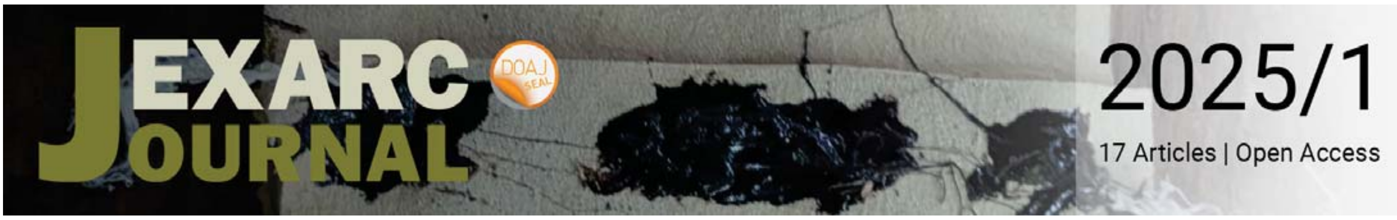


Reviewed Article:

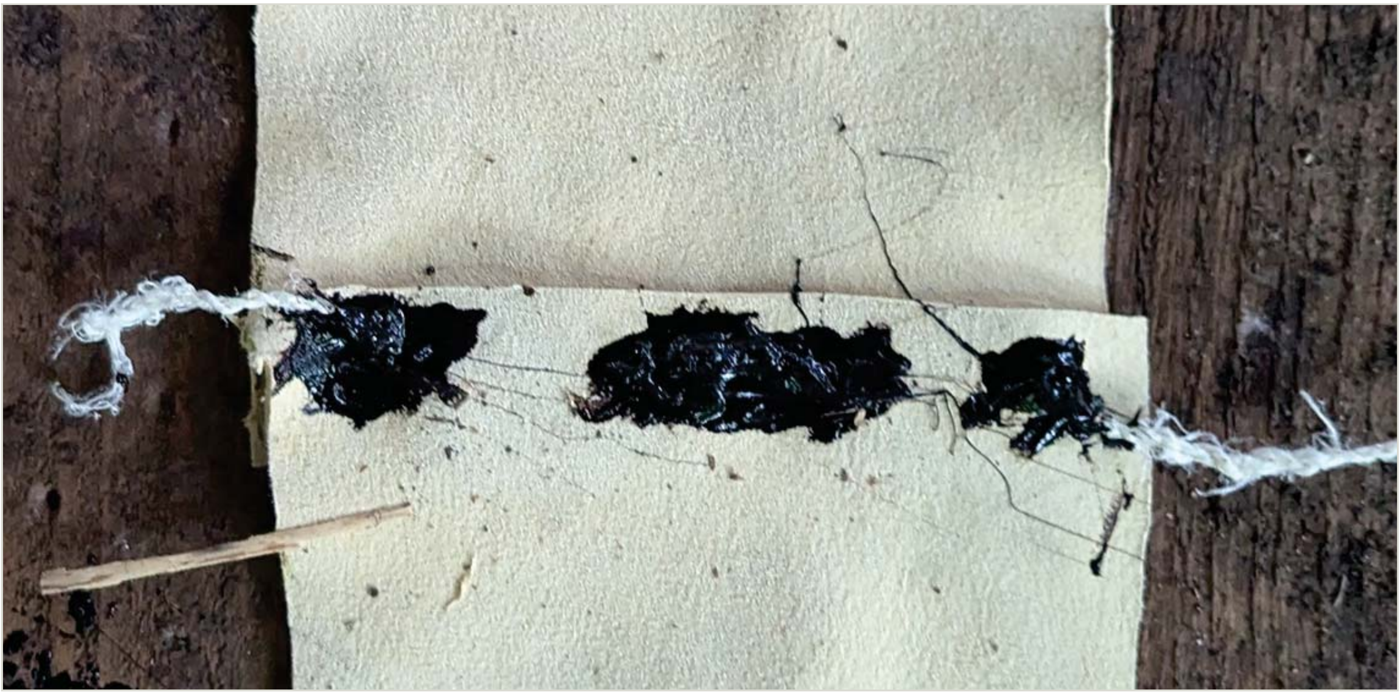
Neanderthals in the Rain: Assessing Neanderthals' Strategies to Survive Wet and Cold Environments through an Experimental Analysis

Persistent Identifier: https://exarc.net/ark:/88735/10782

EXARC Journal Issue 2025/1 | **Publication Date:** 2025-03-25

Author(s): Eleonora Scandola [1] ✉, Penny Spikins [1]

[1] University of York, Heslington, York, YO10 5DD, United Kingdom



Neanderthals' adaptations to cold climates have been extensively debated, however, limited attention has been given to their survival in cold and wet environments. These conditions increase the dangers of cold-induced injuries such as frostbite or hypothermia, as wet

clothing loses its insulative capacities. This research explores whether and how Neanderthals faced such changes and their implications on activities and behaviours. After reviewing biological and cultural adaptations and behaviours, this thesis devises experimental strategies to waterproof clothing. These experiments, inspired by ethnographic accounts, utilise Neanderthals' technological repertoire. The results revealed that the most successful strategy required significant effort to be produced. Evidence suggests Neanderthals tended to remain isolated in their territories and cover shorter distances in their lifespan. Larger group numbers and greater interconnectivity could have supported job division and promoted technological complexity. Therefore, the challenges posed by cold and wet environments may have constrained Neanderthals' territorial expansion, reducing group sizes and limiting social networks. Simultaneously, their restricted interconnectivity could have hindered the development of complex successful strategies, further limiting Neanderthals' ability to cope with wet and cold conditions. This research calls for a deeper, more focused understanding of environmental adaptations and proposes a framework to unravel the tangled relationships between environment, behaviours and technology.

> " Discussions about the strategies used in Neanderthals' occupation of Eurasia can spark speculations about behaviours and environmental adaptations to wet and cold environments.

Introduction

Neanderthals have lived between 800 kya to 30 kya in Eurasia, occupying many territories. Figure 1 shows their extension in Eurasia. They have lived through various Marine Isotope Stages (MIS, which are paleoclimate periods deduced from oxygen isotopes) that have recorded numerous climatic fluctuations (See Figure 2). The affiliation of different hominin species' occupation of Eurasia from MIS 20 is debated, with early European occupations by *Homo Antecessor,* to northern expansion by possible *Homo Heidelbergensis* in 500 ka (Ashton and Lewis, 2012). The Sima de los Huesos MIS 12 individuals have been debated to be either early *Homo Neanderthaliensis,* finding similarities with the MIS 13 evidence in Boxgrove, UK (Lockey *et al.,* 2022) , or a different taxon but with common descendants (Arsuaga *et al.*, 2014).

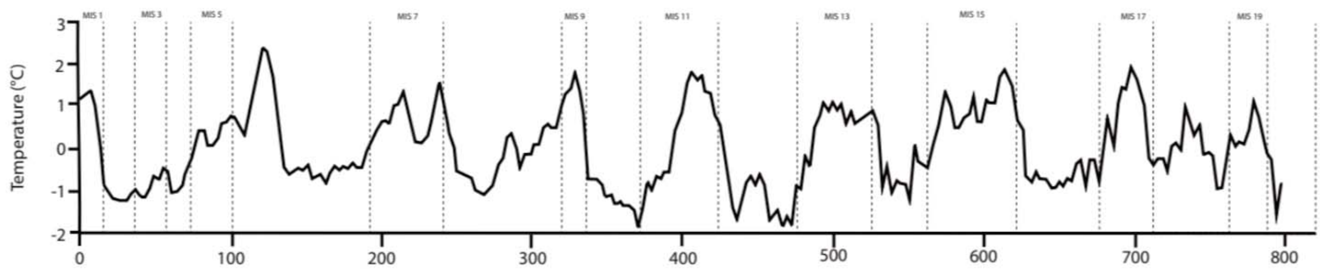


FIGURE 2. GRAPH OF MEAN TEMPERATURES FROM MIS 1 TO MIS 19. ADAPTED FROM HUGHES ET AL. 2020.

Palaeoecological reconstructions suggest Neanderthals occupied several cold and low-temperature climates. Candy *et al.* (2015) explore Britain's occupation during MIS 13 and recognise paleoenvironmental data suggesting cool climates, at lower temperatures than present, with winters well below freezing. Neanderthals inhabited sites well below their naked tolerance, according to measurements of Aiello and Wheeler (2003). Northern Europe occupations reveal the most extreme temperatures sustained during most glacial and interglacial periods (Bertran *et al.*, 2016). MIS 4 and 3 are the coldest and most unstable millennia Neanderthals ever endured (Gilligan, 2007; Wales, 2012; Melchionna *et al.,* 2018; Niekus *et al.*, 2019), with possible winter temperatures reaching as low as -27° C in Northern Europe (Van Andel *et al.*, 2003). Table 1 presents some of the coldest temperatures recorded at sites from older evidence of occupation of northern Europe (MIS 13) to the last period (MIS 4-3).

Period	Site	Location	T min. of coldest months (°)	Reference
MIS13	Sidestrand	UK	-9 to +9	Candy *et al.*, 2015
	Brooksby		-10 to +2	
	Happisburgh I		-11 to -3	
MIS4	Combe Grenal	France	-10.5 to -12.3	Aiello & Wheeler, 2003
	Temnata Cave	Bulgaria	-20.1 to -21.8	
	Pena Miel	Spain	-11.3 to -12.4	

TABLE 1. WINTER TEMPERATURES OF SELECTED SITES FROM OLDER EVIDENCE OF HOMININ IN NORTHERN EUROPE TO THE LAST PERIOD OF OCCUPATION OF EUROPE.

Neanderthals have long been associated with cold climate adaptations, as they lived during various glaciations (Howell, 1952). Many physiological aspects have often been associated with cold resistance. This is not as certain when counterarguments are considered, which debate these adaptations in the first place or devise other explanations for their presence.

A stockier physiology and shorter limbs have been argued to dissipate less heat (Bergmann, 1847; Allen, 1907). Pomeroy *et al.* (2012) and Bogin *et al*. (2022) have revisited this notion claiming these facts are unreliable when health, nutrition and diseases are factored in during development. These characteristics have also been linked to forestal mobility adaptation (Stewart, 2005). Thicker bones, while possibly indicative of greater muscle mass and hence greater insulation (Mariotti and Belcastro, 2011), could also depend on hormonal anomalies (Maureille and Bar, 1999) or greater energetic and physical activity requirements (Shaw and Stock, 2013). Many suggestions have also been made for other characteristics often associated with cold resistance such as enlarged nasal cavities (Rae *et al.*, 2011 for alternative argument), higher Basic Metabolic Rate (BMR) (Longman *et al.*, 2022 for alternative argument) and a larger thorax (Ocobock *et al.*, 2021 and Ben-Dor *et al.,* 2016 for alternative arguments). These alternative arguments do not necessarily negate the fact that Neanderthals could be better adapted to survive cold climates. They want to illustrate that some characters cannot be solely explained as cold adaptations. A recurrent observation made by these authors is that biological adaptations are mostly related to high-intensity activities, consuming greater energy in shorter but more powerful actions. Hence, Neanderthals' biological adaption to cold environments should not be unambiguously assumed. This is further sustained by the notion that thermoregulation is dependent on many aspects that are not visible archaeologically, such as hair coverage (Dàvid-Barrett and Dunbar, 2016), body fat, muscle mass and Brown Adipose Tissue values (BAT) (Steegmann *et al.*, 2002; Snodgrass and Leonard, 2009) and resistance to the cold from exposure in developmental phases (Hrdlicka, 1945; Jones, 1972).

As cold adaptations are fundamentally still unclear, there are debates surrounding temperature resistance. Collard *et al.* (2016) suggests a minimum temperature of 1 to 2.5° C lower than humans. Aiello and Wheeler (2003) estimate a limit of 6.5° C for Neanderthals, against 10° C for Sapiens. Hosfield (2020) argues for a 7.6° C value for a naked Neanderthal. There is no definite agreement on specific temperature values, however, most models oppose an extreme difference between Sapiens' and Neanderthals' naked tolerance.

It is also important to consider demographic variations, as some physiological models are based solely on male values (e.g. Aiello and Wheeler, 2003). Males and females have different temperature resistance because they have different BMRs (Rodríguez *et al.*, 2021). Trinkaus (1980) suggests Neanderthals had greater sexual dimorphism than Sapiens, hence BMR and temperature endurance could have been even more disparate between biological sex, rendering females more susceptible to lower temperatures. Children are also more vulnerable to the cold as they have more gracile skulls - Neanderthals presenting parallel growth to Sapiens (Tillier, 2011) - and BMR decreases with age, hence elderly individuals are more susceptible to low temperatures than the young male population (Luo *et al.*, 2018).

In summary, Neanderthals' biological adaptability to the cold is not to be taken for granted. This research considers Neanderthals were not immune to the dangers of cold temperatures. Frostbite, hypothermia, and cell damage are common complications of exposure to low temperatures that can lead to permanent damage or death (Cheung, 2015; Daanen and van Marken Lichtenbelt, 2016). Neanderthals would have been particularly susceptible to sinusitis and otitis because of their skull and inner ear conformation (Trajer, 2023), thus lower temperatures exacerbated these risks. Moreover, this is increased for vulnerable demographic groups: elderly, children, ill and pregnant women.

Archaeological evidence - Cultural insulation

As well as possibly being biologically susceptible to low-temperature environments, the archaeological record is fundamental to understanding Neanderthals' cultural practices adopted to survive certain climatic challenges. Records of fire and shelter uses are available; however, they present biases that limit the understanding of the evidence (Ocobock *et al.*, 2021; Rodríguez *et al.*, 2021) and they are not sufficient insulators when individuals are away from settled camps (White, 2006; Gilligan, 2010). That is why the focus of cultural insulation practices is placed on clothing.

Clothing traps warm air, insulating the body in colder external temperatures (Soresen, 2009). A 'Clo' unit, roughly corresponding to one layer of coverage, is used to indicate clothing thermal resistance (Gagge *et al.,* 1941; Sloan, 1979). Authors have tried to determine Neanderthals' Clo requirements in relation to the inhabited environments (e.g. Gilligan, 2007; Wales, 2012). Secondary strands of evidence have been utilised to deduce clothing manufacture in Neanderthals for example: the exploitation of faunal resources (Cervidae) (Collard *et al*., 2016; Martisius *et al.,* 2020), genetic lice evidence (Li *et al*., 2010; Ocobock *et al*., 2021), tooth wear and tools for leather manufacturing and possible hide curing purposes (Soresen, 2009; Soressi *et al*., 2013; Heth, 2015), hide curing (Koller and Baumer, 2010; Rots *et al*. 2015 - desiccants). The greater debate concerning Neanderthals' clothing stands in the evidence for simple or complex clothing. Simple clothes are wrapped around the body with strings and not sewn. Complex clothes are more specialised and involve sewing. For this reason, they are recognised after the appearance of specific tools that are classed as 'mode 4 technology' (with cutting, scraping and piercing tools) and the presence of eyed needles (Gilligan, 2007). They first appear in association with Sapiens in parts of North and South Africa during colder episodes (Gilligan, 2007).

Anatomical differences in Neanderthals' hands compared to Sapiens reveal a more powerful rather than precise grip, hence some argue this would have impeded the act of sewing and handling small objects (Bardo *et al*., 2020; Ocobock *et al*., 2021). Wales (2012) models a prediction for the percentage of covering required for Neanderthals in various habitats in different periods. He claims that tailored clothing is necessary only above the 93% body coverage needs. The models presented (See Figure 3) place Neanderthals into a maximum of 80-90% of body coverage according to site evidence, hence rejecting tailored clothing as a requirement. Additionally, he argues that hunter-gatherers can obtain sufficient body coverage (80%) and survive without tailored clothing as the Jaralde and other Australian groups can prove.

Wales' arguments fail to consider two aspects. First, body coverage needs are higher for more vulnerable sections of the populations (as illustrated above) - ill and injured, children, elderly and pregnant women - thus tailored coverage might have been required where Wales' (2012) models predict 80-90% coverage. Secondly, the Jaralde are not an exemplar of Neanderthals' lifestyles, as they relied on hunting with long-distance projectiles, in particular spear throwers (Berndt, 1940). Neanderthals relied on hunting at close quarters, such as ambushing megafauna (Marín *et al*., 2017) as is evident from the non-extensive projectile technology and the common skeletal evidence for trauma and injury (Hosfield, 2016; Ocobock *et al.,* 2021). Moreover, cutting and piercing technology, retained necessary for complex clothing and being mostly affiliated with Sapiens, and the more specialised tools such as blades and needles appearing from the Gravettian/Aurignacian (Gilligan, 2007; Collard *et al.,* 2016), are visible for Neanderthals as well - Lithic and bone awl-like points to pierce hides and blade-like tools (Soresen, 2009). One piece of evidence for fibre technology has been recently discovered at Abri Du Maras, which attests to Neanderthals' knowledge and capacity to obtain fibre strings. Hand sewing and alternative needles (pine needle or small bone fragments) are also considered as possible sewing techniques (Soresen, 2009; White, 2006).

Lack of knowledge - wet environments

Biological and cultural adaptations have so far focused only on survival in cold climates. Most research lacks attention to the dangers that not only cold but also wet environments pose to the physiological limits and clothing technology of Neanderthals. Wet clothing annuls clothing insulation, thus invalidating its protecting properties and conducting to more rapid body heat dissipation (Golant *et al*., 2008; Hagen *et al*., 2024). Wet environments, therefore, increase substantially the risks of hypothermia and frostbite (Kuklane *et al.,* 1998). Wet environments also create a problem in finding reliable dry fuel, essential for drying and keeping warm. When discussing palaeoecology, it is important to consider snow, precipitation and humidity factors. To understand that Neanderthals were effectively living, moving in and navigating zones affected by the risk of wet and cold, Trajer (2023) proposes an overview of biome occupations of Neanderthals through time (See Figure 4). Biomes are good indicators that consider multiple aspects of the environment - temperatures, precipitation, windchill, fauna and flora (Trajer, 2023). Site presenting biome forest environments can be good indicators of climates affected by higher precipitation values to lower temperatures (list of sites in Appendix 1).

In summary, it is considered here that Neanderthals could have engaged in such strategies, even if there is no direct archaeological evidence. Wet environments would exacerbate cold-related complications. Neanderthals did inhabit environments that would pose the risks of the cold and wet, thus they are likely to have developed strategies to counter such dangers. Evidence for the care of more vulnerable groups such as elderly and pregnant women, and for recovery of the ill and injured, attests that, in these environments, risks were acknowledged and contrasted.

Materials and Methods

Methods

The following research will, first, devise a possible waterproofing strategy, utilising materials and technologies available to Neanderthals, inspired by ethnographic accounts of waterproofing activities in modern mid-to-high-latitude hunter-gatherers. These have been collected from a search of the *eHRAF World Cultures Database* with the following key words: 'adhesives'; 'rain gear'; 'snowshoes'; 'waterproof'; 'specialised clothing'. Following this, an experimental strategy to test the waterproofing capacities of the materials selected will be conducted. The results will evidence the success rates of various materials. The discussion will investigate the implications of waterproofing efforts in technological complexity, activities, and social dynamics.

Ethnographic sources

A review of 68 ethnographic accounts of mid-to-high latitude small-scale groups of hunter-gatherers has been conducted (a summary of the strategies divided into categories in the Appendix 2). The results show that groups would select either specific animal skins or plant-based resources for their more water-resistant properties to fashion clothing items (ponchos, hats, capes, mittens, jackets, leggings). For more specific applications, some groups utilise natural adhesives (named 'pitch', 'tar', 'resin') as waterproofing agents. These are often applied on shoes, cordage made for bow strings or stitched seams to prevent the seam from opening (e.g. Chippewea, Pomo, Inuit: Densmore, 1929; Barrett, 1952). The experiment here developed will investigate the possible waterproofing qualities of different adhesive admixtures in relation to fitted, complex clothing.

Experiment and Materials

Rationale for materials

As discussed, plausibly manufactured by Neanderthals, this experiment fashions fitted clothing. The inaccessibility of non-eyed needles in the archaeological record and the power-grip type of hand morphology suggests the use of hand-sewing for tailored seams. There is direct and secondary archaeological evidence to understand possible Neanderthals' strings and cordage manufacture. Hardy *et al*. (2020) revealed the discovery of a single evidence of cordage technology made of plant fibres (bark). Ethnographic sources reveal that Nettle stalk stems and deer or reindeer sinew are efficient materials for making string (Chippwea, Inuit: Densmore, 1929; Oakes, 1991; Saami: Anderson, 1978; Copper Eskimo: Diamon, 1946; Pomo: Barrett, 1952). Nettle is very common and can be easily found in many environments (Plants of the World Online, 2024) including boreal forests cold climates, hence available to Neanderthals even in harsher conditions. Deer/reindeer sinew and hide would be available, as specimens from Cervidae families represented a great part of Neanderthals' faunal exploitation (Collard *et al*., 2016). The rationale behind the choice of adhesives is suggested by ethnographic accounts (above) in combination with archaeological and experimental evidence. Experiments have aimed to grasp possible Neanderthals' understanding of adhesives' material properties. Natural adhesives (birch bark tar, beeswax and pine resin) have been a stable component of Neanderthals' behaviour at least from MIS 7 until MIS 3 (Mazza *et al*., 2006; Degano *et al*., 2019). These adhesives would all be available in boreal forest environments (Encyclopedia Britannica, 2024a; USDA Forest Service, 2024).

Methods of extraction of beeswax can imply climbing or felling branches of trees to collect the honeycomb and then filtering the wax from the honey (Turnbull, 1965; Heinen, 1973). It can imply a level of fire control to boil and cook the wax (Holmberg, 1950). Honeybees are found in many biomes; however, they retreat in their hives at temperatures below 10° (Encyclopedia Britannica, 2024b). Therefore, although honey and honeycomb are available, they might be less visible and active during winter or colder periods.

Experiments have revealed that tar can be extracted from a roll of bark of birch trees exposed to a 300-350° C fire, with careful fire management and constant attention (Schmidt *et al*., 2023). Schmidt *et al*. (2023) reveal that producing and treating birch bark tar required time and great attention to the heating procedure, as few minutes and lower/higher temperatures could significantly impact the quality of the adhesive. Kozowyk and Poulis (2019) conclude that tar presents better working properties and is more versatile than resin, hence it might have been preferred to the quicker, and easier-to-extract, resin. Kozowyk *et al.* (2016) conclude that beeswax, as a bonding agent, significantly improves the quality of the adhesive, having a plasticising effect. Considering this literature, this experiment will test the waterproofing properties of these different adhesive admixtures on the sinew and nettle seams.

Experimental design

Birch bark tar as a fabric glue, in combination with various additives, has been tested by Baker *et al*. (2021), who concluded that it is not suitable to glue pieces of fabric together and hold the stress of movements. This research explores a novel strategy that opts for the use of tar not as sole glue but as a resistant glue and waterproofing layer in combination with seams, as attested by ethnographic sources. The experiment consists of joining two pieces of leather together, as possibly required for joining the ends of a cape to the neck, joining the sides of mittens or limb covers. It utilises deer leather (with no fur, as it would complicate the sewing process) processed in traditional methods (rhubarb root as a tanning agent), nettle and sinew as threads and birch bark tar (BBT), pine resin (PR) and beeswax (BW) as adhesives. A process of pre-testing is used to determine the most valuable percentages of admixtures for the experiment, illustrated in Table 2.

Adhesive/additive	Quantity (g)
Birch Bark Tar (BBT)	12 (100 wt%)
Birch Bark Tar (BBT) + Beeswax (BW)	BBT: 10 (70 wt%)
	BW: 4.2 (30 wt%)
Birch Bark Tar (BBT) + Pine Resin (PR)	BBT: 10 (70 wt%)
	PR: 4.2 (30 wt%)
Beeswax (BW)	12 (100 wt%)

TABLE 2. ADHESIVES QUANTITIES USED IN THE EXPERIMENT.

Experimental procedure

Two leather squares were hand-sewn together using sinew and nettle strings. The seam was coated with an adhesive admixture, which covered the sinew/nettle thread and sealed the pierced holes. While ethnographic accounts refer to strings dipped in pitch before being sewn (see Appendix 3), here the seam was coated and not the string, as a coated string would be less flexible and manageable. The product was left to dry for seven days (as in Baker *et al.*, 2021). The experiment investigated which material combination better maintains the structural integrity of the seam after being immersed in water for 48 hours (pre-testing showed that less than 48 hours did not have an immediate effect on a shear test, and more than 48 hours rendered all samples too unstable). The test was conducted by applying a force pulling the sewn leather squares apart and observing their reaction. The experiment tested the reaction to a pulling force of a total of 10 leather samples (See Table 3).

Squares letter	Adhesive	String
A	BBT	Nettle
B	BBT	Sinew
C	BBT + BW	Nettle
D	BBT + BW	Sinew
E	BBT + PR	Nettle
F	BBT + PR	Sinew
G	BW	Nettle
H	BW	Sinew
Control N	None	Nettle
Control S	None	Sinew

TABLE 3. SAMPLE NAME WITH ADHESIVE AND STRING MATERIAL.

The hypothesis is stated as follows:

1. The control group fails.
2. The coated sinew resists better than the nettle.
3. Some combinations hold better than others (possibly BBT+ additive), but none are completely unaffected by the water.

Preparation:

1. The sinew and nettle strings were created. When dried, hair-thin fibres were manually extracted from both. The fibres were collected in bundles and twined to form resistant strings (See Figures 5, 6) (approximately 5 mm wide and 15 cm long) with an S-and-Z twist (See Figure 7).

2. The deer leather was cut into squares. Two squares were selected for each of the 10 samples. The extremities of each couple of squares were superimposed for approximately 2-3 cm, four holes were pierced through and sewn with sinew and nettle (See Figure 8). The holes were pierced using modern metal implements, for time constraints, however, one hole was created using flint tools to demonstrate that it is achievable (See Figure 9).
3. Birch bark tar was extracted from birch bark with traditional methods from the University of York. 100% pure beeswax and resin have been purchased from online retailers. The three adhesives were heated up on an open fire (See Figure 10). As per Schmidt *et al.* (2023) results, the tar was maintained on the heat for approximately 90 minutes, with the temperature shifting between 80° and 300° C in an open fire setting. Beeswax and Resin were heated until liquid (5-10 min). Each adhesive combination was applied on its proper leather and string sample with the aid of a stick, quickly reheating the adhesive when hardening (See Figure 11). The samples were left to dry for seven days in a closed environment. Figure 12 illustrates the eight samples with adhesives right after application.

Test

All 10 samples were immersed in water for 48 hours. Following, two pierced rivets were applied to each side of the leather squares (total of four rivets per sample) to protect the leather from ripping during the shear test. One side of the sample was hung from two wires passing through the rivets. On the other side, a weight was hung from two wires passing through the rivets. The weight pulled down the leather squares simulating a shear test. The weight selected was 5 kg, producing a force of 49.05N (W=mg). The weight had been selected through a process of pretesting. The experiment recorded the reaction of the various samples to the pulling force through visual evidence. When the seam was held, the weight was removed after 30 seconds.

Results

Table 4 illustrates the visual results of the experiment and observations.

Image	Observations
	BBT: The adhesive lost mass in the water because it was not completely dried. The seam held the weight.

	BBT: Fails, however it took longer to slip out of the holes than the other sinew failure samples (approximately 10s).
	BBT+BW: Fails. It is suspected a fault in the processing of the adhesives, leather piercing or strings.
	BBT+BW: Fails.
	BBT+PR: Well performing. It maintained the leather squares attached.
	BBT+PR: Well performing. It maintained the leather squares attached.
	BW: While easy to crumble, BW still partially sealed the pierced holes and maintained the string attached to the leather, hence it is more successful than the control group.
	BW: the BW starts to crumble but it was still well adhered to the leather and the seam, hance kept the squares well attached.
	Control: The nettle partially held the leather squares together.

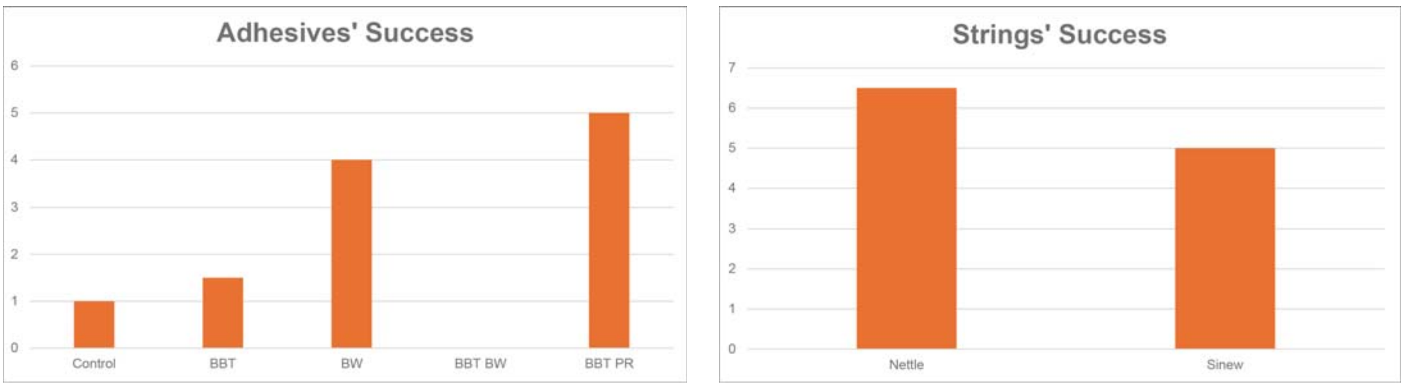
	Control: The sinew slipped out immediately.

TABLE 4. PHOTOGRAPHS OF THE EXPERIMENT AND VISUAL OBSERVATIONS.

Sinew was overall less successful than nettle in water because it became porous and absorbent (countering hypothesis 2.). Here, it is noted that BBT+PR and BW were the only combinations completely dried after seven days. The other adhesives were still tacky and viscous on the seam. Hence, the drying conditions might be important for the success of the strategy. Table 5 assigns a value to the success rate of the combinations (Graph 1 in graphic form). There is a difference between BW and BBT+PR in terms of bond stability. BW rendered the seam stiff and was more prone to mass loss, as the hardened nature of the adhesive rendered it easy to peel off from an adhering surface. BBT+PR, instead, retained its mass and rendered the seam much more flexible. Details of the time employed for the activities carried out during the experiments are in Appendix 3. However, the author recognises that time is relatively indicative of an activity because it reflects the skilfulness and knowledge of the maker. The limits of this author's skills and experience in conducting these activities are acknowledged.

	BBT	BBT+PR	BBT+BW	BW	Control
Nettle	1	2.5	0	2	1
Sinew	0.5	2.5	0	2	0

TABLE 5. ASSIGNED VALUE IN RELATION TO SUCCESS RATE. 1 = COMBINATION THAT HOLDS, THE COMPARISON IS NETTLE CONTROL GROUP. 2 = HOLDS WELL, BETTER THAN NETTLE CONTROL GROUP. 0 = DO NOT HOLD, THE STRING SLIPPED OUT OF THE HOLES IN LESS THAN 5S. 0.5 = DO NOT HOLD BUT TAKE A LONGER TIME TO FAIL (~10S). +0.5 IS ADDED TO DISTINGUISH THE MOST SUCCESSFUL ADHESIVES THAT HOLD WELL THE SEAM.



GRAPH 1. GRAPHIC OF THE ASSIGNED VALUE IN RELATION TO ADHESIVES' SUCCESS AND TO STRING'S SUCCESS.

This experiment encountered some limitations. The failure of the BBT+BW for both sinew and nettle might have resulted from a mistake in the admixture's heating and application, alternatively, it might have resulted from thinner strings or larger holes. Even though treated as constant, handmade strings, leather holes, and drying conditions might have resulted in variable aspects given the actualistic nature of the experiment. The 5 kg weight to test the samples' resistance has been maintained stable for each sample to obtain a constant. An actual shear test calculating the force necessary to break the seam could have been a feasible strategy, however, it would have added variables to the experiment. The experiment has purposefully not tied the strings at the extremities of the leather squares, allowing the string to slip out of the hole. If done otherwise, it would have been difficult to methodically determine if the seam was held by the adhesive or by the string knot.

Discussion

Firstly, the experiment demonstrated that it is possible to devise a waterproofing strategy for complex clothing. According to Graph 1, certain combinations, for both sinew and nettle, were better performing than those with no adhesive (control sample), hence confirming hypothesis 1. Secondly, the results have highlighted the combinations' success rate, revealing that some performed better than others. BBT+PR and BW provided greater structural integrity to the seam after immersion in water (BBT+ PR providing better flexibility to suit body movements). Thirdly, it was noticed that, for better waterproofing performance, it is essential for the adhesive to dry completely on the adhering surface.

Discussions about the strategies used in Neanderthals' occupation of Eurasia can spark speculations about behaviours and environmental adaptations to wet and cold environments. To interpret use, it is important to engage in a conversation about technological complexity, understanding the efforts necessary to build technology.

Oswalt (1976) measures complexity by counting the number of units ('techno units') composing the technology, with more parts rendering it more complex. Perrault *et al*. (2013) add that not only the number of parts but also the 'procedural units' (the number of steps to manufacture each part) influence the overall complexity. Compound tools attest to a certain level of complexity and ability to conduct multi-level planning. Each part requires an individual process and mastery for manufacture, to be a unit of an interconnected whole. In this interconnectivity, if one element fails, the whole structure does too (Sterenly, 2020). Therefore, the success rate of each component must be exceptional for the whole complex to be reliable.

If the complexity of the strategies employed for this experiment is evaluated and compared with success, some interesting arguments can arise. Looking at the materials selected, aspects such as availability in the territory and ease of collection and manufacture can shed light on the complexity of each part composing the tool. The 'Materials and methods' section has evidenced the wider availability, ease of collection and manufacture of nettle in respect to sinew. Hence, nettle could present a quicker and more reliable component (according to the results). Focusing on adhesives, it is understood that BBT, while its primary source (birch bark) is available and easy to collect, requires a complex and long process for extraction and reduction (24 minutes to 24 hours according to Koch and Schmidt, 2023; 1.5 hours for heating reduction on an open fire at high temperatures during this experiment). PR, on the other hand, as noted in 'Materials and Methods', is similarly available to BBT (as pine and birch belong to the same biome) and quite easy to extract - collected from wounds in trees and branches (Kozowyk and Poulis, 2019; De Freitas *et al.*, 2023). It also resulted quick to melt on an open fire (≈5/10 minutes). BW, while available but to a lesser degree to BBT and PR, was understood to possibly retain a level of risk in collecting (climbing trees, risk of bee stings) and some complexity in extraction - filtering honey to obtain the honeycomb material. However, it is likely the byproduct of honey collection and it resulted extremely easy to melt and reheat throughout the experiment. Based on these observations, BBT + PR requires the most effort as it involves the collection and association of two different components, with their relative complexities in acquiring and manufacturing. BBT + BW is excluded from the evaluation as its success was uncertain during the experiment.

BBT+PR presents the highest success rate and the highest cost value. Hence, the main result that can be extracted from this experiment is that successfully waterproofing a seam implies a great amount of effort, as a minimum of three, or even four, separate technological units are required - fibre, leather, adhesive, plus possible admixture. A successful waterproofing technology implies the mastery of all technological units, which demonstrate a level of technological sophistication in themselves. At this point, relating these observations to Neanderthals' evidence, this research asks: what are the conditions that can generate enough effort to successfully occupy wet and cold environments?

Complex systems theory sustains that interconnectedness and population size are directly proportionate to complexity (Kauffman, 2000; Bentley and Mashner, 2003; Kholer, 2012). Muthukrishna *et al.* (2013) notes that increases in group numbers can lead to greater technological diversity and sophistication. Smaller and more isolated groups are more likely to lose information transmission, hence losing skill sets. This lack of network increases group vulnerability and fragility and diminishes the chances for innovation (Premo and Khun, 2010).

Greater population sizes, instead, increase the need and the possibility for a division of labour, consequently, division of labour allows for the development of more sophisticated and generationally accumulated skillsets (Nakahashi and Feldman, 2014).

Therefore, granted suitable material availability, the prerequisite with which to generate enough efforts to occupy and survive the risks of wet and cold environments are:

- Cognitive: requiring a hierarchical organization of at least three technological units and the consequential capacity for multi-level planning. This capacity is attested in Neanderthals' evidence with adhesive technology which appears from MIS 7 and fibre technology (80 kya).

- Social: successful and reliable strategies, to counter more unfamiliar, fluctuating and unknown environmental circumstances are facilitated by increased group size and geographical interconnectivity, which provide greater chances for job division, technology sophistication and cultural accumulation.

As cognitively able, Neanderthals' social expansion seemed to be limited. Isotopic data of singular teeth and bones, as those found in Lakonis, Greece; Moula Guercy, France and Gruta de Oliveira, Portugal, is employed to sustain a general relevance of individuals' short-distance mobility patterns, in the range of 20 km to 50 km (Richards *et al.,* 2008; Benson *et al*., 2013; Pike *et al*., 2016). Moreover, genetic evidence indicates that, in Neanderthal groups throughout Eurasia, high levels of interbreeding generated low diversity rates (Melchionna *et al*., 2018). It follows that communities were isolated in the territory, delineating patches with low levels of interconnectivity (Castellano *et al.,* 2014; Skov *et al*., 2020). Additionally, shorter distances covered could have been more beneficial for certain groups such as ill and injured, pregnant women, the elderly and small children. The archaeological record suggests that the support for more vulnerable groups, such as the injured and the elderly - who were probably not able to sustain long daily travels - is attested (Spikins, 2019). There is also isotopic evidence that pregnant women would remain in one location for several months, before and after pregnancy (for instance, Isernia La Pineta, Nadale 1, Riparo Broion and Fumane Cave; Lugli *et al*., 2017; Nava *et al*., 2020). This evidence would support a local, short-distance activity model, where long-distance connections were limited, and familiar territories and base shelters were probably preferred. This strategy would avoid dangers such as walking in snow for long distances or being caught in rain or blizzards with no familiar shelter around. With a short-distance movement strategy, a waterproofing solution that can be moderately successful but easily re-adjustable, such as beeswax could be feasible. With long-distance travel, a more successful strategy that does not fail throughout the journey might be more recommended, such as the more costly birch bark tar and pine resin.

These evidence and observations reveal a possible snapshot of Neanderthals as isolated in the territory, hence their development of cumulative culture and more sophisticated, but successful, technologies might have been limited by this factor. For this reason, technological sophistication might have been insufficient to sustain a greater territorial extension. It might have limited their survival in unfamiliar and unknown territories through long-distance travels, presenting the risks of wet and cold environments. In other words, there is a simultaneous presence of causation and consequence: the lack of interconnectivity and limited group sizes would have hindered the achievement of a successful waterproofing strategy contrasting the dangers of wet and cold environments; simultaneously, these dangers would have limited groups migrations and long-distance travels, hence limiting interconnectivity and the possibility for greater success in technological components.

Limitations

The discussions and considerations developed in this research are limited by the hypothetical nature of the experiment. The strategies developed are not the result of direct evidence but a proposition of how a waterproofing strategy, if employed, might have appeared. Therefore, the results and conclusions obtained are hypothetical in nature. The scarce evidence of adhesives and fibre technology constrains the discussion about waterproofing strategies in a limited chronological range (adhesives being around from MIS 7 and the single plant fibre evidence only from MIS 3). Hence, it could be argued that this research's conclusions only apply to occupations of a much-restricted range than that explored in the introduction. However, the scope of this research is to provide one technological possibility and investigate its implications for behaviours and environmental adaptations. The wider context that has been presented provides a broader picture of hominins' occupation of, and adaptations to, wet and cold environments in Eurasia. It is acknowledged that climate fluctuates, periods are dryer and warmer, and technology is not chronologically linear. This research's conclusions do not presume to be relevant for all Eurasian occupations. They provide one possible framework to investigate and understand the relationship between the risks of wet and cold environments and behaviours.

Conclusion

This research has devised a possible fitted clothing waterproofing solution, utilising ethnographic comparisons and Neanderthals' known technological repertoire, that might have protected individuals from the risks encountered in wet and cold environments. It has been discussed that the better-performing material combination requires a high level of technological complexity, as expected for compound tools. Following, the discussion investigated whether the effort analyses can shed light on the challenges that wet and cold climates may have imposed on Neanderthals and the limitations they might have possessed to counter wet and cold conditions. While cognitively able, as evidenced by archaeological findings, Neanderthals may have been constrained by social dynamics, as geographic isolation likely limited their group sizes, exchanges, and networks within their territory. Here is proposed that ecology and behaviours are co-constituted. A social limitation would restrict the development of complex waterproofing strategies, hence wet and cold environments would limit Neanderthals' territorial expansion. Simultaneously, the dangers of wet and cold environments, as met only with great efforts, would restrict territorial expansion, hence the social network.

This research has added relevant information on the technological performance of organic, perishable materials - leather, fibre technology and natural adhesives. These are highly understudied, as they are rarely preserved in the Palaeolithic archaeological record. This research has aimed to spark an interest in a more focused understanding of environmental adaptations. It has investigated Neanderthals' cold adaptations through a narrower perspective that centred on the risks and potential solutions for cold and wet environments.

Moreover, it has proposed a discussion that unravels the tangled relationships between environments, behaviours and technology, finding mutual causation and consequentiality between them. Future research could devise countless other experimental methodologies testing: other adhesives, strings' strength, other fitted clothing designs, the point of breakage through a proper shear test rather than a fixed weight and testing other possible waterproofing strategies (e.g. water resistance qualities of different furs/vegetable clothing sources). Moreover, future research could, through a GIS investigation, determine if there is a visible avoidance, in various chronological timeframes, of wet environments or not, which could suggest successful adaptations. Finally, an attention to waterproofing could be expanded not only to clothing but also to containers, to understand how liquids might have been stored and transported. This particular interest could then initiate investigations into adaptations to particularly arid and hot environments instead. In conclusion, this research has proposed a methodology that optimizes the use of experimental strategies, even when hypothetical, and it has investigated environmental limits through a wider lens, recognising complex and ambiguous dynamics that affect, and are affected by, hominins.

Acknowledgements

This research is the result of my MSc dissertation at the University of York. I want to thank my supervisor, Professor Penny Spikins, for her availability and guidance through this research, Professor Andy Needham and Professor Gareth Perry for providing me with the material and information to conduct my experiment at the YEAR centre in the University of York.

Keywords skin or leather
glue
sewing

Appendix 1

Period	Number	Site
>MIS 20	1	Happisburgh
	2	Pont de Lavaud
	3	Soleilhac
	4	Kozarnika
MIS 19-9	5	Ambrona
	6	Visogliano
	7	Steiinheim
	8	Schoningen
	9	Blizingsleben
MIS 8-5	10	Ehiringsodrf

	11	Krapina
	12	Stajnia Cave
	13	Scladina
	14	Obi-Rakhmat
<MIS 4	15	Rio Secco Lagar Velho
	16	El Sidron
	17	Veldegoba
	18	La Ferrasie
	20	Rochers de Villeneuve
	21	Grotta di Fumane
	22	Monti Lessini
	23	Vindija
	24	Pestera cu Oase
	25	Subalyuk
	26	Kulna Cave
	27	Warendorf (Neuwarendorf)
	28	Kleine Feldhofer Grotte
	29	Engis
	30	Zeeland Ridges
	31	Mezmaiskaya
	32	Okladnikov
	33	Denisova

SITES CORRESPONDING TO THE NUMBERS IN MAPS IN FIGURE X, TAKEN FROM TRAJER 2023.

Appendix 2

Waterproofing strategies	Materials and groups	References
Adhesives	Shoes covered in resin (Blackfoot Indians)	Hellson, 1974
	Cordage (sinew) dipped in pitch (Chippewea, Pomo) to prevent seams from opening	Densmore, 1929; Barrett, 1952
	Nettle stalk fibre dipped in pitch (Inuit) (for bowstrings)	Pharand, 2012
Floral	Cedar bark hats, capes (Tlingit, Cape Flattery Indians, Nootkan, Clayoquot, Quinault)	Boas 1890; Swan, 1870; Drucker, 1951; Koppert, 1930; Olson, 1936
	Spruce root (Nootkan)	Arima & Dewhirst, 1990

	Moss socks (Tlingit)	De Laguna, 1972
	Birch bark cape (Micmac Indians)	Wallis & Wallis, 1955
Faunal	Jackets of Intestines of bears (Tlingit)	De Laguna, 1972
	Salmon skin (fish skin) boots and blankets (Ingalik)	Osgood, 1970
	Deerskin cap, rain-coat (Ungava District, Atayal, Chin-Shui Ts'un, Miaoli Hsien)	Turner, 1894; Rui et al. 1955
	Duck mocassins (Montagnias Indians)	McGee, 1961
	Caribou skins mittens, leggings, boots (Copper Eskimos)	Diamon, 1946; De Coccola et al. 1986
	Sealskin (Copper Eskimos)	De Coccola et al. 1986
	Wolverine fur boots (Eskimos, Lapps)	Itkonen & Minn, 1948; De Coccola et al. 1986
	Wolf skin snowshoes (Assiniboines)	Long et al. 1961
	Guanaco leggings (Fireland Indians)	Gusinde, 1931
	Seal gut (Aleuts)	Shade, 1949
	Sea dog gut (Miscellaneus)	Langsdorff, 1817
	Halibut bladder (Miscellaneus)	Sauer, 1802
	Whale tongue (Miscellaneous)	Sauer, 1802
	Bear wool overcoat (Lapps)	Itkonen & Minn, 1948
	Reindeer skin coat (Lapps)	Itkonen & Minn, 1948
	Fish/whale oil cover on shoes (Lapps)	Itkonen & Minn, 1948
	Swan/goose fat cover on shoes (Lapps)	Itkonen & Minn, 1948

MATERIALS USED FOR CLOTHING WATERPROOFING STRATEGIES BY VARIOUS MODERN SMALL-SCALE, MID-TO-HIGH-LATITUDE HUNTER-GATHERERS AND REFERENCES.

Appendix 3

TIME	Processing	Manufacturing
Nettle	from collection to fibres: 10x : 1hr	1hr (10x)
	drying time: 4h-12h	
Sinew	from pounding of tendon to fibres: 1hr	4-5hr (10x)
	drying time: 7 days (approx.)	
BBT	90 min	n.a.
BW	~10 min	n.a.
PR	~10 min	n.a.
Coating	40 min for all 8 samples	n.a.

DETAILS OF TIMES EMPLOYED DURING THE EXPERIMENT TO FABRICATE MATERIALS AND SUBSTANCES USED. FOR THE STRINGS, THE AUTHOR HAS BEEN INVOLVED IN THE PROCESSING – COLLECTING NETTLE AND ITS FIBRES, EXTRACTING SINEW FIBRES – AND IN THE MANUFACTURING – CREATING THE STRINGS. FOR THE ADHESIVES, THE AUTHOR HAS BEEN INVOLVED ONLY IN THE HEATING PROCESS OF SAMPLES THAT WERE ALREADY BEEN MANUFACTURED AND EXTRACTED (HENCE, NON-APPLICABLE: N.A.).

Bibliography

Aiello, L. C. and Wheeler, P., 2003. Neanderthal thermoregulation and the glacial climate. In: T. Van Andel & W. Davies, eds. *Neanderthals and modern humans in the European landscape of the last glaciation: Archaeological results of the Stage 3 project.* Cambridge: Macdonald institute for archaeological research, pp.147-166.

Allen, J. A., 1907. The influence of physical conditions in the genesis of species*. Scientific American*, 63 (1637supp), pp.26226-26227. DOI: 10.1038/scientificamerican05181907-26226supp

Anderson, M., 1978. *Saami Ethnoecology: Resource Management in Norwegian Lapland.* Ann Arbor, Mich.: University Microfilms International.

Arsuaga, J. L., Martínez, I., Arnold, L. J., Aranburu, A., Gracia-Téllez, A., Sharp, W. D., Quam, R. M., Falguères, C., Pantoja-Pérez, A., Bischoff, J., Poza-Rey, E., Parés, J. M., Carretero, J. M., Demuro, M., Lorenzo, C., Sala, N., Martinón-Torres, M., García, N., de Velasco, A. A., … Carbonell, E., 2014. Neandertal roots: Cranial and chronological evidence from Sima de los Huesos., *Science (American Association for the Advancement of Science)*, 344(6190), pp.1358-1363. https://doi.org/10.1126/science.1253958

Ashton, N. and Lewis, S. G., 2012. The environmental contexts of early human occupation of northwest Europe: The British Lower Palaeolithic record. *Quaternary International*, 271, pp.50-64'. https://doi.org/10.1016/j.quaint.2011.10.022

Baker, P., Scott, C., Gethin, P. and Sinclair, A., 2021. Birch Bark Glue and its Potential Use in Neanderthal Clothing: A Pilot Study. *EXARC Journal,* Issue 4. [Online] Available at: <https://exarc.net/ark:/88735/10608> [Accessed 03 October 2024]

Bardo, A., Moncel, M.-H., Dunmore, C. J., Kivell, T. L., Pouydebat, E. and Cornette, R., 2020. The implications of thumb movements for Neanderthal and modern human manipulation. *Scientific Reports,* 10(19323), pp.1-12. DOI: 10.1038/s41598-020-75694-2

Barrett, S. A., 1952. Material Aspects of Pomo Culture. *Bulletin of the Public Museum of the City of Milwa, 2,* Volume 507.

Ben-Dor, M., Gopher, A. and Barkai, R., 2016. Neandertals' large lower thorax may represent adaptation to high protein diet. *American Journal of Physical Anthropology,* 160(3), pp.367-378.DOI: 10.1002/ajpa.22981

Benson, A., Kinsley, L., Willmes, M., Defleur, A., Kokkonen, H., Mussi, M. and Grün, R., 2013. Laser ablation depth profiling of U-series and Sr isotopes in human fossils. *Journal of Archaeological Science,* 40(7), pp.2991-3000.DOI: 10.1016/j.jas.2013.02.028

Bentley, R. A. and Mashner, H. D., 2003. *Complex Systems and Archaeology: Empirical and Theoretical Applications.* Salt Lake City: University of Utah Press.

Bergmann, C., 1847. *Ueber die Verhältnisse der Wärmeökonomie der Thiere zu ihrer Größe*. Vandenhoeck und Ruprecht.

Berndt, R. M., 1940. A Curlew and Owl Legend from the Narunga Tribe, South Australia. *Oceania,* 10(4), pp.456-462.

Bertran, P., Allenet, G., Brenet, M., Chadelle, J.-P., Dietsch-Sellami, M.-F., Hébrard, J.-P., Madelaine, G., Mercier, N., Pasquet, V., Ponel, P., Queffelec, A. and Sirieix, C., 2016. Last Glacial palaeoenvironments at Lascaux, southwest France, with special emphasis on MIS 4 (Ognon II interstadial). *Palaeogeography, Palaeoclimatology, Palaeoecology,* Volume 449, pp.149-165.DOI: 10.1016/j.palaeo.2016.02.008

Bogin, B., Hermanussen, M. and Scheffler, C., 2022. Bergmann's rule is a "just-so" story of human body size. *Journal of Physiological Anthropology,* 41(1).DOI: 10.1186/s40101-022-00287-z

Candy, I., Schreve, D. and White, T. S., 2015. MIS 13-12 in Britain and the North Atlantic: understanding the palaeoclimatic context of the earliest Acheulean. *Journal of Quaternary Science,* 30(7), pp.593-609.DOI: 10.1002/jqs.2816

Castellano, S., Parra, G., Sánchez-Quinto, F. A. and Paabo, S., 2014. Patterns of coding variation in the complete exomes of three Neandertals. *Pnas,* 111(18), pp.6666-6671. DOI: 10.1073/pnas.1405138111

Cheung, S. S., 2015. Responses of the hands and feet to cold exposure. *Temperature,* 2(1), pp.105-120. DOI:10.1080/23328940.2015.1008890

Collard, M., Tarle, L., Sandgathe, D. and Allan, A., 2016. Faunal evidence for a difference in clothing use between Neanderthals and early modern humans in Europe. *Journal of Anthropological Archaeology,* Volume 44, pp.235-246.DOI: 10.1016/j.jaa.2016.07.010

Daanen, H. A. M. and van Marken Lichtenbelt, W. D., 2016. Human whole body cold adaptation. *Temperature,* 3(1), pp.104-118.DOI: 10.1080/23328940.2015.1135688

Dávid-Barrett T., Dunbar R. I., 2016 Bipedality and hair loss in human evolution revisited: The impact of altitude and activity scheduling. *Journal of Human Evolution*, Volume 94, pp.72-82. doi: 10.1016/j.jhevol.2016.02.006.

De Freitas, J. A., Freire Neto, A. O. da L., Bucci, L. A., Souza, T. C. de, Menucelli, J. R., Amorim, E. P., Aguiar, A. V. de, Lima, I. L.and Longui, E. L., 2023. Effect of resin tapping system and collection period on resin production and growth traits in 12-year-old Pinuselliottii var. elliottii. *Scientific Electronic Archives,* 16(9). DOI: 10.36560/16920231773

Degano, I. Soriano, S., Villa, P., Pollarolo, L., Lucejko, J. J., Jacobs, Z., Douka, K., Vitagliano, S., and Tozzi, C., 2019. Hafting of Middle Paleolithic tools in Latium (central Italy): New data from Fossellone and Sant'Agostino caves. *Plos One,* 14(6).DOI: 10.1371/journal.pone.0213473

De Laguna, F., 1972. Under Mount Saint Elias: The History and Culture of the Yakutat Tlingit. *Smithsonian Contributions to Anthropology,* 7(3).

Densmore, F., 1929. Chippewa Custom. *Bulletin, xii,* Volume 209.

Diamon, J., 1946. The Material Culture of the Copper Eskimos. *Report of the Canadian Arctic Expedition, 1913-1918, Southern Party, 1913-1916*, Volume 16.

Encyclopedia Britannica, 2024a: Pine. [Online] Available at <https://www.britannica.com/search?query=pine> [Accessed 15 September 2024]

Encyclopedia Britannica, 2024b: Where Do Honeybees Go in the Winter? [Online] Available at<https://www.britannica.com/story/where-do-honeybees-go-in-the-winter>[Accessed 15 September 2024]

Gagge, A. P., Burton, A. C. and Bazett, H. C., 1941. A practical system of units for the description of the heat exchange of man with his environment. *Science,* Volume 94, pp.428-430.

Gilligan, I., 2007. Neanderthal extinction and modern human behaviour: the role of climate change and clothing. *World Archaeology,* 39(4), pp.499-514. DOI: 10.1080/00438240701680492

Gilligan, I., 2010. The prehistoric development of clothing: Archaeological implications of a thermal model. *Journal of Archaeological Method and Theory,* 17(1), pp.15-80.DOI: 10.1007/s10816-009-9076-x

Golant, A., Nord, R. M., Paksima, N. and Posner, M. A., 2008. Cold exposure injuries to the extremities. *Journal of the American Academy of Orthopaedic Surgeons,* 16(12), pp.704-715.

Hagen, L. T., Brattebø, G., Dipl-Math, J. A. *et al.* Effect of wet clothing removal on skin temperature in subjects exposed to cold and wrapped in a vapor barrier: a human, randomized, crossover field study. *BMC Emerg Med* 24, 18 (2024). https://doi.org/10.1186/s12873-024-00937-8

Hardy, B. L. Moncel, M.-H., Kerfant, C., Lebon, M., Bellot-Gurlet, L. and Melerd, N., 2020. Direct evidence of Neanderthal fibre technology and its cognitive and behavioral implications. *Scientific Reports,* 10(4889), pp.1-9.DOI: 10.1038/s41598-020-61839-w

Heinen, H. D., 1973. *Adaptive Changes in a Tribal Economy: A Case Study of the Winikina-Warao.* Ann Arbor, Mich: University Microfilms.

Heth, C. L., 2015. The skin they were in: Leather and tanning in antiquity. In: S. Rasmussen, ed. *Chemical technology in antiquity.* Washington DC: ACS Publications.

Hrdlicka, A., 1945. *The Aleutian and Commander islands and their inhabitants.* Philadelphia: Wistar Institute of Anatomy and Biology.

Holmberg, A. R., 1950. Nomads of the Long Bow: The Siriono of Eastern Bolivia. *Smithsonian Institution. Institute of Social Anthropology,* iv (104).

Hosfield, R., 2016. Walking in a Winter Wonderland? Strategies for Early and Middle Pleistocene Survival in Midlatitude Europe. *Current Anthropology,* 57(5), pp.653-682.DOI: 10.1086/688579

Howell, F., 1952. Pleistocene glacial ecology and the evolution of "Classic Neandertal" man. *Southwest Journal of Anthropology,* Volume 8, pp.377-410.

Jones, D. M., 1972. *A study of social and economic problems in Unalaska, an Aleut village.* Ann Arbor, Mich: Univeristy Microfilms.

Kauffman, S., 2000. *Investigations.* New York: Oxford University Press.

Kholer, T. A., 2012. Complex systems and archaeology. In: I. Hodder, ed. 2012 *Archaeological Theory Today.* Cambridge: Polity Press, pp.93-123.

Koch, T. J. and Schmidt, P., 2023. Adhesive Strenght and Rupture Behaviour of Birch Tars Made with Different Stone Age Methods. *Journal of Palaeolithic Archaeology,* 6(1). DOI: 10.1007/s41982-023-00135-1.

Koller, J., Baumer, U., 2010. The organic traces on a silex blade from Neumark-Nord. In: Meller, H. (Ed.), *Elelefantenreich, ein Fossilwelt in Europa. Landesamt für Denkmalpflege und Archa€eologie Sachsen-Anhalt e Landesmuseum für Vor- geschichte Halle (Saale)*, pp. 553-562.

Kozowyk, P. R. B., Langejans, G. H. J. and Poulis, J. A., 2016. Lap Shear and Impact Testing of Ochre and Beeswax in Experimental Middle Stone Age Compound Adhesives. *Plos One,* 11(3).DOI: 10.1371/journal.pone.0150436

Kozowyk, P. R. B. and Poulis, J. A., 2019. A new experimental methodology for assessing adhesive properties shows that Neandertals used the most suitable material available. *Journal of Human Evolution,* Volume 137. DOI: 10.1016/j.jhevol.2019.102664

Kuklane, K., Geng, Q. and Holmér, I., 1998. Effect of Footwear Insulation on Thermal Responses in the Cold'. *International Journal of Occupational Safety and Ergonomics,* 4(2), pp.137-152.

Li, W., Ortiz, G., Fournier, P.-E., Gimenez, G., Reed, D. L., Pittendrigh, B., and Raoult, D., 2012. Genotyping of human lice suggests multiple emergences of body lice from local head louse populations. *PLoS Neglected Tropical Diseases,* Volume 4.DOI: 10.1371/journal.pntd.0000641

Lockey, A. L., Rodríguez, L., Martín-Francés, L., Arsuaga, J. L., Bermúdez de Castro, J. M., Crété, L., Martinón-Torres, M., Parfitt, S., Pope, M. and Stringer, C., 2022. Comparing the Boxgrove and Atapuerca (Sima de los Huesos) human fossils: Do they represent distinct paleodemes? Journal of Human Evolution, 172, 103253-103253.
https://doi.org/10.1016/j.jhevol.2022.103253

Long, J. L., Kennedy, M. S., Standing, W. and Writer, 1961. The Assiniboines: From the Accounts of the Old Ones Told to First Boy (James Larpenteur Long)'. *Civilization of the American Indian Series,* lxxvi (209).

Longman, D. P. Merzbach, V., Pinto, J. M., Atkinson, L. H., Wells, J. C. K., Gordon, D. and Stock, J. T., 2022. Alternative Metabolic Strategies are Employed by Endurance Runners of Different Body Sizes; Implications for Human Evolution. *Adaptive Human Behaviour and Physiology,* 8(1), pp.79-97. DOI: 10.1007/s40750-021-00183-3

Lugli, F., Cipriani, A., Arnaud, J., Arzarello, M., Peretto, C. and Benazzi, S., 2017. Suspected limited mobility of a Middle Pleistocene woman from Southern Italy: strontium isotopes of a human deciduous tooth'. *Scientific Report,* 7(1), pp.1-8. DOI: 10.1038/s41598-017-09007-5

Luo, M., Wang, Z., Ke, K., Cao, B., Zhai, Y. and Zhou, X., 2018. Human metabolic rate and thermal comfort in buildings: The problem and challenge. *Building and Environment,* Volume 131, pp.44-52.DOI: 10.1016/j.buildenv.2018.01.005

Marín, J., Saladié, P., Rodríguez-Hidalgo, A. and Carbonell, E., 2017. Neanderthal hunting strategies inferred from mortality profiles within the Abric Romaní sequence. *PloS one,* 12(11).DOI: 10.1371/journal.pone.0186970

Mariotti, V. and Belcastro, M. G., 2011. Lower limb entheseal morphology in the Neandertal Krapina population (Croatia, 130 000 BP)'. *Journal of Human Evolution,* Volume 60, pp.694-702.DOI: 10.1016/j.jhevol.2010.12.007

Martisius, N. L., Welker, F., Dogandzic, T., Grote, M. N., Rendu, W., Sinet-Mathiot, V., Wilcke, A., McPherron, S. J. P., Soressi, M., and Steele, T. E., 2020. Non-destructive ZooMS identification reveals strategic bone tool raw material selection by Neandertals. *Scientific reports,* 10(1), pp.140-149.DOI: 10.1038/s41598-020-64358-w

Maureille, B. and Bar, D., 1999. The premaxilla in Neanderthal and early modern children: Ontogeny and morphology. *Journal of Human evolution,* 37(2), pp.137-152. DOI: 10.1006/jhev.1999.0312

Mazza, P. P. A., Martini, F., Sala, B., Magi, M., Colombini, M. P., Giachi, G., Landucci, F., Lemorini, C., Modugno, F. and Ribechini, E., 2006. A new Palaeolithic discovery: tar-hafted stone tools in a European Mid-Pleistocene bone-bearing bed. *Journal of Archaeological Science,* Volume 33, pp.1310-1318.DOI: 10.1016/j.jas.2006.01.006

Melchionna, Di Febbraro, M., Carotenuto, F., Rook, L., Mondanaro, A., Castiglione, S., Serio, C., Vero, V. A., Tesone, G., Piccolo, M., Diniz-Filho, J. A. F. and Raia, P. 2018. Fragmentation of Neanderthals' pre-extinction distribution by climate change. *Palaeogeography, Palaeoclimatology, Palaeoecology*, Volume 496, pp.146-154. DOI: 10.1016/j.palaeo.2018.01.031

Muthukrishna, M., Shulman, B. W., Vasilescu, V. and Henrich, J., 2013. Sociality influences cultural complexity. *Proccedings of the Royal Society B, 281*(1774). DOI: 10.1098/rspb.2013.2511

Nakahashi, W. and Feldman, M. W., 2014. Evolution of division of labor: emergence of different activities among group members. *Journal of Theoretical Biology,* 7(348), pp.65-79. DOI: 10.1016/j.jtbi.2014.01.027

Nava, A., Lugli, F., Romandini, M., Badino, F., Evans, D., Helbling, A.H., Oxilia, G., Arrighi, S., Bortolini, E., Delpiano, D., Duches, R., Figus, C., Livraghi, A., Marciani, G., Silvestrini, S., Cipriani, A., Giovanardi, T., Pini, R., Tuniz, C., Bernardini, F., Dori, I., Coppa, A., Cristiani, E., Dean, C., Bondioli, L., Peresani, M., Müller, W. and Benazzi, S., 2020. Early life of Neanderthals. *Proceedings of the National Academy of Sciences - PNAS*, *117*(46), pp.28719-28726.DOI: 10.1073/pnas.2011765117

Niekus, M. J. L. Kozowyk, P. R. B., Langejans, G. H. J., Ngan-Tillard, D., van Keulen, H., van der Plicht, J., Cohen, K. M., van Wingerden, W., van Os, B., Smit, B. I., Amkreutz, L. W. S. W., Johansen, L., Verbaas, A., and Dusseldorp, G. L., 2019. Middle Paleolithic Complex Technology and a Neandertal Tar-Backed Tool from the Dutch North Sea. Proceedings of the National Academy of Sciences of the United States of America 116 (44), pp.22081-87. DOI: 10.1073/pnas.1907828116

Oakes, J. E., 1991. Copper and Caribou Inuit skin clothing production. *Canadian Ethnology Service paper,* Volume 118, pp.XII-277.

Ocobock, C., Lacy, S. and Nicloou, A., 2021. Between a rock and a cold place: Neanderthal biocultural cold adaptations. *Evolutionary Anthropology,* Volume 30, pp.262-279.DOI: 10.1002/evan.21894

Oswalt, W. H., 1976. *An anthropological analysis of food-getting technology.* New York: Wiley-Interscience.

Perrault, C., Brantingham, P. J., Kuhn, S. L., Wurz, S. and Gao, X., 2013. Measuring the Complexity of Lithic Technology. *Current Anthropology,* 54(8).DOI: 10.1086/673264

Pike, A.W., Angelucci, D., Cooper, M.J., Linscott, B., Matias, H. and Zilhão, J., 2016. Reconstructing neanderthal mobility and range at Gruta da Oliveira, Portugal, using high resolution laser ablation Sr isotope analysis. *Proceedings of the European Society for the study of Human Evolution 5 (PESHE 5*), p.188.DOI: 10.1073/pnas.2204501120

Plants of the World Online, 2024: Kew Science, Royal Botanic Garden, Urtica dioica. [Online] Available at: <https://powo.science.kew.org/taxon/260630-2> [Accessed 25 September 2024]

Pomeroy, E., Stock, J. T., Stanojevic, S., Miranda, J. J., Cole, T. J. and Wells, J. C. K., 2012. Trade-offs in relative limb length among Peruvian children: extending the thrifty phenotype hypothesis to limb proportions. *PloS One,* 7(12).DOI: 10.1371/journal.pone.0051795

Pomeroy, E. 2023. Review: The different adaptive trajectories in Neanderthals and Homo sapiens and their implications for contemporary human physiological variation. *Comparative Biochemistry and Physiology. Part A, Molecular & Integrative Physiology*, *280*, pp.111420-111420DOI: 10.1016/j.cbpa.2023.111420.

Premo, L. S. and Khun, S., 2010. Modeling effects of local extinctions on culture change and diversity in the Paleolithic. *PLoS ONE, 5*(12).DOI: 10.1371/journal.pone.0015582

Rae, T. C., Koppe, T. and Stringer, C. B., 2011. The Neanderthal face is not cold adapted. *Journal of Human Evolution,* Volume 60, pp.234-239.DOI: 10.1016/j.jhevol.2010.10.003

Richards, M., Harvati, K., Grimes, V., Smith, C., Smith, T., Hublin, J-J.,Karkanas, P. and Panagopoulou, E., 2008. Strontium isotope evidence of Neanderthal mobility at the site of Lakonis, Greece using laser-ablation PIMMS. *Journal of Archaeological Science* 35(5), pp.1251-1256.DOI: 10.1016/j.jas.2007.08.018

Rodríguez , J., Willmes, C. and Mateos, A., 2021. Shivering in the Pleistocene. Human adaptations to cold exposure in Western Europe from MIS 14 to MIS 11. *Journal of Human Evolution,* Volume 153.DOI: 10.1016/j.jhevol.2021.102966

Rots, V., Hardy, B. L., Serangeli, J. and Conrad, N. J., 2015. Residue and microwear analyses of the stone artifacts from Schöningen. *Journal of Human Evolution,* Volume 89, pp.298-308.DOI: 10.1016/j.jhevol.2015.07.005

Schmidt, P., Koch, T. J., Berthold, C., Lauxmann, F. and Nickel, K. G., 2023. The evolution of strength, elasticity and rupture behaviour of birch tar made with "double-pot" techniques during tar cooking. *Archaeometry,* 65(2), pp.409-422.DOI: 10.1111/arcm.12820

Shaw, C. N. and Stock, J. T., 2013. Extreme mobility in the Late Pleistocene? Comparing limb biomechanics among fossil Homo, varsity athletes and Holocene foragers. *Journal of Human Evolution,* 64(4), pp.42-249.DOI: 10.1016/j.jhevol.2013.01.004

Skov, L., Coll Macia, M., Sveinbjoernsson, G., Mafessoni, F., Lucotte, E. A., Einarsdottir, M. S., Jonsson, H., Halldorsson, B., Gudbjartsson, D. F., Helgason, A., Schierup, M. H. and Stefansson, K., 2020. The nature of Neanderthal introgression revealed by 27,566 Icelandic genomes. *Nature,582*(7810), pp.78-83.DOI: 10.1038/s41586-020-2225-9

Sloan, A. W., 1979. *Man in Extreme Environments.* Springfield, IL: Charles C. Thomas.

Snodgrass, J. J., and Leonard, W. R., 2009. Neandertal Energetics Revisited: Insights Into Population Dynamics and Life History Evolution, *PalaeoAnthropology*, pp.220, 237. doi:10.4207/PA.2009.ART31

Soresen, B., 2009. Energy use by Eem Neanderthals. *Journal of Archaeological Science,* 36(10), pp.2201-2205.DOI: 10.1016/j.jas.2009.06.003

Soressi, M., McPherron, S. P., Lenoir, M. and Texier, J.-P., 2013. Neandertals made the first specialized bone tools in Europe. *Pnas,* 110(35), pp.14186-14190.DOI: 10.1073/pnas.1302730110

Spikins, P., Needham, A., Wright, B., Dytham, C., Gatta, M., and Hitchens, G., 2019. Living to fight another day: The ecological and evolutionary significance of Neanderthal healthcare. *Quaternary Science Reviews,* Volume 217, pp.98-118.DOI: 10.1016/j.quascirev.2018.08.011

Steegmann, A. T., Jr., Cerny, F. J. and Holliday, T. W., 2002. Neandertal cold adaptation: Physiological and energetic factors. *American Journal of Human Biology*, Volume 14, pp.566-583. https://doi.org/10.1002/ajhb.10070

Sterenly, K., 2020. Innovation, life history and social networks in human evolution. *Phylosophical Transactions Royal Society B, 375*(1803).DOI: 10.1098/rstb.2019.0497

Stewart, J., 2005. The ecology and adaptation of Neanderthals during the non- analogue environment of oxygen isotope stage 3. *Quaternary Intrnational,* Volume 137, pp.35-46. DOI: 10.1016/j.quaint.2004.11.018

Tillier, A. M., 2011. Facts and ideas in Paleolithic growth studies (paleoauxology). In: S. Condemi and G. Weniger, ed. 2011. *Continuity and discontinuity in the peopling of Europe.* Dordrecht: Springer, pp.139-153.

Trajer, A. J., 2023.'Ecological evaluation of the development of Neanderthal niche exploitation. *Quaternary Science Reviews,* Volume 310.DOI: 10.1016/j.quascirev.2023.108127

Trinkaus, E., 1980.'Sexual differences in Neanderthal limb bones. *Journal of Human Evolution,* 9(5), pp.377-397.

Turnbull, C. M., 1965. The Mbuti Pygmies: An Ethnographic Survey. *Anthropological Papers,* pp.139-282.

USDA, 2024. U.S. FOREST SERVICE: resins. [Online] Available at: <https://www.fs.usda.gov/wildflowers/...> [Accessed 26 September 2024]

Van Andel, T. H., Davies, W. and Weninger, B., 2003. The human presence in Europe during the last glacial period I: human migrations and the changing climate. In: T. Van Andel & W. Davies, eds. *Neanderthals and modern humans in the European landscape during the last glaciation: archaeological results of the Stage, 3.* Cambridge: Macdonald Institute for Archaeological Research, pp.31-56.

Wales, N., 2012. Modeling Neanderthal clothing using ethnographic analogues. *Journal of Human Evolution,* 63(6), pp.781-795.DOI: 10.1016/j.jhevol.2012.08.006

White, M. J., 2006. Things to do in Doggerland when you're dead: Surviving OIS3 at the northwestern-most fringe of Middle Palaeolithic Europe. *World Archaeology,* 38(4), pp.547-575.DOI: 10.1080/00438240600963031

Corresponding Author

Eleonora Scandola
University of York
Heslington, York, YO10 5DD
United Kingdom
E-mail Contact

Gallery Image

FIG 1. EXTENSION OF NEANDERTHALS IN EURASIA (INCLUDING DEBATED EARLY OCCUPATION OF GREAT BRITAIN AND DENISOVAN OCCUPATION OF NORTH EASTER EURASIA). AFTER POMEROY, 2023, P.3.

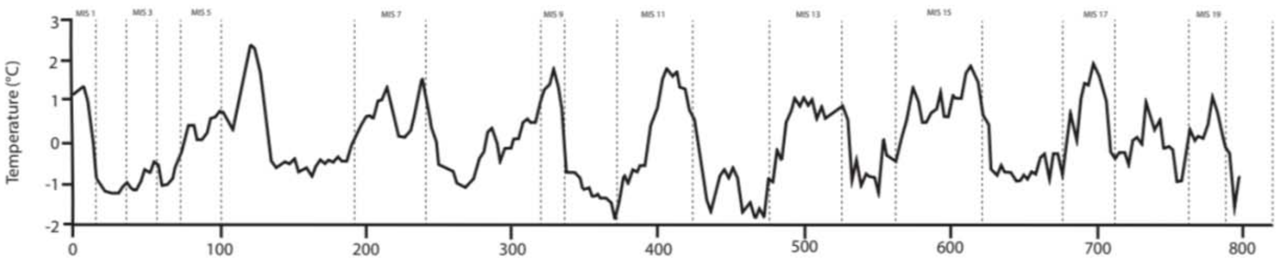


FIG 2. GRAPH OF MEAN TEMPERATURES FROM MIS 1 TO MIS 19. ADAPTED FROM HUGHES ET AL. 2020.

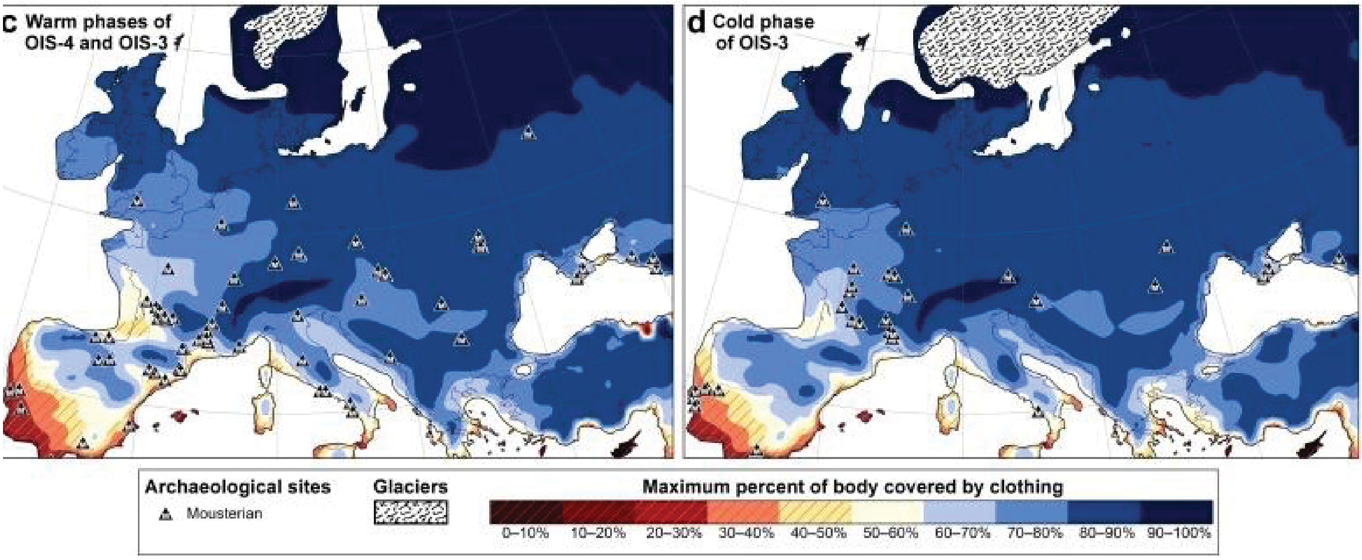


FIG 3. MODEL BY WALES (2012) SHOWING THE PREDICTION FOR PERCENTAGE OF BODY COVERAGE FOR NEANDERTHALS ACROSS THE RECONSTRUCTED LANDSCAPE. HERE, ONLY MIS 4 AND 3 ARE PRESENTED BECAUSE THEY REVEAL THE HIGHER PERCENTAGE OF BODY COVERAGE NECESSARY IN ALL NEANDERTHALS' OCCUPATION OF EUROPE. DETAILS OF PHYSIOLOGICAL AND ENVIRONMENTAL PARAMETERS AND SITE EVIDENCE FOR THESE MODELS ARE FOUND IN WALES (2012).

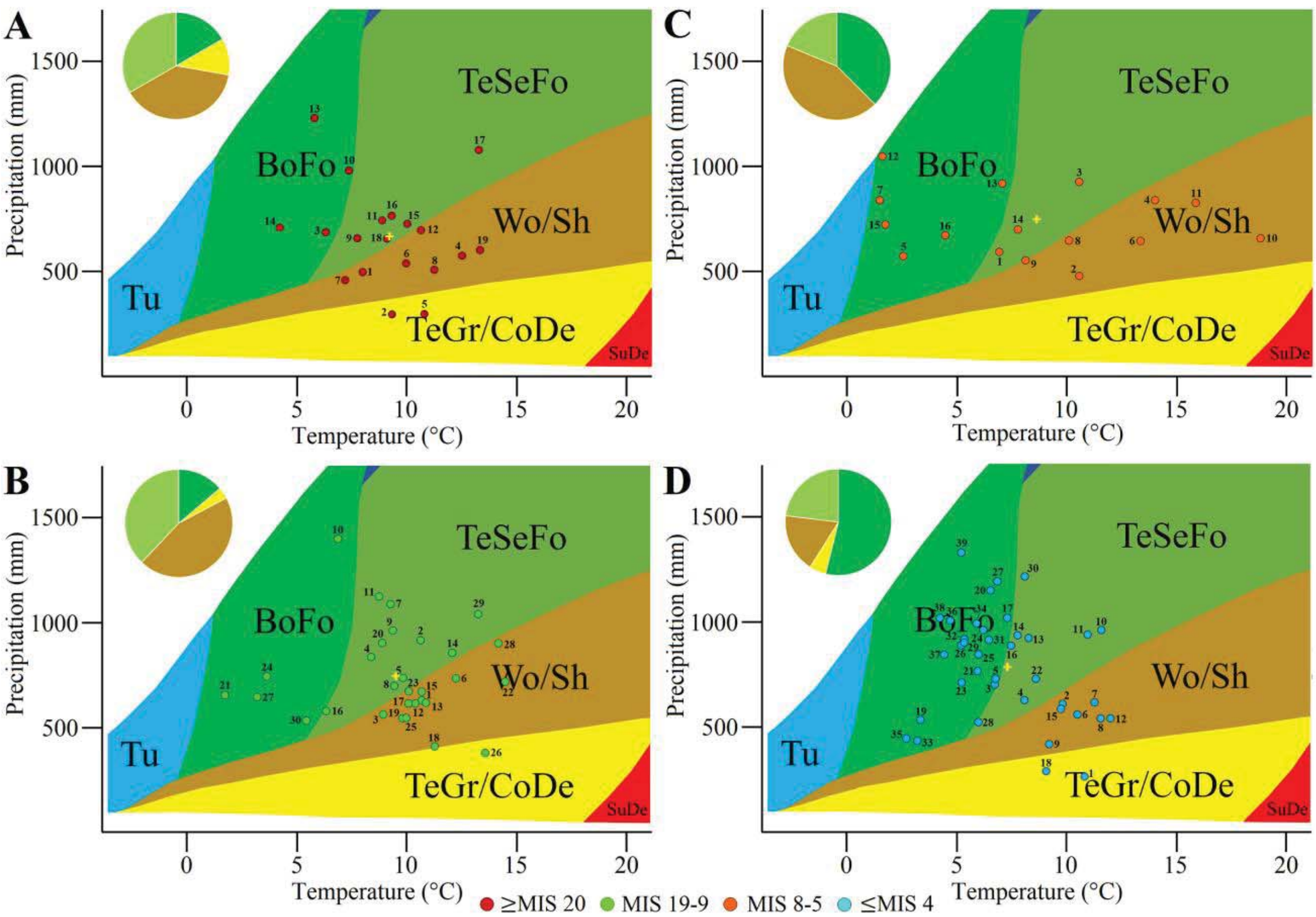


FIG 4. DISTRIBUTION OF HOMININS OCCUPATION SITES IN EURASIA ACROSS DIFFERENT BIOMES. A) SITES OLDER THAN MIS20, B) SITES BETWEEN MIS19-9, C) SITES BETWEEN MIS8-5, D) SITES YOUNGER THAN MIS4 (SPECIFIC TO MOUSTERIAN EVIDENCE). SITES ASSOCIATED WITH NUMBERS AND DETAILS ON ENVIRONMENTAL PARAMETERS TO BUILD THE MODEL ARE FOUND IN TRAJER (2023).

FIG 5A. PART OF A POUNDED STEM. PHOTO BY ELEONORA SCANDOLA.

FIG 5B. FIBRES BUNDLES PEELED OFF AND LEFT TO DRY. PHOTO BY ELEONORA SCANDOLA.

FIG 6A. LEFT: DRIED SINEW, CENTRE-LEFT: POUNDED SINEW, CENTRE-RIGHT: SEPARATED FIBRES, RIGHT: STRING. PHOTO BY ELEONORA SCANDOLA.

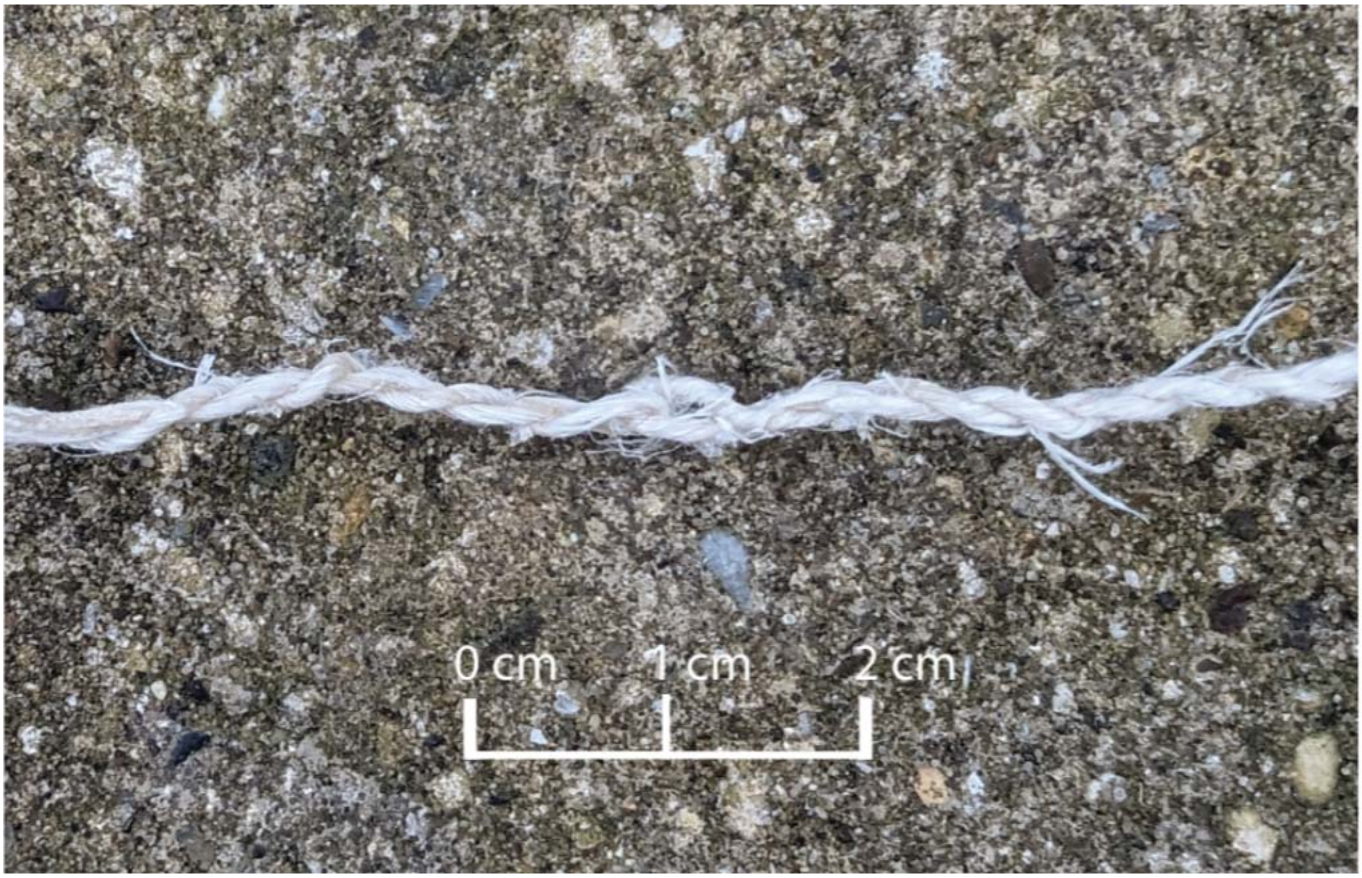


FIG 6B. DETAIL OF STRING. PHOTO BY ELEONORA SCANDOLA.

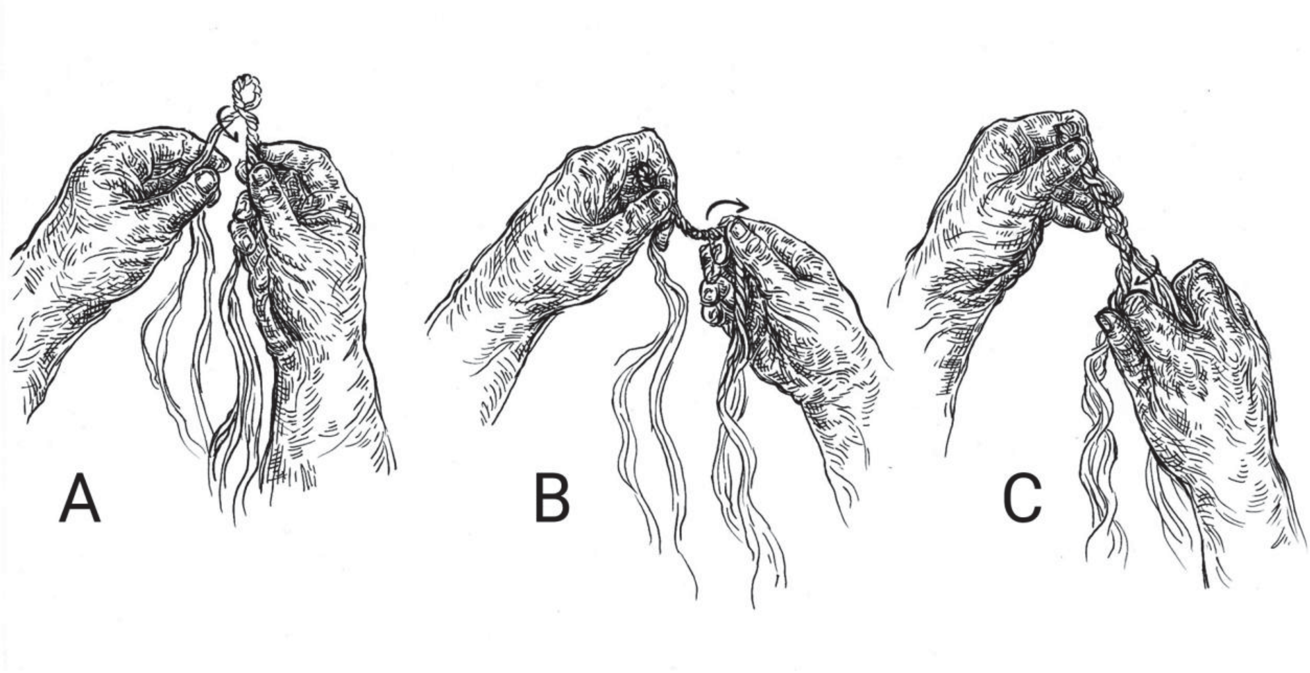


FIG 7. ILLUSTRATION OF S (A-C) AND Z (B) TWIST, COURTESY OF CARTER, 2024.

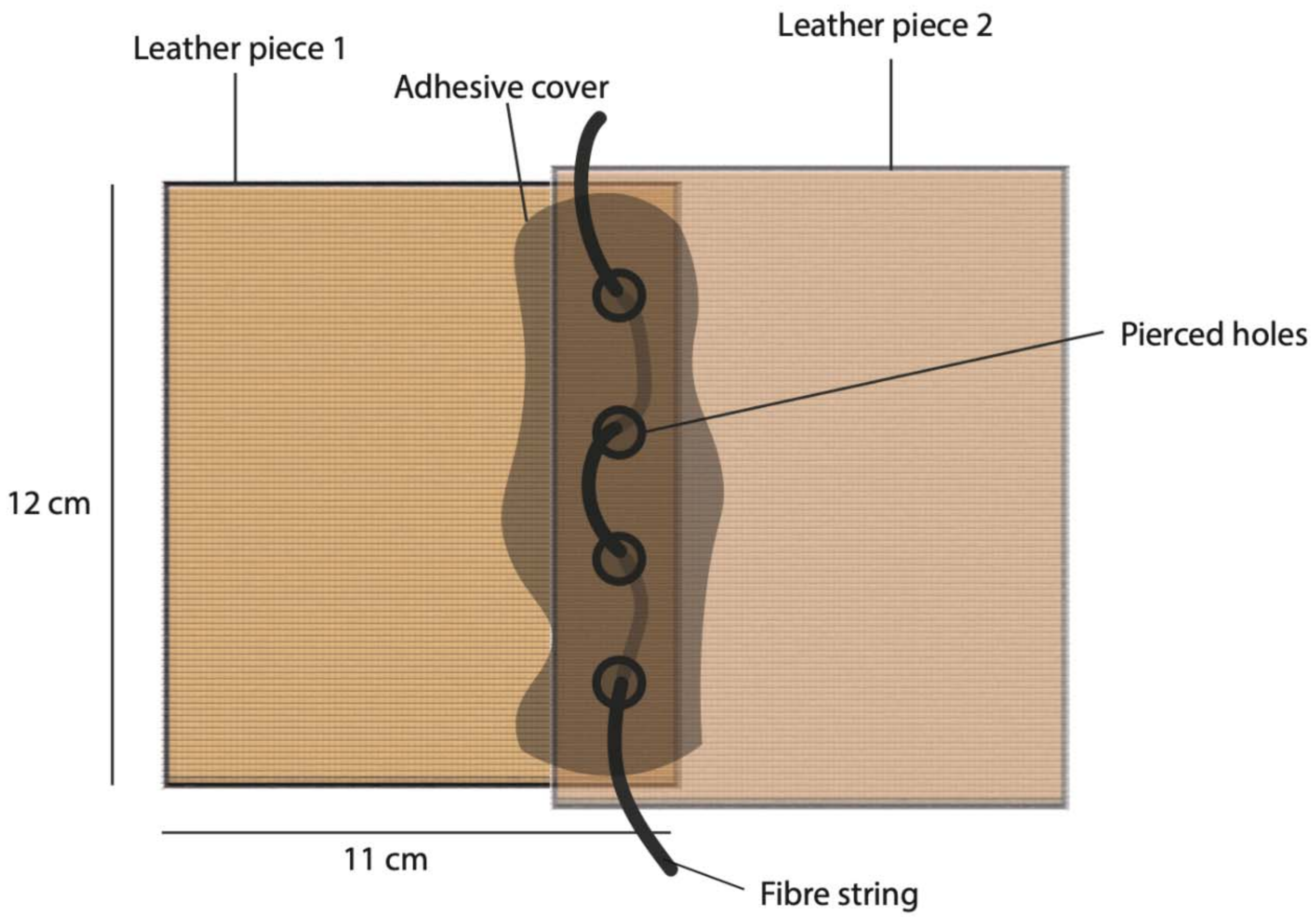


FIG 8. SCHEMATIC REPRESENTATION OF SEWING PATTERN. IMAGE BY ELEONORA SCANDOLA.

FIG 9A. FLINT FLAKE PENETRATING THE HIDE AND PIERCING A HOLE. PHOTO BY ELEONORA SCANDOLA.

FIG 9B. FLINT TOOLS USED FOR THE PROCESS. PHOTO BY ELEONORA SCANDOLA.

FIG 9C. MODERN TOOLS USED TO PIERCE THE HIDE. PHOTO BY ELEONORA SCANDOLA.

FIG 10. THREE BBT SAMPLES HEATING UP ON THE CHARCOALS (2 SAMPLES BEFORE ADMIXTURE WITH BW AND PR). PHOTO BY ELEONORA SCANDOLA.

FIG 11. APPLICATION OF ADHESIVE ON SEAM. PHOTO BY ELEONORA SCANDOLA.

FIG 12A. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12B. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12C. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12D. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12E. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12F. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12G. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.

FIG 12H. THE 8 SAMPLES USED IN THE EXPERIMENT (EXCEPT CONTROLS) RIGHT AFTER ADHESIVES' APPLICATION (1 SIDE ONLY). PHOTO BY ELEONORA SCANDOLA.