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Energy use by Eem Neanderthals

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Abstract

An analysis of energy use by Neanderthals in Northern Europe during the mild Eem interglacial period is carried out with consideration of the metabolic energy production required for compensating energy losses during sleep, at daily settlement activities and during hunting expeditions, including transport of food from slain animals back to the settlement. Additional energy sources for heat, security and cooking are derived from fireplaces in the open or within shelters such as caves or huts. The analysis leads to insights not available from archaeological findings that are mostly limited to durable items such as those made of stone: Even during the benign Eem period, Neanderthals faced a considerable heat loss problem. Wearing tailored clothes or some similar measure was necessary for survival. An animal skin across the shoulder would not have sufficed to survive even average cold winter temperatures and body cooling by convection caused by wind. Clothes and particularly footwear had to be sewn together tightly in order to prevent intrusion of water or snow. The analysis of hunting activity evolvement in real time further shows that during summer warmth, transport of meat back to the base settlement would not be possible without some technique to avoid that the meat rots. The only likely technique is meat drying at the killing site, which indicates further skills in Neanderthal societies that have not been identified by other routes of investigation.

Keywords: Energy balance; heat loss; metabolism; Neanderthal; Eem interglacial; Fire; Clothes; Footwear; Meat drying

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1. Introduction and background

The Neanderthals had an average body mass above that of modern humans, a more sturdy bone structure and a lower height. Food was primarily obtained by hunting big game. The aim of the present paper is to explore the energy requirements of Neanderthals during the warm interglacial Eem period (around 125 ky BP), and based on such analysis to discuss the need for clothes and footwear, as well as methods for food conservation and preparation. The climatic environment is taken as that of Northern Europe, using Eem temperature data from Bispingen close to the Neanderthal site Lehringen near Hamburg (Kühl and Litt, 2007). The climatic conditions would be similar in most of Northern Germany, Belgium and Denmark, while Eastern Europe would have slightly colder winters, as would Finland. Some 30 European Neanderthal sites dating from the Eem, with roughly equal shares in Southern, Middle and Northern Europe, are listed by Wenzel (2007). Traces of seasonal presence have been found at Hollerup, Denmark (Møhl-Hansen, 1954) and at Susiluola Cave, Finland (Schulz, 2001, 2006), indicating that Neanderthals had a high mobility. Assuming a group

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size of 25 (Hassan, 1981), the total European Neanderthal population at any given time within the Eem period could have been around 1000, depending on how many sites were simultaneously populated and which fraction the sites surviving and found are of the true settlement count. Patou-Mathis (2000) lists 73 Eem settlement levels in Middle and Northern Europe, indicating that some sites were re-occupied at different times within the Eem period.

Throughout their presence in Europe, the diet of Neanderthals consisted mainly of meat. Large herbivores seem to have been actively hunted rather than scavenged (Bocherens *et al.*, 2005). The Neanderthal hunting strategy was to specialise and concentrate on a few large herbivore mammal species, among which horse (*equus* sp.) red deer (*cervus elaphus*), woolly rhinocerous (*coelodonta antiquitatis*), woolly mammoth (*mammuthus prinigenius*) and bison (*bison priscus*) were present both during the Eem interglacial and the adjacent colder periods. During the Eem, additional forest-based species appeared, and the volume of species preferring open space, such as mammoth, was lower than in adjacent periods: mammoth is found in 22.5% of the Eem-occupied site levels considered by Patou-Mathis (2000), but in 50-60% of the levels belonging to adjacent time periods. Mammoth is in this study selected as an example for investigating the energy use involved in Neanderthal hunting, slaying and readying meat for eating, because of its size that demands a maximum of logistic skills by the hunters. However, proof of mammoth presence in North-Western Europe during the Eem period is nearly absent. Mammoth remains have been found in Grotte Scladina, Belgium (in level 4, dated by thermo-luminescence to between 106 and 133 ky BP, and in level 5, dated to 110-150 ky BP), but according to magnetic susceptibility relative dating in the lowest part of the uncertainty intervals and thus possibly younger than the marine isotope stage 5e usually associated with the Eem period (Döppes *et al*. 2008; Ellwood *et al*., 2004). The scarcity of mammoth finds at the settlement sites may be explained by only meat, not bones, being carried back to camp after a kill (Patou-Mathis, 2000; Balter and Simon, 2006). A straight-tusked elephant, a species preferring the warmer Eem environment, has been found at Lehringen with a Neanderthal spear through its rib, so it could also have been used as an example of extreme-weight prey. In the assessment made in the present study, the species exemplified is represented by its meat-mass alone, and results (such as energy-use by carrying) scale directly with the mass of the parts transported back to the group. Large herbivores were hunted and killed by sinking spears into their body by a party of several Neanderthals (Wenzel, 2007). Spears were rarely thrown, as deduced from the absence of shoulder and upper arm bone asymmetries characteristic of more recent hunters using spear-throwing techniques (Rhodes and Churchill, 2009). The Neanderthal population density was low enough to make big-game hunting sustainable, and famines due to insufficient food would not normally occur (Harpending, 1998).

One similar analysis of needs for clothes and footwear has been made for the marine isotope stage 3 around 40 ky BP (Aiello and Wheeler, 2004), however with some unrealistic features: It uses subjective wind-chill temperatures (Lee, 2001) in the heat-loss expression valid for real temperatures (to which heat loss by the action of wind could have been added in the way it is done below), and it uses an arbitrary increase of the average metabolic rate to three times the basic one. This is suggesting an ability of the Neanderthal body to regulate its metabolism according to ambient temperature (Steegmann *et al*., 2002), in contrast to the body of modern humans, where this can be done only in a very minor way in infants, through adrenaline stimulation of a special fat deposit in brown adipose tissues (BAT) near the shoulder (Farmer, 2009). Steegmann *et al.* (2002) suggest that recent Tierra del Fuego Ona (Selk'nam) aborigines had a particular cold adaptation and that the Neanderthals might also have had it. However, no search for BAT in Ona remains has to my knowledge been made, and the photo reproduced in Steegmann *et al*. (2002) shows people posing for a 1901-picture, dressed in heavy fur and similar hats, but with bare feet or moccasins. To make inferences, one should have time distributions of clothing used and corresponding temperatures, and to to compare with Neanderthals, the differences between the Ona, deriving their food from the camel-like guanaco, from gathering and from fishing, e.g of seal, and the Neanderthal providing food by big-game hunt with walking or running over extended distances and durations should be kept in mind. The Neanderthals would during cold periods be better compared with present or recent Inuit populations, which use several layers of clothing and heavy, furred footwear. Should the Neanderthals really have had a genetic advantage in cold adaptation that modern humans do not have, it becomes more difficult to understand why modern humans and not Neanderthals survived the cooling period up to the last glacial maximum, 40-20 ky BP. Without *ad hoc* assumptions on the genetic make-up of Neanderthals, one must assume that in order to increase metabolism, muscle work is required, so that a sleeping and freezing Neanderthal person must get up and swing the arms, jump up and down or otherwise perform the muscle work that will bring the level of metabolism up and create the associated heat that can keep the body warm. Generating a total of 300 W of heat (including the basic metabolic heat production during sleep of 80-90 W) requires about 100 W of muscle work (Sørensen, 2004, p. 17).

The analysis of energy production and use presented below is divided into two parts: first the energy balance is evaluated during sleep, and then the various components of energy production and use during activities taking up the wake time of Eem Neanderthals.

2. Energy balance during sleep

Table 1 summarises the assumptions and results for conditions suitable for survival during sleep in the North European Eem environment. The calculation considers heat losses due to radiation, conduction and convection from the surface area of the sleeping male or female Neanderthal, including the heat removed by convection caused by wind blowing along the exposed body surface, in case of insufficient shelter. When clothes or bed cover (say a mammoth skin) is used, a multilayer heat-loss calculation is performed, using simple models known to work in engineering applications such as heat loss from buildings, multilayer windows and solar panels (Sørensen, 2004, p. 361),

$$L = A\,(T_0 - T)/(R + C^{-1}), \quad R=\Sigma_i\, s_i / k_i.$$

Here, the heat loss L (in W) is expressed in terms of the body surface area A (m^2, see Table 1), the body temperature T_0 (°C) to be maintained, taken as 37 °C, the ambient temperature T, the thermal resistance R summed over each layer i of clothes or cover (including the subcutaneous layer of fat under the human skin), and the wind-related convection term described by C (W m^{-2} K^{-1}). The thermal resistance of a particular layer is the ratio of the layer thickness s_i (m) and the heat conductivity of the layer, k_i (W m^{-1} K^{-1}). The thickness of the subcutaneous fat layer is taken as 0.010 m (male) and 0.014 m (female), the thermal conductivity of fat as 2 W m^{-1} K^{-1}. For bed covers of skin from large animals such as mammoth or bison, as well as for animal furry clothes, the heat conductivity is taken as 0.035 W m^{-1} K^{-1}. The effective thickness of one layer of clothes is taken as 0.01 m, that of a mammoth bed cover as 0.03 m. An approximate form for the wind convection used in engineering applications is

$$C = a + b\,V^{f},$$

where a is taken as 5 W m^{-2} K^{-1}, b as 3.95 W m^{-2} K^{-1} and f as 0.6 when the wind speed V is inserted in m s^{-1} (Duffie and Beckman, 1991). Scaling of measured wind speeds between heights, e.g. from standard meteorological observation boxes at 10 m height to the height of a standing or lying Neanderthal is done by standard neutral atmosphere relations (Sørensen, 2007, p. 63).

It is now straightforward to compare metabolic rate (human heat production by conversion of stored food energy) with heat losses to a given environment, and e.g. determine the minimum ambient temperature that can be endured by Neanderthals. Death from negative heat balance has a time delay of several hours to days but not weeks, as deduced from the fate of modern shipwreck victims. The basic metabolic rate *B* (during sleep) used here is given in Table 1 (Sorensen and Leonard, 2001). Seasonal average ambient temperatures during the Eem period for typical Neanderthal settlement sites in northern Germany are shown in the two last lines of Table 1, based on pollen analysis at Bispingen (Kühl and Litt, 2007) near Hamburg, and with four numbers added in parenthesis: the lowest and highest are 100-year extreme minima and maxima, while the middle ones are 30-year average minima and maxima, taken from modern records (Statistical Yearbook Denmark, 1976). The minimum endurable temperature calculations presented in Table 1 show, that sleeping naked in a cave or hut (sheltered from wind) requires temperatures above 27 or 28 °C (male and female), and 5 °C more if sleeping outside, even in a place with low wind (1.5 m s^{-1}). Wearing one layer of clothes, the minimum endurable temperatures change to 13 and 15 °C inside, 16 and 20 °C outside, and with a mammoth-equivalent skin cover to –15 and –10 °C inside and -9 and –4 °C outside in a 5 m s^{-1} wind. Clothes plus mammoth-equivalent skin cover lowers the endurable temperatures by another 13-14 °C. The implication is that bed cover equivalent to a large mammoth skin would have been indispensable at nearly all times during the year, and that hunters on a multi-day winter hunting expedition would have had to bring some form of cover to use when sleeping along on the trip. Exposed body areas such as the face would need heat transfer from adjacent areas. Extremities are more cold-sensitive than the whole-body average, and only small exposed areas would receive enough heat transfer from covered parts of the body. Thus, the conclusion drawn is that in average winter conditions, the clothes worn must have been capable of preventing air flow from penetrating to more than small body surface areas, and that footwear in particular must have been tailored to wrap the feet entirely during the long walks associated with day-long hunting trips. Lithic remains from the Eem include awl-like points suited for making holes in skin material (found e.g. at the Stuttgart-Untertürkheim site; Wenzel, 2007), as well as knife-like blades suited for cutting strips of animal skin, that could be inserted and weaved through the holes, in order to convert plain furs into fitting clothes.

Fires would have contributed to lowering the endurable temperature during sleep. A family hut would have had one fireplace, a cave several, and additional fires were lit in the open. However, the individual indoor fires would have been converting energy at a rate less than 1 kW when maximised for cooking (Sørensen, 2004), and presumable only embers of dwindling fires would have provided (mainly) radiative heat during night. Due to the poor insulation of huts and openings in caves, heat losses would have limited the effect of fires on minimum endurable temperature to only a couple of degrees C, on average, starting a little higher but declining to near-zero during the night.

3. Influence of activities involving muscle work on energy balance

Turning now to daytime activities, the main results are presented in Table 2. The Neanderthal group considered comprise some 25 people, of which about 15 would have been children and a typical hunting party thus hardly more than six. I assume five male and one female hunter (following the suggestion by Kuhn and Stiner (2006) that women occasionally participated in the hunt). According to Hassan (1981), the hunting territory of such a Neanderthal group would be about 10^4 km^2 and 50 km would thus be a typical distance between prey killing site and base settlement. The metabolic rate increases with the muscle work performed during activities such as walking, tree felling, stone tool manufacture, prey pursuit and killing, separating hide by use of scrapers, cutting meat, extracting marrow from bones, and so on. The maximum average metabolic rate that can be sustained for an entire workday is about three times *B*, of which some 100 W can be delivered as work, the rest being heat. During short periods of time, considerable higher metabolic rates can be achieved (Sørensen, 2004). Estimates of the time used on different activities during a hunting expedition are given in the upper lines of Table 2.

I assume that meat was brought back to the group members left at the base settlement rather than them moving to the kill site. A common view (see e.g. Patou-Mathis, 2000) is that Eem Neanderthals had a base settlement plus a few seasonal camps. It seems little likely that pregnant women and infants would have been moved around to new kill sites at each major successful hunt, and although the seasonal camps would have been placed on trajectories of preferred prey, the distance between camp and kill site could still have been considerable. I therefore assume that the hunting party performed the butchering and any preservation treatment of the meat at the kill site and that it was necessary to bring the proceeds back to the families left behind.

Bringing meat back to the base settlement must have been a great challenge, particularly for the largest prey species. The mass of an adult woolly mammoth (taken as the most challenging example) is some 6-8 metric tons, and at least 2 tons would be meat suitable for eating (with an energy content of around 16 GJ, enough to feed the entire Neanderthal group for some 50 days). However, bringing this meat to a location 50 km from the site of slaughter would require 25 round trips of four people, assuming that two would have to stay at the killing site to guard the remains. During summer, the meat would have rotten before reaching its destination. Essentially only one method of meat preservation was available to the Neanderthals: drying. Hanging the meat on a wooden scaffold for some days, eventually with the aid of a fire, would reduce the mass to roughly a third (FAO, 1990). Wood was available in sufficient quantities for construction and fire-making in most of the North European Eem sites, characterised by mixed forest and occasional semi-open landscapes. Carrying dried meat from a mammoth home could now be done by 7-8 round trips (14-16 days), each person carrying 20-25 kg, and the meat would arrive suitable for storing and eating. Evidence for carrying such weights is found in Neanderthal skeletons showing signs of *Osteoarthritis* damage (Dawson and Trinkaus, 1997). The risk of hurting a foot on a sharp stone or twig is increased by carrying heavy loads and thus reinforces the heat-loss based deduction of Neanderthals using well-designed and sturdy foot wear. For smaller prey types, the energy associated with carrying trips diminishes in proportion to the meat weight.

Energy use by the hunters during walking and running (Leonard and Robertson, 1997), and walking with weights on the shoulder (Watson *et al.*, 2008), is presented in Table 2, on the basis of estimates of time used for each activity. Added is energy use by the group members staying at the settlement site, where the most energy-requiring activity would be wood-cutting (averaging some 350 W during 15-20% of working hours), leading to an overall average energy spending of 145 and 125 W per cap. for male or female adult members of the group, in good agreement with estimates for early modern humans (Sørensen, 2004). Adding further an estimate of the energy use of the children, I arrive at about 1750 W for the entire group. With a 30% loss, this would require food intake containing 2500 W or 813 kg of meat per month. The Neanderthal group thus had to bring down the equivalent of one mammoth every 7 weeks, allowing quite decent time for the other activities needed.

In order to arrive at the total energy use by Neanderthals, the bottom lines of Table 2 adds an estimate of wood-fuel energy used to maintain fires. The average total energy in food and fuel use is then 319 W per cap., of which more than half is from wood-fuel, supporting the statement that trees and other wood-fuel sources were abundantly available at the prevailing population density.

4. Conclusions

The estimate of Neanderthal energy requirement beyond the basic metabolic rate during sleep has defined the necessary environment during North European Eem winters, proving the need for bed-covers equivalent to a large furry hide, and day-time clothes and footwear with fairly modest inlets left for wind to penetrate through. The use of fires in caves, tents or huts without significant insulation and tightness is a help, but cannot in winter substitute for bed-cover and some underlay, such as straw (or a hide large enough to be swept around the body).

The energy use for daytime activities have been estimated on the basis of a distribution if the durations of different tasks either known to have taken place at the settlement or inferred from the break-down of subtasks associated with hunting and food management, treatment of hides and making of clothes, as well as the stone-tool industry. The required average food energy intake to be converted is found to be 135 W or 1.7 times the basic metabolic rate at sleep. This is considerably lower than the 163-217 W estimated by Steegmann *et al*. (2002) or the 240 W implied by the factor-3 assumption of Aiello and Wheeler (2004), due to the energy cost of their assumed built-in thermo-regulation ability. To this the energy connected with use of fires would be added, a quantity reaching about 180 W and useful for both space heating and process heat, but with very low conversion efficiency.

Clearly, energy use will go up during the colder periods following the Eem, but more slowly if thermo-regulation is assumed to be dealt with through clothes, rather than if it had to involve elevated levels of muscle work.

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Table 1.
Estimate of ambient minimum endurable temperatures
for Eem Neanderthals during sleep, and actual temperatures (°C).

Deg. C if no other unit mentioned	male	female
Body mass (kg)	80	75
Body height (m)	1.65	1,55
Body surface area (m^2)	1.87	1.74
Metabolic rate of energy conversion at sleep (W)	92	77
Naked on dry ground (at wind speed v = 1.5 m/s)	31.8	32.3
On dry ground with one layer of clothes (v = 1.5 m/s)	17.8	19.6
On dry ground with mammoth skin cover (v = 1.5 m/s)	-10.3	-5.7
On dry ground with mammoth skin cover (v = 5 m/s)	-8.6	-4.1
Temperature rise from dying wood fire (v = 0)	1-2° for a few h	
Naked in cave or small hut	26.9	27.8
In cave or small hut with one layer of clothes	12.9	15.2
In cave or small hut with mammoth skin cover	-15.3	-10.1
In cave or small hut with mammoth skin cover and one layer of clothes	-29.3	-22.7
Temperature rise from body heat and embers from dying wood fire in small hut	1-3° for some 4 h	
Temperature rise from body heat and embers from dying wood fires (5) in cave	up to 10° for 4 h	
Eem (Bispingen, 125 ky BP) July temperatures (average and ranges, see text)	17.4 (0, 8, 27, 36)	
Eem (Bispingen, 125 ky BP) January temperatures (average and ranges, see text)	1.0 (-30, -9, 7, 12)	

Table 2.
Neanderthal energy use

*Example of time and corresponding rate of monthly average energy use (W/cap)**	*4 males*	*1 male*	*1 fe-male*	*4 fe-males*
Hunt: tracking down prey (8 h, 1 day in month)	2.04	2.04	1.71	
Hunt: prey killing (1 h, 1 day in month)	0.45	0.45	0.37	
Hunt: parting mammoth, drying, (3 h, 1 days in month)	0.96	0.96	0.80	
Hunt: eat, sleep, rest at hunt site (12 h, 1 day in month)	1.69	1.69	1.41	
Hunt: eat, watch, cut, scrape, sleep (24 h, 12 days in month)		44.16	36.96	
Hunt: carrying meat back (10 h, 7 or 1 days in month)	26.83	3.83	3.21	
Hunt: sleep, rest at home (14h, 7 or 1 days in month)	13.77	1.97	1.65	
Hunt: returning to hunt site from home (8 h, 6 days in month)	12.27			
Hunt: eat, sleep, rest at hunt site (16 h, 6 days in month)	14.72			
Home: wood cutting (8 h, 5 days in month)	15.33			
Home: stone flaking, tools construction, clothes making (8 h, 11, 16, 30 d)	22.49	32.71	27.38	61.33
Home: fire attention, child rearing, food prep., leisure, eat (8 h, 16, 30 d)	22.90	22.90	19.16	42.93
Home: sleep (8 h, 16 or 30 days in month)	16.36	16.36	13.69	25.67
Monthly average energy expenditure, adult humans (W/cap)*	**149.81**	**127.06**	**106.35**	**129.93**
Summary:	*male*		*female*	
Average adult minimum energy requirement (W/cap)	145.26		125.22	
Total average adult energy requirement, W for whole group of 10	1352.37			
Children's average energy requirement (W for whole group of 15)	400.00			
Equivalent meat intake (loss 30%), W and GJ per month for whole group of 25	2503 W or 6.5 GJ/month			
Equivalent meat intake (loss 30%), in kg per month for whole group of 25	813 kg/month			
Fires: 5 cooking fires 8 h, 30 d (346 kg dry wood), average over month	1667 W			
Fires: large outdoor fire 8 h, 30 d (622 kg dry wood)	3000 W			
Fires: Possible fire at hunt site 12 h, 14 days in month (168 kg)	810 W			

* *1 W (watt) is 1 J/s or 2.63 GJ/month or 0.73 MWh/month*