceptibility to zoonotic STEC, while the human equivalents do not. The absence of Neu5Gc from our milk probably adds to our resistance, as babies, to diarrheal diseases caused by ungulate and proboscidean pathogens. Urashima *et al.* (2009) speculated that this loss occurred around 2.8 million years ago – precisely when stone tools, which might date as far back as 3.4 Ma (McPherron *et al.* 2010), were becoming more sophisticated and providing some hominins with the means to acquire meat consistently, while giving them both the means and incentive to detach and use hides as carrying devices.

Another important difference between anthropoid and human milks is the fact that our free milk oligosaccharides are longer than those of gorillas or chimps. This probably prevents many of the molecules from being metabolized in the small intestine, which allows them to reach the colon, where they act as prebiotics by becoming a substrate for infant gut flora (Bode 2009). They might also block pathogenic microbes from attaching and invading babies' intestinal tracts. Human infants who are fed baby formula instead of being breast-fed, for example, have different gut flora and lower sialic acid content in their brain (Bode 2009, Milligan, Bazinet 2008, Sarwar *et al*. 1998, Tao *et al*. 2011).

The importance of human milk in preventing gastroenteritis is further suggested by the fact that so many infants get weaning diarrhea, which is a major cause of infant mortality, after being weaned (Dubos 1965: 72). Although this has been ascribed to the onset of malnutrition and the loss of passively transferred immunoglobulins, it also seems to be partly caused by the simultaneous loss of the oligosaccharides that serve as prebiotics and increased exposure to animal products containing a combination of diarrheal zoonoses (Enterotoxic *E. coli*, rotavirus, *Shigella* spp., etc.) and Neu5Gc.

The antiquity of our sweat-based thermoregulatory system

Another reason to think baby slings have been used since the early Pleistocene, or even earlier, is that the Turkana Boy's elongated body and hip, knee and ankle joints indicate that he engaged in extended walking and running (Bramble, Lieberman 2004). This suggests that *ergaster* adults were so active by 1.53 Ma that they must have benefited from a thermoregulatory system based on sweating from denuded skin. If the suite of adult *ergaster* skin adaptations was built on a template of foetal hairlessness, then the trait must have provided an earlier

benefit, which had to be different, to individuals in the stage between foetuses and adults – juveniles.

Converging evidence

This places selection for hairless juveniles even farther back in time than *ergaster*, during the rise of *habilis* and *rudolfensis* – in other words, when stone tools become common, CMAH is deactivated, the EQ shifts, and neoteny appears in the skull – all between 2.7 and 2.3 Ma.

So overlapping signs such as:

1. the appearance, confirmed by Procrustes analyses of skulls, of neotenic traits in such habiline crania (Penin *et al.* 2002) as OH 16;
2. signs that habiline juveniles derived some benefit from a neotenic hair distribution, before that distribution provided the basis of the thermoregulatory system of *ergaster* and *erectus* adults, starting around 1.8 Ma;
3. the departure in the encephalization quotient from gracile australopithecines to *habilis*, which took place when *habilis* evolved between 2.5 and 2.3 Ma;
4. the genetic deactivation of an infectious pathway for diarrheal diseases linked to the probable material of the earliest slings – ungulate hides – that is estimated to have occurred around 2.7 Ma;
5. the departure in the ratio of newborn-to-adult brain sizes after 4 million years of near stasis among bipedal hominins, seen by 1.2 to 1.53 Ma; and
6. the spread of skin pigmentation over 1.2 Ma (Jablonski, Chaplin 2002), which suggests that skin was becoming more exposed to radiation as it lost its hair covering, all suggest that slings were first used by at least one hominin shortly before one or more of these phenomena arose – with at least four strands of evidence converging on the rise of habilines.

TESTING THE FIRST HYPOTHESIS

One way to prove that both human hair distribution and the inactivation of the CMAH gene could have been products of juvenile adaptations to slings is an experiment which must be described as assiduously as the selective infant mortality that probably underlies both traits, although it would be unlikely to receive ethical approval today. The experiment would subject newborn animals with foetal body baldness, but hair at birth, to infectious conditions comparable to those expected in early slings. If the population, which must have a maternal instinct for grooming, experiences mutations that, one, cause neotenic hair loss, and, two, close pathogenic pathways, the case will be almost irrefutable.

Another experiment (which would probably not receive ethical approval either) would confine two populations of mice – one bald, the other furry – in microbially laden microenvironments, between superficial efforts to cleanse them. If the ones that could be cleaned with the least effort developed fewer infections, the hypothesis would receive further support.

A kinder way of testing the immunological component of this hypothesis would be to identify additional candidate genes (similar to CMP-Neu5Ac) which might have played a role in giving immunological resistance to zoonoses or other pathogens, and to evaluate their coalescence dates, since mutations linked to slings should give a consistent signal pointing to an emergence of increased immuno-resistance sometime before the spread of skin pigmentation, signalling newly denuded skin, at least 1.2 Ma (Jablonski, Chaplin 2002), and probably as early as 2.7 Ma. If candidate genes could be identified *a priori*, their coalescence dates would provide one of the most robust tests of the body baldness-sling hypothesis, even if a consistent signal is more recent than the CMAH deactivation.

The present hypothesis might also be strengthened by dating mutations discovered while comparing the human and chimp genomes that have affected the timing, level and pattern of gene expression as it concerned regulatory proteins involved in the prolongation of neonate body baldness.

Maynard Olson's "less-is-more" hypothesis, which focuses on loss-of-function mutations that have impacts upon regulatory, catalytic and structural proteins during speciation events like the one represented by the first *Homo* species (Olson 1999), might provide yet another avenue for examining its merits. Maynard Olson and Ajit Varki have speculated that genetic loss caused hair reduction and delayed postnatal development in humans, since both features seem "degenerative", and noted that its great advantage as a mechanism for phenotypic evolution is that it can occur so rapidly (Olson, Varki 2003). The very rapidity of a genetic loss like the inactivation of the CMAH gene makes it a prime candidate for a "crucial causal" event (Olson, Varki 2003: 24) which might have occurred in response to such a radically new environment as the one experienced by newborns in early slings – rather than just new gene functions. But the dating of other gene losses that might be relics of the initial "quick fix" might lend further support to the body baldness-sling hypothesis.

DISCUSSION AND THE SECOND HYPOTHESIS

Competing scenarios

The debate over the effects of slings comes down to two scenarios:

1) Slings were invented *after* human body baldness evolved as part of a package of whole-body thermoregulatory adaptations associated with the emergence of striding bipedalism, and therefore had no effect on human hair distribution, although the microenvironments inside slings might still have had immunological consequences. This conventional scenario does not provide an explanation for the apparently neotenic nature of our species' hair pattern, which suggests that its original benefits must have been for juveniles, before being extended, because of a different set of benefits, to adults.

2) Slings were invented *before or as* full-body thermoregulatory mechanisms involving sweat evolved. In this case, the adult body baldness that evolved to cope with heat stress during the emergence of full striding bipedalism (Jablonski 2010, Jablonski, Chaplin 2002) probably built on a neotenic hair pattern in juveniles that had first been an adaptation to slings. To many paleoanthropologists, this scenario will appear to place the cart before the horse because they see baby slings as a solution to the problem of less mature babies rather than a contributor to that increasing immaturity.

Reservations

Given the pitfalls, some major reservations are in order before venturing into, one, comparisons with competing hypotheses, and, two, further ramifications of the present ones.

First, although this essay argues that the invention of baby-carrying devices removed a *roadblock* to postnatal encephalization and that both pre-existing and future pressures for larger brains suddenly had a clear road to exploit that potentiality, the paper should not be construed as arguing that there was an innate tendency in our lineage towards the evolution of larger brains or that brain size had to increase once the constraint was lifted. Far from it. Brain tissue is metabolically expensive and evolutionary increases in brain size only occur when the selective advantages of being brainier outweigh the energetic costs of bigger brains and associated reduced reproductive rate. Of course, the relaxation of constraints, such as dietary shifts to more animal tissue,

which allows a reduction in metabolically expensive gut tissue, that were proposed by Aiello and Wheeler (1995), and again, below, in relation to a greater appetite for meat induced by having more altricial infants, can greatly facilitate the evolution of larger brains, but only if there is a selective advantage to having bigger brains. Otherwise selection will favor channeling the energy savings from smaller guts into faster reproduction. Such selective pressures for larger brains might have existed both before and after the invention of baby slings – finding one of its first expressions in a tendency towards the development of large birth canals like the one seen in BSN49/P27.

As noted above, this paper's secondary hypothesis – which might be dubbed the altricial-nutrient hypothesis – may also be criticized for having gotten human evolution backwards by postulating that adaptations to baby slings could have unleashed consequences that led to dietary and behavioral shifts with a cascade of ancillary effects. Critics might argue that when selective pressure for larger brains became great enough, selection also favored workable developmental, morphological and behavioral solutions to the problems associated with producing big-brained babies (whether by deferring a significant amount of brain growth to the postnatal period, finding workable compromises between locomotor and obstetric demands on the pelvises of females, or by increasing foraging efficiency by fostering the development of baby-carrying devices). According to this conventional approach, baby slings were simply a response and solution to an encephalization trend propelled by selective advantages for larger brains. Ironically, there is a heavy dose of linear orthogenesis concerning brain expansion in this explanation. First, there is a push for big brains, and, then, everything falls into place to accommodate it.

This means that both of the paper's hypotheses might be criticized for depending on an unexplored assumption of orthogenesis and for getting the evolutionary steps backwards, although such critiques are themselves based on an orthogenic assumption that there was a thrust towards larger brains.

But the situation might not be black or white. First, one variant of the altricial-nutrient hypothesis does not contradict the current consensus on how braininess, locomotor and thermoregulatory mechanisms evolved in tandem as part of a feedback mechanism – it just adds a refinement and places accents differently. Thus, any pre-existing selective pressure for larger brains – which might have already led, for example, to wider birth canals – would certainly have favored the users of an invention that removed a roadblock to encephalization while also fostering such things as compromises between locomotor and obstetric demands on pelvises. The only difference between the conventional explanation and this version of the hypothesis is its contention that the first baby slings contributed a building block to the evolving thermoregulatory model – body baldness – and had indirect consequences that amplified the trend.

But the hypothesis's other version is admittedly more radical and amounts to a new prime mover model for a speciation event. According to this variant, slings came so early that

1) infants were still being born with brains that were mature enough to provide strong clinging reflexes shortly after birth; and

2) slings led indirectly to greater reliance on meat acquisition, planned hunting, long-distance walking and loping, and, eventually, bigger brains, placing the sling's impact near the root of our genus.

Even if only the most conservative version is correct, the selective pressure of infectious slings might have triggered the most dramatic neotenic episode ever experienced by hominins, punctuating the broader trend observed by Gould, and even contributing to speciation. This is because the adaptations required to resist infections and parasites linked to slings, whether by closing pathogenic pathways or prolonging a foetal hair pattern, and their post-genomic effects would have created a founder's effect and set off feedback mechanisms which affected other features.

Competing hypotheses

An analysis of earlier hypotheses and comparable adaptations will highlight some particularities of the present hypotheses while bringing candidates for side effects into focus.

Thermoregulatory hypotheses of hominin body baldness

Peter Wheeler reasoned that an ancient hominin could have reduced its exposure to solar radiation by moving bipedally when crossing open ground in mosaic environments (Aiello, Wheeler 1995, Falk 1990, 1992: 94–97, Wheeler 1984, 1985). This would have minimized the body surface exposed to sunlight, making body hair somewhat superfluous as a shield against radiation, and allowed the human ancestor to forage while competitors and predators were avoiding heat stress by seeking shade.

We would counter that it is doubtful, as Amaral (1996) and Cabot (1975) have demonstrated, that

hominins would have lost their hair over the entire body just because an upright posture reduced the beating received from sunlight. If this were so, the relatively shaded areas on the flanks and between the legs of many quadrupeds should be denuded. Come to think of it, why aren't one's shoulders, which are nearly as exposed to sunlight as the tops of human heads, almost as hairy?

The answer might be because a different mechanism is responsible for our species' bald bodies. Thick body hair would have been so useful for avoiding abrasions in rough thorny landscapes and providing attachment points for clinging infants in the absence of horizontal backs and slings that our ancestors must have been subjected to a radical shift in their environment (or microenvironment) to have lost their protective hair – even if hair was somewhat less important as a solar shield. Wheeler might be right that bipedalism reduced the need for body hair as a shield against the sun, but the question remains, could hominins afford to undergo radical hair loss until after the invention of the sling? Two brakes had been removed, one related to body hair reduction and the other to encephalization, but other brakes had to be released before either potentiality could be realized.

The extension of a juvenile trait

We have already seen that there would have been little to stop the extension of juvenile body baldness, which had been an adaptation to slings, into the adulthood of females who no longer required body hair for clinging infants – if only because their biological investment in such hair was no longer needed. But what about among males? Both sexes would now have had strong incentives to select mates whose relative lack of body hair suggested that they could produce progeny who were bald enough to survive in slings.

Other forces would probably have contributed to the rapid extension of the foetal (now juvenile) trait to adults as well. The first is the hygienic benefit to animals feeding on large carcasses – especially if scavenging and hunting increased because of a trend towards less mature infants, which would have induced cravings for the kinds of foods (or rather their underlying chemicals) needed to sustain altricial brain growth.

Cystine and its implications for feeding strategies

These cravings might have left markers in human milk. While all primates have similar milk components, our milk has the highest cystine content, for example, with the great apes coming in second (Lee 1998). Our bodies use cystine to make taurine, which is concentrated in the brain and eyes, so its higher levels in human and anthropoid milks might reflect the fact that hominid brains take longer to mature than those of other primates – with humans taking the longest (Lee 1998).

An increased appetite for chemicals like cystine, which might have been needed by more slowly maturing, altricial babies, could have caused adults to change their feeding strategies. Such adjustments are known to occur in squirrel monkeys (Lyons *et al.* 1998), gelada baboons (Barrett *et al.* 1995), long-tailed macaques (Karssemeijer *et al.* 1990), and yellow baboons (Altmann 1980), whose females all change the way they forage in order to care for their infants after giving birth (Falk 2004). It is also known that prosimians, which carry their young while lactating, produce more dilute milks than other prosimian species which park their young while foraging (Tilden, Oftedal 1997). This implies that a species, which finds ways to avoid the energy expense of carrying infants inefficiently and uses its time better to collect food, can produce richer milk. If that insight is transferable to the huge energy savings (Wall-Scheffler *et al.* 2007) and increased efficiency during foraging provided by the sudden ability to use two hands, instead of just one, once baby slings were adopted, then the shift might have been expressed quite quickly in the production of the kind of milk required by greater post-natal brain development.

Although an increased appetite for foods such as cystine was probably just one of the nutritional trends triggered by the drift towards altriciality, this desire alone could have encouraged parents to seek foods such as eggs, whose raw whites have 1196 mg of cystine per 200-calorie serving, raw bovine meat and spleens at 1009 mg, raw pork and kidneys from animals such as warthogs at 722 mg, and raw buffalo at 659 mg, all of which have more cystine than such protein-rich vegetable products as lentils (SelfNutrition Data: Know what you eat 2012), which were largely unavailable before the birth of agriculture.

If adjustments in feeding strategies included seizing more opportunities for raiding kills and hunting, they would have increased the users' contact with gore while favoring somewhat better runners, with longer legs and a heat regulatory system based on more extensive cooling glands, which would have made hygienic body baldness adopted from neotenic juveniles work even better for active adults. Each tendency would have reinforced others in the trend, creating an adaptive feedback mechanism.

But the pressures which transformed small-brained foraging hominins without carrying slings into long-limbed, big-brained, and probably hunting erectines probably could not have begun as long as mothers had

to be hairy and infants had to be born with brains that had already matured to the point of providing tenacious clinging reflexes within a few weeks of birth. Instead, all these selective pressures that led to *erectus* might have built upon the body baldness that showed up as a neotenic adaptation to sojourns in slings, before being extended to adults because of
– sexual selection;
– attrition of an unnecessary biological investment;
– hygienic benefits – similar to those enjoyed by bald-headed vultures – to more avid meat eaters (especially ones attracted to cystine-rich internal organs);
– and its foundation for the development of a new cooling system.

So the juvenile body-baldness hypothesis actually fits explanations for hair loss as certain hominins turned to eating more animal products – either, most radically, as their precursor and foundation or, more conventionally, as part of a tandem package with the evolution of cerebral cooling systems and greater locomotor efficiency.

The aquatic hypothesis for thinned hair

Another hypothesis for our hair distribution is that it is linked to a semi-aquatic phase when our ancestors supposedly lost most of their body hair and acquired hydrodynamic hair patterns as an adaptation to swimming (Hardy 1960, Morgan 1997). This is doubtful both because many aquatic mammals in the human size range actually have thick hair and because the oldest evidence of humans exploiting coastal shellfish is only 164,000 years old (Marean *et al.* 2007), whereas evidence of body baldness goes back to at least 1.2 Ma (Jablonski, Chaplin 2002). But even if the aquatic hypothesis can be partly salvaged, can its explanation of hair reduction pre-date adaptations to slings? Probably not, since, once again, females would have had to remain hairy as long as they needed hair for infants to cling to.

But once they had slings and both infants and adults began to be selected on the basis of thinned body hair, their descendants might have been attracted to water not only to quench their thirst, but to clean their infants, reach egg-sources at island-and-marsh rookeries, and forage for mollusks which contain an average of 453 mg of cystine per 200 gm serving. Just as there might be some truth to thermoregulatory models for thinning (adult) hair – as long as we see them as being built on a neotenic juvenile template, the aquatic hypothesis might cast light on adaptations after body hair reduction had occurred because of infectious slings.

Previous ectoparasite hypotheses

What about other explanations that link our hair distribution to ectoparasites, including an experiment which showed the sensitivity of vellus hairs to marauding lice (Dean, Siva-Jothy 2011) and Markus Rantala's hypothesis concerning the advantages of having thinner hair to the first users of reused nests (Rantala 1999, 2007)? The experiment with lice is largely irrelevant since it examined the benefit of having short vellus hair as opposed to being shaved, rather than the benefit of vellus over terminal hair.

But Rantala's hypothesis might have actually pinpointed a factor that amplified the sling's effect. The question is, which came first: planned hunts by adults, who systematically left at least a few females at home bases with reused nests for extended periods, or slings? Even if females operated within a smaller radius, like modern !Kung women, who contribute two thirds of their groups' calories (Lee 1979) with the aid of leather slings (Falk 2009: 34) (*Figure 6*), they would have needed one of two things; nurseries, which might have been one of the strongest motives for establishing the first base camps, or baby-carrying devices – or both, once their infants were born without clinging reflexes or mobility. But even the nursery theory for base camps requires that food be carried back to individuals who were not gathering it for themselves – nannies and their charges – something that is difficult to do without carrying devices. Either way, slings probably came at least as early as base camps, and probably earlier, facilitating their longer use.

It is interesting to note, before passing on, the possible link between the unusual loudness and persistence of crying in human babies compared to other young primates (Sokol and Thompson 2004), and the possibility that the trait, which tends to be contagious in nurseries, evolved once hominins began using creches. Sokol and Thompson (2004) pointed out that such vocalizations are unnecessarily loud for drawing the attention of a mother in close proximity or contact with a child, while wailing could have evolved as part of an auditory arms race when numerous infants were left in the custody of a few care-givers, since it would have forced babies to compete like chicks in a nest (*Figure 9*). The suggestion that the first nurseries were the scene of an oral arms race implies that they were defensible or chosen for their inaccessibility to predators, in which case they were probably reused and doubled as base camps, which would probably have been provisioned by regurgitating food or bringing it back in carrying devices.

All the same, Rantala's insight is complementary with the present hypothesis, since the reuse of nests (Rantala 1999, 2007) would have rapidly extended the need for body hair loss from newborns, who could only have survived by rapidly acquiring traits more suitable to an environment even more infectious and parasite-ridden than nests – reused and decaying slings – to older juveniles and, eventually, even adults.

Vestiary hypotheses

There are those who argue that human bodies grew balder in response to clothing (Glass 1966, Kushlan 1985). If the differentiation of human head and body (clothes) lice around 190,000 years ago (Kitchen *et al.* 2010) was a response to the creation of a new louse environment in the form of clothes, then the lineage leading to modern humans should have started losing most of its body hair no earlier than then according to the vestiary hypothesis. Yet, once again, it has been shown that melanin probably increased to protect denuded skin from ultraviolet (LTV) radiation (Jablonski, Chaplin 2002) by at least 1.2 Ma (Rogers *et al.* 2004) while male *Homo ergasters* were exerting themselves so much by 1.53 Ma (Bramble, Lieberman 2004, Brown *et al.* 1985) that they must have had efficient whole-body cooling systems – putting bald bodies millennia before clothing.

Avian strategies and adaptations to parasite-ridden nests

Another type of infant that must survive confinement is baby birds in nests (*Figure 9*). The two most extreme strategies that birds evolved for surviving in these parasite-ridden places (Møller *et al.* 1990, Rothschild, Clay 1961) relate directly to the altricial-nutrient hypothesis, since they concern the effect of having more altricial babies on adult cravings for fats and proteins, and the parents' consequent recourse to increased meat acquisition.

The first strategy is to hatch with high mobility, lots of down, and open eyes – in other words, with levels of maturity closer to those observed among ape babies than human infants. Such birds, which leave the nest within two days and quickly forage for their own food, are "precocial". The opposite strategy is to hatch earlier with little or no down, closed eyes, and a basic feeding reflex – and to depend entirely on parents for food for an extended period. One of the adaptations of such "altricial" hatchlings is to emerge with less plumage than chicks that leave the nest quickly, making it easier for parents to stay ahead of nest parasites by removing more than would otherwise be possible. This is hardly

incompatible with the observation that well-adapted parasites avoid killing their hosts.

Paradoxically, precocial species show a trade-off between their juvenile and adult brain sizes, since they hatch with more fully developed brains than altricial species, only to end up with smaller skill sets and adult brains in relation to their body weight (Ehrlich *et al.* 1988). Similarly, newborn apes have relatively mature brains by comparison to their human counterparts, but their brains never grow as big or complex as a human's, making apes more precocial than *Homo sapiens*.

FIGURE 9. Young passerine birds like these robins resemble baby humans in several ways. These include loud cries that seem to have evolved in response to their need to draw attention to themselves in nursery-like environments, nearly bald bodies, which reduces hiding places for parasites, and richer diets than their precocial cousins. Altricial birds have also evolved the avian equivalent of diapers – faecal sacs, one of which can be seen at the top of the photograph. These sacs allow adults to remove their chicks' wastes from the confined environment, where they could increase the risk of infection by providing nutrients for microbes. Courtesy of S. Bedford.

Parrots resemble humans by combining the two strategies: they are altricial, but lay nutrient-rich eggs like precocial birds. As a result, their brains are both large and ready to continue growing upon hatching as the parents continue to invest their energies in feeding chicks (Ehrlich *et al*. 1988). Humans are similar with a mix of semi-precocial traits (brains which are as big as they can possibly be given the rigidity of the human birth canal, as a result of bipedalism, and open, but unfocused, eyes) and altricial characteristics, including bald-bodied newborns, with high rates of postnatal brain growth and helplessness. That mixture, which gives humans, like parrots, the benefits of both strategies, probably came about when baby slings forced users towards investing more time in nurturing offspring with one or more slowed developmental rates.

Passerine birds, which are all altricial, have two more insights to impart. The first is that they tend to collect foods that are richer in fats and proteins than those of precocial species. Their helpless chicks need such food more than precocial ones since their brains still have so far to grow (Ehrlich *et al*. 1988). By removing the constraint on helplessness, which opened the path to neotenic cerebral development, and inducing a second type of neoteny as a means of creating quick body baldness, the invention of the sling might have forced hominin bands – like passerine birds – to focus more on collecting protein-and-fat-rich foods in order to produce the type of nourishment required by more altricial babies with brains which could and increasingly did mature later than before. If the subsistence strategy of the first sling users shifted even slightly towards obtaining such foods, then the invention of the sling might have set off the feedback mechanisms mentioned above in regard to scavenging and hunting.

The final insight involves the way altricial nestlings have adapted to long periods in containers by creating the equivalent of disposable diapers by excreting "fecal sacs" (Campbell, Lack 1985: 433). These thick protein bubbles filled with excrement are so strong that the parents can pick them up in their beaks and fly them out of the nests, before the wastes draw pathogens and parasites. The lesson of these observations is that any animal which must survive in potentially infectious microenvironments – including the first hominins to use and be carried in slings – probably has to adapt to them both biologically and behaviorally.

The implications of alternating confinement and bath times for mirror neuron research

Finally, we must touch upon the implications of these hypotheses for the study of infant interactions with adults

(Eibl-Eibesfeldt 1989) and their links with mirror neurons (Bråten 2004, 2007: Fig. 2, Bråten, Trevarthen 2007, Falk 2004b, Gilissen 2004, Rizzolatti, Arbib 1998), although a thorough analysis must await future publications. The present hypotheses point in several directions that were either unexplored or just glanced on during the debate over Dean Falk's (2004a, 2004b, 2009) hypothesis concerning the importance of baby-parking before the use of slings for the development of motherese and language.

The first of these directions concerns the intervals between an infant's sessions in unsanitary containers, when a mother would have had to clean, and just as importantly, in light of the bacterial blooms caused by such confinement (Suter *et al.* 2011), dry infants. These intervals correspond to the daily, and often more frequent, bath times of modern infants (Falk 2009: 25) (*Figure 10*), when so much of the face-to-face and kinesthetic interaction between mothers and their offspring that has been described by Stern (1985), Eibl-Eibesfeldt (1989), Bråten (2004), Trevarthen, and others takes place. Although such interaction also occurs during bottle feeding (Schögler, Trevarthen 2007: Fig. 3), it is not so much the case with breast-feeding. The feeding of solid foods, which often meant the mouth-to-mouth passage of food masticated by mothers even after the invention of cooking and gruel (Forge, Evans-Pritchard

FIGURE 10. Modern infants, such as this newborn Wodaabe girl, tend to be washed daily, if not more often. Many of the studies of mirroring behaviors between mothers and their infants correspond to such moments, when they tend to be face-to-face. Adopted from Beckwith and Fisher (1999: 21), courtesy C. Beckwith and A. Fisher.

1973: 130), adds a second type of face-to-face interval once chimp (Goodall 1986), bonobo (Falk 2004a: 494, Kano 1992) and human infants (*Figure 11*) can digest such food around five months old.

The other situation automatically created by the sling was immobilization of infants in positions that allow a child to observe its mother's interactions closely. Mothers who must constantly bend and squat often place their baby-carrying devices on their backs or flanks,

FIGURE 11. Chimps, bonobos, and humans often feed their offspring mouth-to-mouth like this Mbotgote mother from Malekula Island in the Pacific, who is passing masticated taro to her child. Adopted from Forge and Evans-Pritchard (1973: 130).

which reduces their infants' contact with their mothers' faces, while sometimes putting infants in ideal positions to experience the world from the maternal point of view. A child looking over a mother's shoulder, for example, quite literally witnesses the world from her perspective. This is reminiscent of the fact that chimps start gazing in the same directions as their mothers when they shift from clinging to their bellies to riding their backs (Bråten 2004: 508) and creates the potentiality of building upon such anthropoid mirroring. A modern equivalent to the piggy-back position is allowing a child to "drive" on one's lap, while the adult does the steering.

The sudden combination of a new need for cleaning and drying intervals and placement of children in nearly immobilized positions, which might have aligned them with their mothers' perspectives, would have profoundly changed the potentialities of two patterns of maternal-infant communication simultaneously. Each of these yoked situations would have provided fertile new ground for the development of communication features associated with mirroring, with the developments probably leveraging off each other. The result might have been that slings not only became baby incubators, but neurological and cultural ones as well.

The fact that slings would have made it easier to bring provisions to nannies and their charges in nurseries that doubled as base camps would have amplified these trends by adding a third type of situation, creches, to perspective-sharing during transportation, and face-time during cleanings.

CONCLUSION

In summary, the first hominin mother to put her infant into a sling, who might have been an immediate precursor to the *Homo* genus, transformed herself into an artificial marsupial and invented a tool that opened the path towards the emergence of more slowly maturing brains and more complex communication. Put another way, both *Homo sapiens* and its entire genus might be products, in part, of adaptations to the most influential tool of all time – the baby sling. But the hairy inventor's brain would not have departed very much from the ratio of newborn-to-adult brain sizes among chimpanzees and australopithecines. The invention of the baby sling quite simply had to have taken place before adaptations that, one, extended a high rate of brain growth into the postnatal period, and, two, led to pregnancies that were "shorter" not in length, but in the sense that births were increasingly separated from the stage when a child

developed the reflexes seen in newborn apes. And, when these adaptations did occur, it was probably partially as a result of quick fixes (such as gene inactivation, changed gene expression and neoteny) to risks of parasitism and infection for hairy babies in unsanitary bundles.

Just as vultures and marabou storks have evolved naked heads to avoid having their plumage become a microbial morass with lethal consequences, hominin babies whose foetal body baldness had not disappeared – allowing them to be more easily cleansed – would have been selected for.

Once neoteny had been induced by the selection for the foetal trait, this feature might have been extended into adulthood by a variety of pre-existing and new factors, including sexual selection, sanitary benefits to parents driven to increased meat acquisition as their infants became more altricial and required more fats and proteins to nourish post-natal brain maturation, and eventually, the development of sweating as a means of shedding heat during the strenuous activities involved in killing prey. On the one hand, the feedback mechanisms set off by the elimination of the requirement for a high level of brain maturation at birth and neotenic and immunological changes required by infectious slings might have been part of the rise, in tandem, of the package of thermoregulatory and locomotor adaptations seen in *Homo ergaster*. But, even more radically, they might have set the foundation for a double punctuation, first creating some of the earliest members of our genus, with a higher encephalization quotient (EQ), neotenic crania, and greater appetite for meat, then, through cascading side-effects, larger brained species, who engaged in even more planned hunting, such as *ergaster*. In short, slings and adaptations to their parasites and pathogens might have triggered both body hair loss and created the possibility for extended postnatal brain maturation, opening the path towards the evolution of human intelligence.

ACKNOWLEDGMENTS

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