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Have you got the tine? Prehistoric Methods in Antler Working

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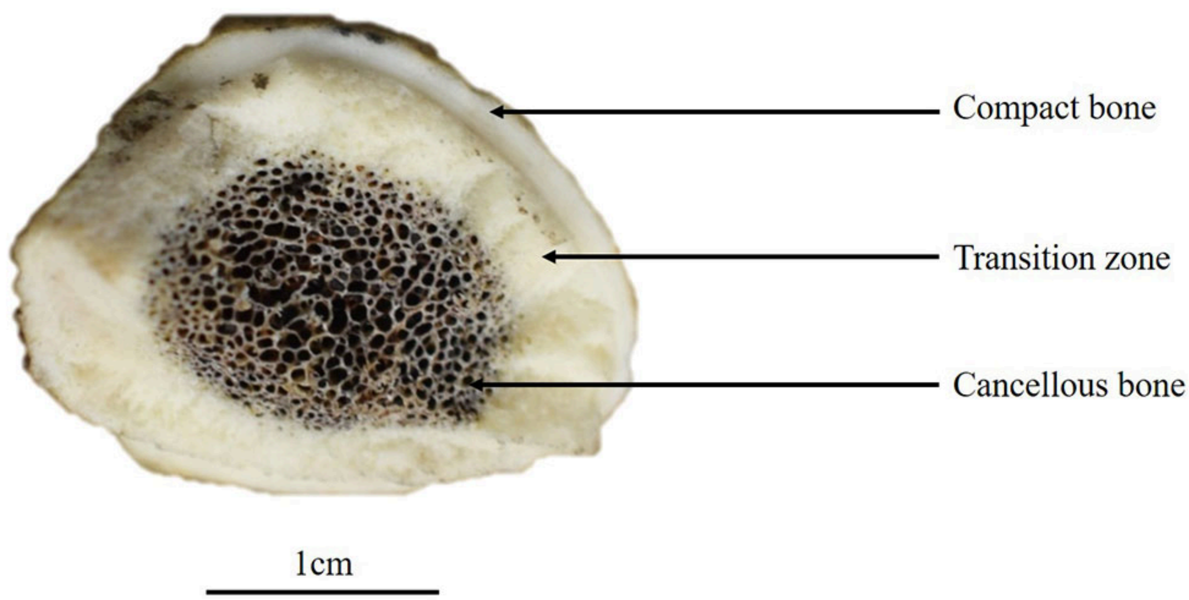

Antler working was prevalent throughout prehistory, with a breadth of intricately detailed and technologically complex antler artefacts observed within the archaeological record. In particular, during the Palaeolithic, Mesolithic, and Neolithic, antler working with flint tools would have been a time-consuming process. While the *chaîne opératoire* of producing certain antler artefacts has previously been explored (Elliott and Milner, 2010; Marquebielle, 2011; Langley, 2014) there is a debate surrounding whether the soaking of antler was a necessary stage in this process. Soaking antler as a part of the *chaîne opératoire* is yet to be explored in depth, and thus the full implications of this stage to antler working processes in prehistory have not been considered. Where soaking antler has been explored, no distinction is made between soaking antler beams whole (for example, with no prior modification) or soaking antler which has had tines removed to expose the interior of the antler. We present the results of experiments which tested whether there is a significant difference between the workability of dry, soaked-whole antler, and soaked-exposed antler. We argue that there is a missing stage in current understandings of the *chaîne opératoire* of antler artefact manufacture. We conclude this stage could be responsible for the observed deposits of tine-removed antler in wetlands at prehistoric sites, such as Star Carr.

> “We experimented with several different methods of tine breaking. This enabled us to explore potential methods for removing tines, the energy expenditure required for each method, and whether there is a diagnostic breakage pattern to the different methods, which may enable identification of specific methods in the archaeological record.

Introduction

The exploitation of antler is observed throughout prehistory; from Lower Palaeolithic soft hammers at Boxgrove (Stout et al., 2014, p.581), antler barbed points in the Mesolithic (Elliott, 2008) , to the abundant use of Neolithic antler picks at Grimes Graves (Simpson, 1996, p.293). The production of osseous technologies has long been perceived as a marker of advanced cognitive capabilities in hominins and the extensive working of osseous material was previously argued to be a defining characteristic of anatomically modern human (AMH) populations since the Upper Palaeolithic (Bar-Yosef, 2002, p.366; Mellars, 2005, p.21). The technical process for working antler has been heavily debated, however, and only few experimental studies exist which explore antler working. Consequently, there is need for research which explores in-depth the techniques used for working antler. This research aims to further our understanding of the nature of antler working in prehistory, primarily through addressing the debate of soaked versus unsoaked antler. This introduction will initially provide an overview of current understandings of prehistoric antler working, including interpretations of the making and meaning of antler artefacts. This intends to demonstrate the lack of an established *chaîne opératoire*, and thus the need for this to be explored experimentally.

Overview of prehistoric antler working

Although lithic technology typifies prehistoric periods, it is increasingly apparent osseous technology was an integral aspect of prehistoric tool kits, permeating throughout the “lithic ages”. Osseous materials are notoriously difficult to work, requiring a different negotiation with the material than stone and thus, one would expect, a more extended *chaîne opératoire*.

This cognitive demand, combined with preservation bias, resulted in past assumptions that the regular use of osseous technology was unique to AMH, arriving with the “cultural explosion” of the European Upper Palaeolithic (Bar-Yosef, 1998, p.156; Gaudzinski, 1999, p.139; Ambrose, 2001, p.1752; Kuhn et al., 2001, p.7642; Bar-Yosef, 2002, p.366; Mellars, 2004, p.461; Mellars, 2005, p.21). It is now apparent, that behavioural modernity did not explode onto the scene with one species, but rather emerged gradually throughout the Palaeolithic across several species (notably Neanderthals and Denisovans) clearly evidencing behavioural and cultural modernity (McBrearty and Brooks, 2000; Langley et al., 2008; Nowell, 2010; Zilhão, 2012).

Unsurprisingly, the realisation of the temporal depth of osseous technology contributed to this understanding. Antler working can be traced back to the Lower Palaeolithic. For example, the Lower Palaeolithic site of Boxgrove in the UK yields the earliest examples of antler use as soft hammers for flint knapping, dating to ~500,000 BP (Pope and Roberts. 2005. p.89; Stout et al., 2014, p.580). Although minimally modified, the technical properties and material attributes of antler were clearly recognised by *Homo heidelbergensis*. Additionally, this highlights the integral role of antler in early toolkits. Modified antler tools appear in the Middle Palaeolithic archaeological record; for example, sites such as Grosse Grotte, in Germany, have evidence of carefully worked antler points (Villa and d’Errico, 2001, p.73; Münzel and Conard, 2004, p.235). This demonstrates that, at the very least, Neanderthals had equally sophisticated antler working capabilities to antler working by AMH. Despite this, antler working is frequently perceived as more prolific in the Upper Palaeolithic. This perception is evident in the characterisation of the Aurignacian technocomplex by antler split-based points from sites such as L’Abri Lartet, France, Geissenklösterle, Germany, Grotte d’Isturitz, France, El Castillo, Spain, and Riparo Mochi, Italy (Kuhn and Stiner, 1998, p.182; Teyssandier and Liolios, 2003 p.188; Bar-Yosef, 2006, p.15; Liolios, 2006, p.39; Tartar, 2012, p.2348; Tejero, 2014, p.88). The archaeological record reflects a diversification in the antler artefacts produced during the Upper Palaeolithic, and by the Magdalenian period the repertoire of antler artefacts included ornately decorated spear throwers, unilateral and bilateral barbed points, baguette demi-rondes, projectile points, and *baton percé* (Pokines, 1998; Langlais et al., 2012; Langley, 2014; Langley et al., 2015).

Mesolithic communities adapted their lithic and osseous technologies to the changing environments of the Holocene, particularly in response to the advancement of woodlands and wetlands, as well as the retreat and disappearance of larger herd prey animals (Bailey, 2008; Fisher, 2006; Lo Vetro and Martini, 2016). The resulting increase in niche foraging possibilities; diverse plant resources, fowl and wetland bird hunting, riparian and littoral exploitation and woodland mammal hunting, led to economic and technological specialisation (Holst, 2010; Zaliznyak et al., 1998; Pickard, 2002; Divišováa and Šídaa, 2015). Antler, and more broadly osseous technology, was serviced in the production of harpoons, barbed points, composite ranged weapons, mattocks, adzes, wedges, bevel ended and sophisticated carpentry tools (Griffits and Bonsall, 2001; Pratsch, 2011; Pitts, 1979; Beldiman, 2005; Bridault et al., 2009). Despite many of the techniques and artefacts having Palaeolithic continuity or similarity - uni and biserial barbed points for instance (Baales et al., 2017; Elliott 2008) , there were novel developments made in antler technology during this time period. In Scandinavia the 'conical core pressure blade concept', introduced circa 7300 cal BC, utilised indirect percussion by antler punches to produce highly standardised blades for ranged weapons (David and Sørensen, 2016). Famously the manufacture of antler headdresses, 90% of which have been discovered at the North Yorkshire site of Star Carr, involved the skilled manipulation of the properties of antler, most likely to produce some form of ritual costume (Little et al., 2016). The rapid spread of woodlands throughout the Holocene also offered new materials for creating boats, wooden artefacts and timber structures (Grøn and Skaarup, 1991; Rowley-Conwy, 2017; Bamforth, 2017). These required antler tools, amongst others, to split and shape the wood, and also would have required the development of new techniques in woodworking as well as techniques in antler working. A number of antler adzes, axes and bevelled tools have been discovered which are asserted to be woodworking artefacts (Winiarska-Kabacińska and Kabaciński, 2017; van Gijn, 2007). A compilation of Mesolithic antler working techniques was produced by David (1999; 2008), these included: incision, sawing, scraping, grinding, grooving, boring, filing, bow perforation, dotted perforation, nicking, breakage, anvil breakage, flexion breakage, prepared breakage, counterblow retouch, flake breakage, wedge/shaft-wedge-splinter and wedge splitter.

The ability to use antler tools to create structures rapidly expands in the Neolithic. Excavations at barrow and cairn sites, as well as flint mines such as Grimes Graves, has revealed the intense use of antler picks and axes in their construction and operation (Saville, 2013; Pollard, 1995; Schulting, 2000; Clutton-Brock, 1984). Red deer were still highly valued for their antlers, as well as teeth and bones, even as the transition away from foraging and towards farming spread across Europe (Ritchie, 2000; Choyke, 2001; Simpson, 1996). Items such as axes, axe sleeves for shock absorption, and sickles were required in this new economy, and antler remained a viable material of choice (Flors et al., 2012; Fischer, 1982; Grygiel and Bogucki, 1990; Menotti, 2004; Maigrot, 2005).

Establishing a *chaîne opératoire* for antler working

This extensive temporal depth of antler exploitation inevitably has resulted in a suite of interpretations regarding the significance of antler artefacts. These interpretations rarely consider the process required to produce the artefact and rather conceptually attribute meaning to the object based on its final form or deposition (Płonka et al., 2011). There are some authors which comment on the *chaîne opératoire* of antler artefacts which enables grounded insight into its significance to, or role within, a past society.

The limited research on prehistoric antler artefact *chaîne opératoire* often discusses a specific part of the process, elucidated through material-oriented approaches. For example, Pokines (1998) reproduces Lower Magdalenian antler points to explore their function using experimental archaeology. While this provided important insight into the durability of the points, and their effectiveness as weapons, there are several issues with the experimental approach taken. Pokines (1998, p.876) reproduces the points, but does not look at the process of producing these objects, adopting to use modern tools (such as a saw) to work the antler, and to soak the antler for several days but with limited discussion of the rationale to do so. Understanding process is inherently important to understanding function; the way in which an object is produced will affect its properties in use. By contrast, Langley's (2014) work on Magdalenian antler barbed points provides a more intricate life history of the objects. Through use wear analysis, Langley (2014) demonstrates the barbed points were retouched and maintained throughout their use life, and thus may have been conceptualised as significant to past societies. Importantly, this research proposes the original dimensions of antler barbed points when they were first produced, based on the attrition of the point through use and retouch. However, again this research does not discuss the process of producing these artefacts. Incorporating debitage analysis into the study of artefact production has had the effect of highlighting particular production methods, such as direct percussion or sawing. Tejero (2014) explores the debitage patterns obtained through experimental reproductions of Aurignacian osseous tools facilitating a comparative approach to the *chaîne opératoire*. The results were a more detailed account of the production process. A similar approach to incorporating debitage into the process is found in the review of Mesolithic antler and bone tools found at Le Cuzoul de Gramat (France) (Marquebielle, 2011). Here a *chaîne opératoire* was outlined for the site that highlighted the volume of waste produced in antler tools production, which was taken as an indication of an abundance of antler, especially when compared to other sites in the region. However, this study did not incorporate any experimental protocols into the analysis, which could have disproved or supported the suppositions about how the antler was worked.

However, more complete *chaîne opératoire* for antler artefacts have been presented. For example, Conneller (2012, p.57) described the *chaîne opératoire* for producing antler barbed points at Star Carr, drawing on work from Elliott (2008) and Clark's (1954) observations. The extraordinary preservation of organic material at Star Carr preserved stages of the working process *in situ*, which Clark (1954) observed during his original excavation of the site. While Elliott's (2008) work uses experimental archaeology to gain insight into the *chaîne opératoire*, such as the benefits of soaking antler during working, it is ultimately shaped by preconceived stages informed by Clark's (1954) observations. This, as noted by Conneller (2012, p.58), therefore overlooks an important aspect of working antler; the materiality and specific relationship which is negotiated between human and material during working.

One of the most comprehensive evaluations of a *chaîne opératoire* from antler working emerges from a continuation of Elliott's (2008) work, in Elliott and Milner's (2010) research into the working process of Mesolithic antler barbed points at Star Carr. While this research certainly contributed in-depth understanding of the production of barbed points at Star Carr, the experimental approach undertaken prevented the exploration of other stages within the *chaîne opératoire*, that may not have preserved in the archaeological record. In particular, while Elliott and Milner (2010, p.85) recognise that soaking likely improves workability, they do not explore specifically how this stage may have manifested in the *chaîne opératoire*. They opt to soak the antler whole, before working, then re-soak the antler throughout the working process. This is used as a method to ensure the antler remains wet throughout the process but appears impractical. It seems unlikely Mesolithic groups would have repeatedly interrupted their working process to re-soak the antler, and if so, one would expect to find a snapshot of chaîne opératoire stages preserved in the wetland area where antler has been lost during the process. While it is likely soaking did occur during the working process, it remains that this specific stage needs to be further explored.

Although past research has provided some insight into the *chaîne opératoire* involved in antler working, very few explore the process from an experimental perspective. Arguably, this restricts research from appreciating the materiality of antler and thus gaining a greater depth of understanding of the intuitive knowledge prehistoric societies would have had about this material. Research which adopts an experimental approach can demonstrate the nuances that may be obtained, but either follow steps of a preconceived *chaîne opératoire* for antler working, or do not relate qualitative observation to the working process. In particular, the process of soaking antler appears to be poorly understood; whether soaking antler improves workability is contested, and where it is accepted, it is often only added as an embellished extra to a preconceived *chaîne opératoire*.

This research therefore aimed to explore and propose a broad *chaîne opératoire* model for antler working. This does not attempt to prescribe one way to work antler; over wide temporal and spatial breadth there will inevitably be a large amount of variation. Instead, through experimental archaeology, we argue for a more in-depth understanding of the materiality of antler which provides insight into the potential macro-stages involved in antler working to improve the workability of antler. Therefore, we aimed to investigate three key areas in this study: tine removal; the effect of soaking on grooving antler; and the effect of soaking on the groove-and-splinter technique. These three methods of working antler are well-documented throughout prehistory. The experiments were carried out on naturally-shed red deer (*Cervus elaphus*) antler gathered from Tatton Park in Cheshire, UK. The flint tools used were produced by the authors and all experiments were conducted in the York Experimental Archaeology Research (YEAR) Centre (University of York).

Structure of Antler

Before discussing the experiments, it is necessary to briefly review the structure of antler and its properties. Antler is a unique material; it is an osseous organ, capable of regeneration and has one of the quickest growth rates among all animal species (Chen et al., 2009, p.694; Elliott, 2012, p.210; Picavet and Balligand, 2016, p.141). Antlers usually only grow on male deer and are absent in females; the notable exception is in reindeer where both males and females have antlers (Chen et al., 2009, p.693). The cycle of antler growth and regeneration is seasonal, and for most species this consists of a period of rapid growth during late spring/summer, full maturity in autumn, velvet shedding in late autumn before the rut, and casting off the antlers in late winter/early spring (Chen et al., 2009, p.694; Elliott, 2012, p.212; Picavet and Balligand, 2016, p.141). Its morphology consists of the burr, pedicle, beam, and tines (See Figure 1). Antlers are attached to the skull through the pedicle, which is an extension of the frontal bone (Elliott, 2012, p.210). The burr is located at the base of the antler, where the antler attaches to the head, and is represented by a circular, crown-like feature. The beam is the main branch of the antler, and the tines protrude forward out from this main branch (Picavet and Balligand, 2016, p.141). Throughout prehistory, one can observe different tools being produced from these different regions of the antler, utilising the natural variation in attributes of the different sections. For example, Mesolithic mattocks were often made using the beam (Elliott, 2012, p.7), and this is likely because this tool type required the natural strength and suitable morphology of this section.

Antlers are primarily thought to be used by *Cervidae* as a weapon/shield during ruts, and may also reflect social hierarchy (Goss, 1983, p.108; Chen et al., 2009, p.694). Consequently, due to its role in ruts, it has remarkable strength and flexibility which is achieved through its internal structure (Goss, 1983, p.107). This is its primary attraction as a material resource; it can withstand direct high-impact forces and thus is ideal for tools and weapons. The internal structure is formed primarily of three zones: the external compact bone; a transition zone; and the spongy-structured internal cancellous bone, and blood vessels permeate throughout this structure, as can be observed in Figure 2 (O'Connor, 1987, p.6; Chen et al., 2009, p.693; Picavet and Balligand, 2016, p.142). The morphological areas described here are referred to throughout the rest of the paper, in the context of the regions worked during the experiments.

Tine Breaking

Methodology

To fully explore a proposed *chaîne opératoire* for antler working, we first established how tines might be removed from the beam of the antler. If one required the beam of the antler to produce blanks for osseous tools (for example, barbed points), one may be tempted to argue either: 1) the tines would be ignored in antler working; 2) tines are a waste product and thus removed and discarded quickly; or 3) tines would be initially removed for use elsewhere. Each hypothesis depends upon the energy expenditure required to remove the tines. If relatively easy and assuming an abundance of antler, one may be tempted to support the second hypothesis, that the tines would be removed and discarded. However, if relatively difficult one may argue the tines would be left on the beam unless absolutely necessary to remove (hypothesis 1). Consequently, it was necessary to explore different methods for removing the antler tines to falsify hypotheses and establish this stage of the *chaîne opératoire*. We explored the following methods, recording the time taken and relative ease of working for each: controlled heating; prepared groove with flint; "heat-shock"; soaking; and combinations therein. Each method was treated as a pre-modification before using direct percussion to remove the tine. Direct percussion was kept consistent each time, using a hammer stone over a stone anvil and was always conducted by the same person (AL).

A prepared groove was conducted each time with a flint blade. The morphology of the flint blades was kept consistent throughout the experiment, and flint blades were immediately replaced if they became blunt during the process. The blades were used to score a groove around the circumference of the tine. As each tine naturally varied in thickness, we adopted an actualistic approach. The groove depth was therefore not kept consistent, and grooving was conducted up until both experimenters were sufficiently happy with the depth achieved. Controlled heating was performed using the glowing ember of a stick which was pressed against the tine and blown to create a hot ember (See Figure 3). This enabled a specific area of the antler to be directly scorched without causing damage to the rest of the tine or beam. The "heat-shock" method alternated the controlled heat method, which was conducted for a fixed length of time, with dousing the heated area with cool water. This was conducted twice before breaking. A combination of prepared grooving and controlled heating involved initially heating the antler for 10 minutes, followed by grooving for 10 minutes. This was conducted twice before breaking. In the one instance of soaking in the tine breaking experiments, a tine was soaked for a week before subjecting it to a prepared groove and controlled heating method. This method served to draw a preliminary comparison between unsoaked and soaked antler working, and informed the design of the soaking antler experiments.

Results

As discussed in the methodology, we experimented with several different methods of tine breaking. This enabled us to explore potential methods for removing tines, the energy expenditure required for each method, and whether there is a diagnostic breakage pattern to the different methods, which may enable identification of specific methods in the archaeological record. The results (See Table 1) will be discussed here.

Method	Tine	Grooved?	Groove depth	Time taken	Heated?	Time taken2	Relative ease (0 – 10) to remove

							with direct percussion
Prepared groove	1	Yes	4 mm	32 mins 29 secs	No	-	4
Prepared groove and controlled heating	2	Yes	2 mm	21 mins 39 secs	Yes	22 mins 02 secs	3
"Heat-shock"	3	No	-	-	Yes	10 mins (twice)	3
Controlled heating	4	No	-	-	Yes	28 mins 18 secs	2
Controlled heating and groove (repeated)	5a	Yes	1 mm	5 mins 16 secs	Yes	10 mins	8
Soaked (1 week), prepared groove and controlled heating	5b	Yes	2 mm	15 mins 27 secs	Yes	10 mins	0
Prepared groove	A	Yes	3 mm	29 mins 4 secs	No	-	7
Prepared groove and controlled heating	B	Yes	1 mm	14 mins 32 secs	Yes	10 mins	5
"Heat-shock"	C	No	-	-	Yes	5 mins (twice)	5
Controlled heating	D	No	-	-	Yes	20 mins	5

TABLE 1. RESULTS FROM DIFFERENT METHODS FOR EXPERIMENTALLY REMOVING TINES.

Each method was able to be conducted without any specialist working required, and all pre-treatments weakened the antler sufficiently to enable the tine to be removed with direct percussion. There are two exceptions where the removal was more difficult than anticipated: repeated controlled heating and grooving with tine 5a; and the prepared groove method with tine A. The latter experienced difficulty primarily due to issues with positioning the antler on the anvil to allow for direct force to be exerted onto the groove, and thus we discount this result as not representative of the pre-treatment. However, the repeated controlled heating and grooving method was the only method which was deemed unlikely to have been used in antler working. Controlled heating appears to cause the antler to become brittle, thus attempts to groove the antler after the surface had been heated was notably more difficult than grooving non-heated antler.

The prepared groove method, although somewhat time-consuming, was relatively easy to undertake. As demonstrated in the results, the groove did not require much depth in order to be effective in creating a weak point in the antler. The breakage pattern from this method was notably more regular than other methods, and thus it is effective in producing a neat break which would not require further working to smooth out. The controlled heating method was also easy to undertake. However, and pertinent to the earliest example of antler working in prehistory, this method requires controlled use of fire. By contrast to the prepared groove, this method was much quicker in weakening the antler for removal. Only 20 minutes was sufficient to weaken the antler, and the cross-section of the breakage from this method demonstrated the heating permeated through the antler to discolour the interior cancellous bone (See Figure 4). Thus, it is likely that this heating was too extensive, and a reduced controlled heating time may be sufficient. The breakage pattern of a controlled heating method for tine removal has some diagnostic features, primarily charring and discolouring of the antler around the break, and a degree of peeling of the compact bone. As each method separately is sufficient to weaken the antler, combinations of the prepared groove and controlled heating method do not increase the ease of tine removal nor speed. The breakage pattern from the two tines subjected to this pre-treatment before removal are variable; tine 2 exhibits extensive peeling as a feature of being controlled heated, and tine B demonstrates a relatively neat breakage pattern.

Preliminary conclusions

The tine removal experiments suggest that, with the exception of repeated controlled heating and grooving, all pre-treatments were effective in improving the ease of removing an antler tine. Controlled heating appeared to be the quickest and relatively easiest method to sufficiently weaken the antler. However, the prepared groove method was the most effective in producing a predictable and clean break. Although all methods resulted in the tines being effectively removed within a relatively short period of time, they all required moderate effort to be exerted. We propose this level of effort expenditure was not sufficient to prevent the removal of tines in antler working, however may have dissuaded the unnecessary removal of antler tines. Additionally, the removal of antler tines results in the cancellous bone of the antler to be exposed at multiple points on the beam. After soaking an antler tine for 1 week, we preliminarily proposed that soaking significantly improves the workability of antler and exposing the interior cancellous bone may aid the soaking process. Indeed, we observed that the soaked antler tine remained soft and malleable, even retaining water, several days after being soaked. We therefore conducted several different soaking experiments, to explore this hypothesis further.

Soaking Antler

Methodology

The elucidation of a significant increase in workability of antler after a week of soaking with the tine removal experiments informed the design of soaking experiments. These aimed to further explore whether soaking improves the workability of antler, establish whether exposing the cancellous bone of the antler during soaking made a notable difference, and to determine the minimum length of time required for soaking. To ensure we could appropriately explore this, and due to limited antler availability, two antler beams were cut into identical sections. Neighbouring sections of one beam were paired together; for each pair, one was left "unsealed" with the cancellous bone exposed, and the other was sealed with beeswax (See Figure 5). Each pair was then subsequently submerged for a specific increment of time. Once soaked, the paired sections were then grooved at the same time until the groove reached through the compact bone outer cortex and both experimenters agreed the outer cortex had been grooved through. The same experimenter grooved either sealed (AL) or unsealed (IW) soaked antler sections, to ensure the speed of grooving for sealed and unsealed antler was internally consistent. The time and depth achieved by the groove on each antler was then recorded.

In the first round of experiments, pairs of antler sections were soaked for 2 hours, 6 hours, 24 hours and 1 week. The results from these initial experiments appeared to show a threshold was crossed between 2 hours and 6 hours, and thus a second round of experiments was conducted. In this round, pairs of antler sections were soaked for 3 hours, 4 hours, and 5 hours. This enabled us to refine where a threshold in the effectiveness of the soaking was crossed, as will be discussed in the results.

Results

The soaking experiments revealed interesting insights into the effect of soaking unsealed and sealed antler. While soaking for fewer than 4 hours demonstrated no significant difference between the workability of sealed and unsealed antler, a disparity became evident after this length of soaking time (See Figures 6 and 7). This suggests a threshold is crossed in the soaking time, whereby unsealed antler becoming much more workable than sealed antler. We propose this is a consequence of the properties of antler; the threshold represents the minimum length of time for the cancellous bone to absorb and retain water in the unsealed antler, improving the workability by ensuring the antler remains wet. Any length of soaking time before this is not sufficient for water to permeate and be retained by the cancellous bone. Additionally, we qualitatively noted the unsealed antler retained moisture for a prolonged period of time after the experiments. Furthermore, the unsealed antler soaked for longer than 4 hours appeared to heavily discolour the water, suggesting the water had replaced some organic materials within the antler.

This would provide an explanation for why the speed of grooving remains the same between sealed and unsealed antler before this threshold is crossed. Consequently, this supports our hypothesis; it is apparent that exposing the cancellous bone significantly improves the workability of the antler. Additionally, it is important to note that for the sealed antler, the length of soaking time appears to have had no, or a very limited, effect on the workability. The difference between speed of grooving between sealed and unsealed antler does appear to peak and decrease after 6 hours of soaking; this may suggest after this time, soaking has a minor effect on the sealed antler. To further explore this and establish whether this is a pattern, future experiments would need to be conducted.

Conclusions

With some caveats, it is possible to conclude that these preliminary results support our hypothesis that soaking antler can be made more effective by exposing the cancellous bone. There is a clear positive relationship between the length of time the unsealed antler was soaked and the length of time it took to groove to a certain depth, with a threshold appearing to be crossed some time after 4 hours. There is also a distinct plateau after which the rate decreases, suggesting that there is a potential maximum amount of time to soak antler, after which the efficiency gains start to diminish. These results do need to be further examined, especially since the depth of grooving was relatively shallow and the sections of antler soaked were small. Both factors will affect the results and further investigations should aim to be more rigorous in their protocols. However, on balance, these results support our hypothesis.

Groove-and-Splinter

Methodology

The results of the soaking experiments showed a positive correlation between soaking antler and improved work speed, and that exposing the cancellous bone during soaking significantly improves the ease of workability. Therefore, we aimed to confirm these results by undertaking a 'groove-and-splinter' technique on a dry, soaked-sealed and a soaked-unsealed antler beam. A dry beam would give us a calibration point for unmodified antler working which could be compared against the two soaked sections. The 'groove-and-splinter' process was carried out using flint burins, blades and flakes and aided by percussive force using antler and bone chisels. The soaked-sealed/unsealed beams were left to soak for five days in clean tap water. The sealed beam was made watertight through applying beeswax over any broken tine sections and anywhere cancellous bone could be in contact with the water. The unsealed beam had the tines removed using the aforementioned methods. The length of time (five days) was a pragmatic decision but also accorded with the above results for maximum impact on the antler tissue. The blanks removed were of the same size for the dry and soaked-sealed beams, approximately 10 cm, but the blank removed from the soaked-unsealed was approximately 16cm (See Figure 8, 9 and 10). This was a conscious attempt to negate 'experience bias', where practice and repetition would naturally improve efficiency. By increasing the size of the third blank we feel this has compensated for any minor increase in skill.

Results

The results for the 'groove-and-splinter' experiment fell into line with the previous results for soaking antler sections (See Table 2). It took approximately seven hours to remove the blank from the dry beam. Following that it took approximately five hours to remove the blank from the soaked-sealed beam. Finally, it took approximately two and a half hours to remove the blank from the soaked-unsealed beam. This would suggest that there is a significant impact on the structure of the antler when the water is able to fully penetrate the cancellous bone and be retained during the grooving. The timings have to be considered in the light of the limited experience of the practitioners, but also in the increased length of the blank removed from the unsealed beam. However, irrespective of our limited skill level, we believe the results demonstrate that soaking antler with the cancellous bone exposed significantly improves the workability of antler.

	Dry Beam	Sealed Beam	Unsealed Beam
Time taken to groove a blank (mins)	420	300	150
Length of blank (cm)	10	10	16
Rate of removal (mins/cm)	42	30	9,3

TABLE 2. TIME TAKEN TO REMOVE BLANKS BROKEN DOWN BY EXPERIMENT.

There were some noticeable observations in the process of removing the blanks. The sealed beam retained a level of water-logging in the compact bone immediately following its removal from the water. However, the water was not retained by the compact bone which dried out fairly rapidly, and thus any advantage of soaking the sealed antler was limited. We believe this may account for the experience of previous experimental research which continuously re-soak the antler throughout working (Elliott and Milner, 2010; Elliott pers. comm.; Pomstra pers. comm.). While this same phenomenon was observed in the compact bone of the unsealed beam, the cancellous bone was able to retain the water. Therefore, the antler remained water-logged, improving workability as the groove deepened into the transition zone. This is characterised in Table 3.

	Dry Beam	Sealed Beam	Unsealed Beam
Compact bone	No advantage	Increased ease (temporary)	Increased ease (temporary)
Transition zone	No advantage	No advantage	No advantage
Cancellous bone	No advantage	No advantage	Increased ease (prolonged)

TABLE 3. ADVANTAGES OF SOAKING BROKEN DOWN BY ANTLER TISSUE TYPE.

Discussion

The above results support our hypothesis that the deliberate removal of tines precedes soaking in order to more easily work the antler. Of course, this does not unequivocally prove that soaking was an integral part of the *chaîne opératoire*, but it does raise the possibility that the *chaîne opératoire* needs to be revised. This supports findings of other researchers studying osseous and antler craft technology across multiple time periods that have noted the likelihood and evidence for soaking, both archaeologically and ethnographically (Deschler-Erb, 2005; LeMoine, 1994). In southwest Slovakia, Germanic tribes living between 1-5 century AD left behind numerous artefacts relating to antler working, including ceramic vessels used for soaking (Hrnčiarik, 2018). A miniature bow was discovered at Isleham, Cambridgeshire (UK), dated to the Middle Bronze Age, which had been carved from an antler blank. Again, the authors note the necessity of soaking antler before working (Gdaniec, 1996). Clarke and Thompson (1954), in their discussion on the 'groove-and-splinter' technique throughout the European Palaeolithic and Mesolithic, experiment with soaking antler and conclude that four days was sufficient to soften it enough for grooving. An early suggestion for the purpose of the Star Carr Mesolithic site was to process antler and deer hide. This proposal was based in part on the requirement for hide processing and tanning, as well as softening antler, on a body of freshwater (Hodges, 1964; Pitts, 1979). At least one recent experiment on soaking antler was conducted by Osipowicz (2007). Four methods were tested of softening bone and antler: immersion in cold water, boiling water, sour milk and sorrel. Although they focused on the wear traces of the tools used to process the bone and antler post soaking, they concluded that any of the four methods was preferable to working dry antler.

What has been lacking so far is a rigorous way of incorporating this knowledge into our understanding of antler artefact production. Most references to softening antler through soaking seem to come from experimental researchers looking for a way to alleviate the lengthy and arduous task, rather than explicitly exploring soaking as a potential stage in a *chaîne opératoire*. Therefore, we propose the following addition to the existing *chaîne opératoire*:

1. Deliberate removal of tines to expose cancellous bone, improving impact of soaking
2. Soaking (or softening) exposed beam
3. Manufacture of tool/object from softened beam

This proposal incorporates two additional steps. The removal of the tines may be both to use tines for another purpose and to ensure the cancellous bone is exposed before soaking the beam of the antler. The second step is to soak the beam with the cancellous bone exposed, in water or a softening agent, to ease workability in later processing stages. Only the second step would result in any potential evidence for this claim, which would likely be the presence of a number of beams, without their tines, in a body of water. Of course, removing tines is only one way that exposing cancellous bone could occur during antler working; it is also possible to remove the crown, the burr, multiple splinters, and the upper or lower beam portion. However, as demonstrated by our tine removal experiments, removing the tines is significantly easier than attempting to remove parts of the beam. Percussive force is highly unlikely to be effective at removing the tines, but a multitude of relatively simple procedures would be sufficient to do so. A final point here is that, whilst we are proposing tine removal and soaking as an intentional act on the part of prehistoric people, there is the possibility that this part of the *chaîne opératoire* could occur unintentionally. The removal of the tines and the sectioning of the beam for further artefacts could occur prior to soaking without the knowledge that this form of softening is more effective than soaking intact antler beams.

This revised *chaîne opératoire* has pertinent implications for understanding antler working within prehistoric lifeways more broadly, beyond the mechanics of exploiting the material. This can be placed in context of unusual deposition practices of osseous material, such as at Star Carr. The extensive deposition of antler, animal parts, and in some cases, whole animals, has been suggested as part of the rich symbolic behaviours at this site (Conneller, 2004; Taylor et al., 2017; Overton and Taylor, 2018, p.390). The proposition that antler was deposited in the lake as part of the *chaîne opératoire* provides an additional, complimentary layer of understanding to this interpretation. If soaking was an integral stage of the antler working process at Star Carr, there may have been a conceptual association between antler and water and thus, in a cyclical sense (Chatterton, 2003, p.78), antler artefacts are "returned" to the water. Although a tentative suggestion, this serves to demonstrate the significance of an in-depth understanding to gaining better insight into the behaviours of past societies. Technology cannot be conceived as an isolated aspect of prehistoric lifeways, but instead embedded within and shaped by past cultural and social worldviews (Dobres and Hoffman, 1994, p.211).

Conclusion

The experiments conducted have provided supporting data for out hypothesis that soaking was an important stage within an antler working *chaîne opératoire*, a finding which has potential significance for antler working in multiple periods. Tine breaking, while seemingly intuitive, required us to creatively consider as many options as possible to remove tines, simply due to the inertia of antler under percussion. Our explorations into how tines could have been removed revealed a plethora of techniques which should leave trace evidence on archaeological artefacts. It also highlighted that any removal of tines would likely be a deliberate act. The protocol of soaking antler, and the subsequent apparent ease with which it could be manipulated, suggest that soaking could have been a viable, low-cost and low-energy, method of both removing tines, but more importantly, further modifying the beam. This hypothesis was corroborated by experimentation with soaking antler sections, sealed and unsealed. The results from this encourage more investigations into soaking whole beams of antler, in various states of internal exposure. The final results from 'groove-and-splinter' confirmed that this technique could form part of a new inclusion to the standard *chaîne opératoire* of antler working, across several time periods.

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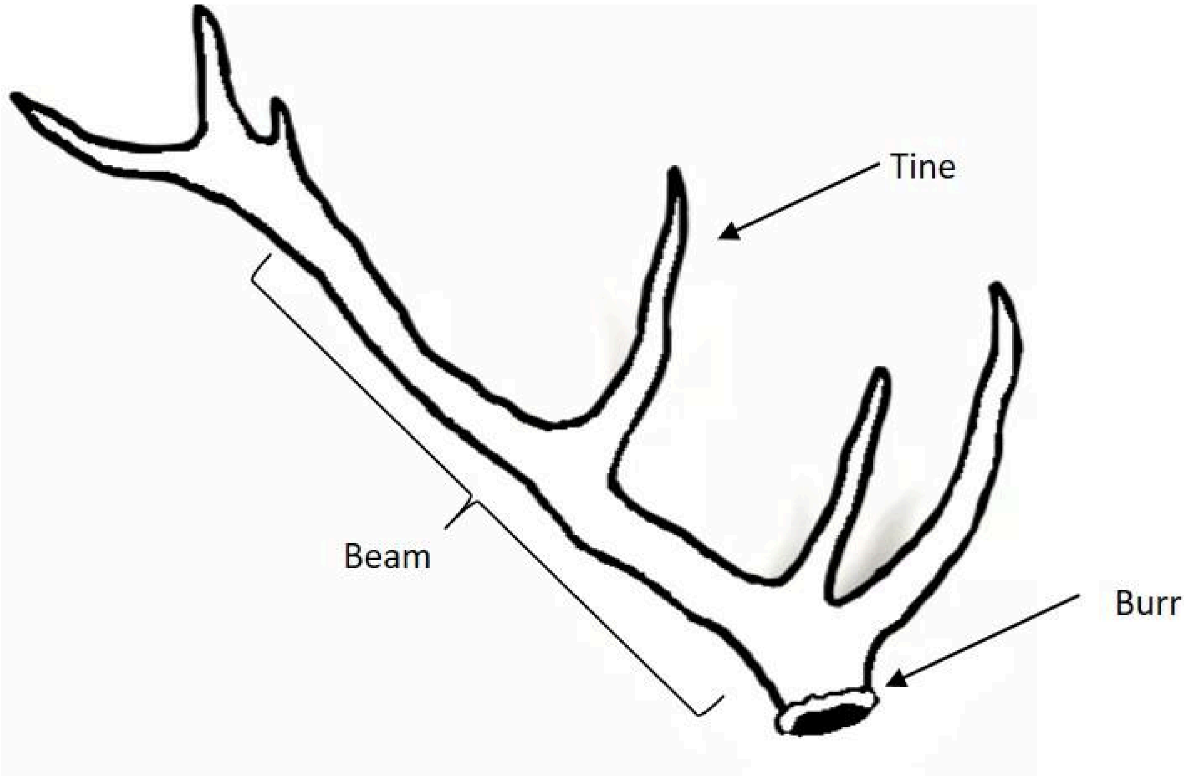

FIG 1. DIAGRAM OF THE MORPHOLOGY OF ANTLER.

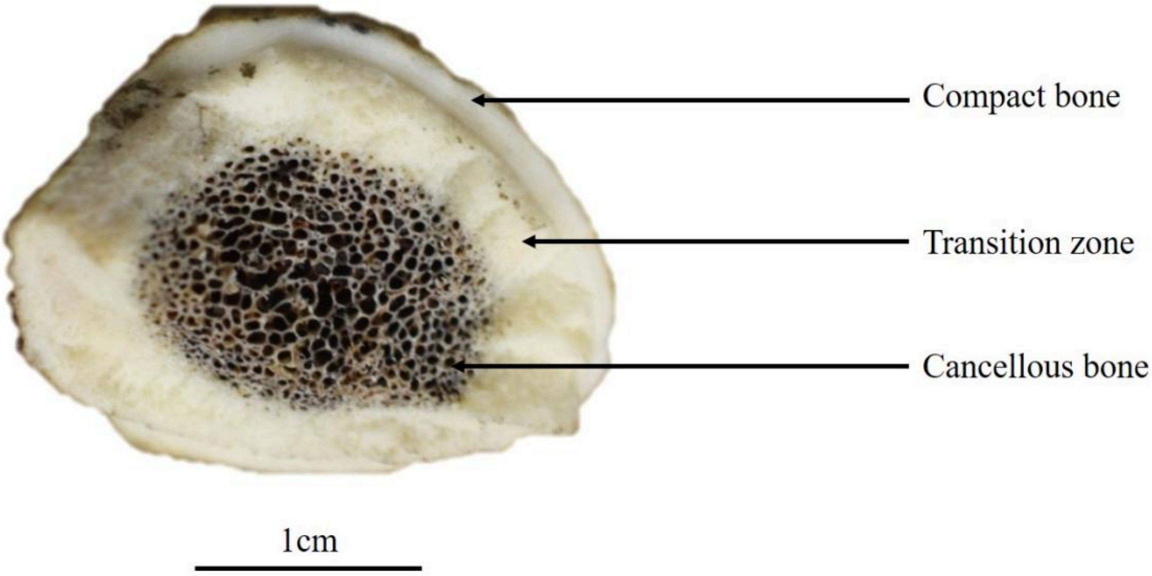

FIG 2. THE INTERNAL STRUCTURE OF ANTLER, ACCORDING TO PICAVET AND BALLIGAND (2016, 142), WHICH WILL BE REFERRED TO THROUGHOUT THIS PAPER.

FIG 3. CONTROLLED HEATING METHOD, SHOWING THE GLOWING EMBER OF THE STICK APPLIED TO THE ANTLER.

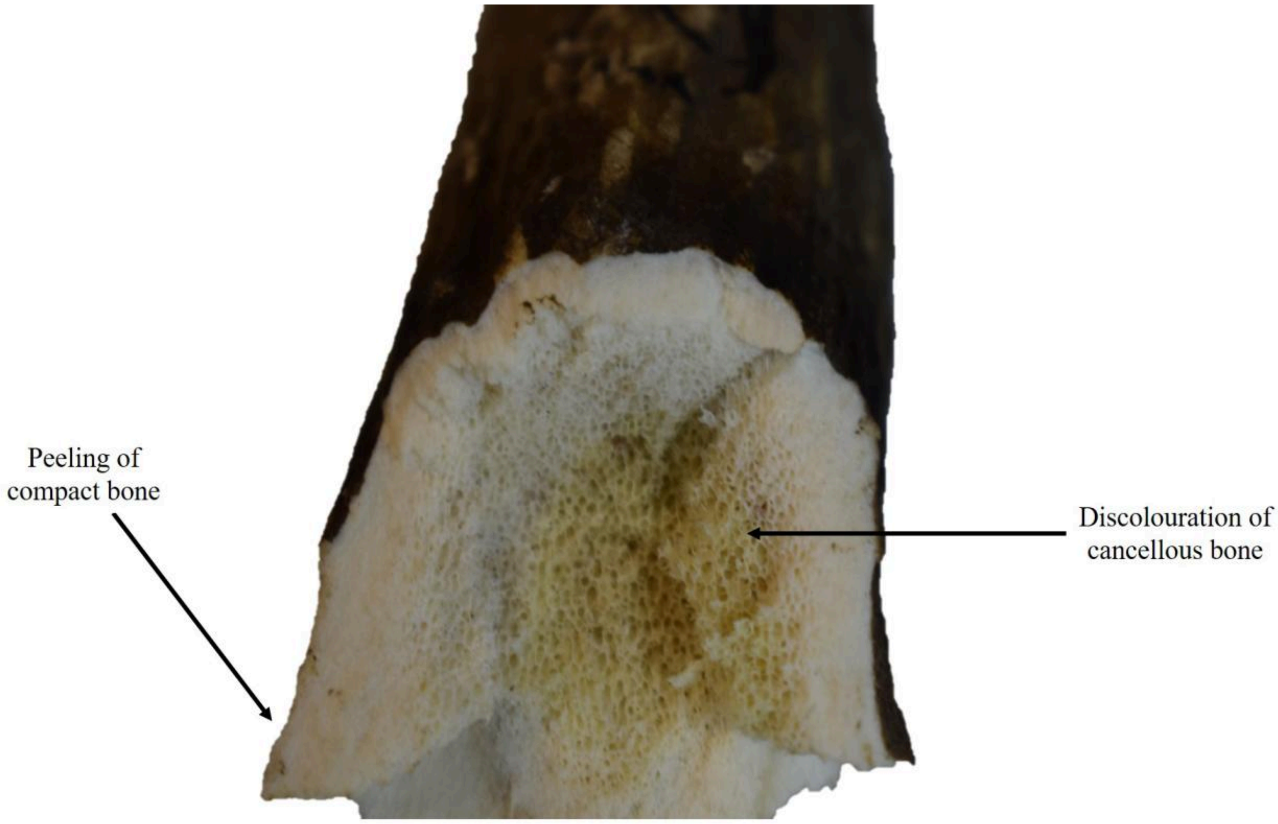

FIG 4. DIAGNOSTIC HEATING EFFECTS ON ANTLER.

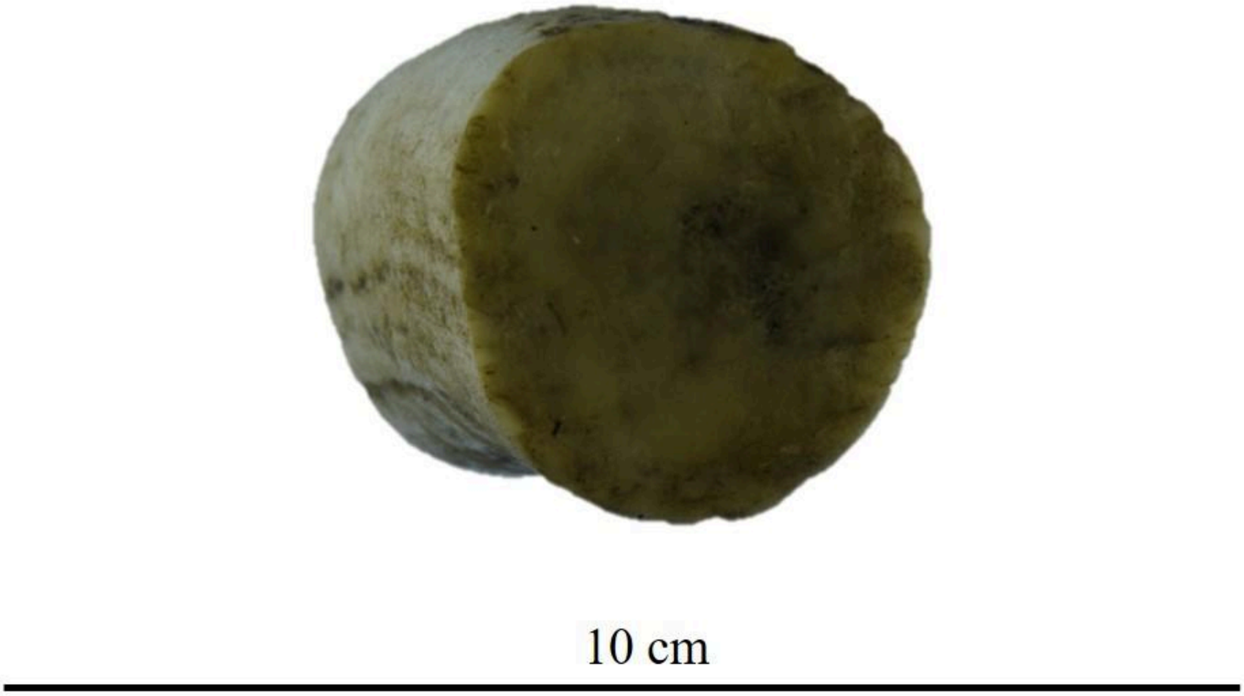

FIG 5. EXAMPLE OF AN ANTLER SECTION SEALED WITH BEESWAX.

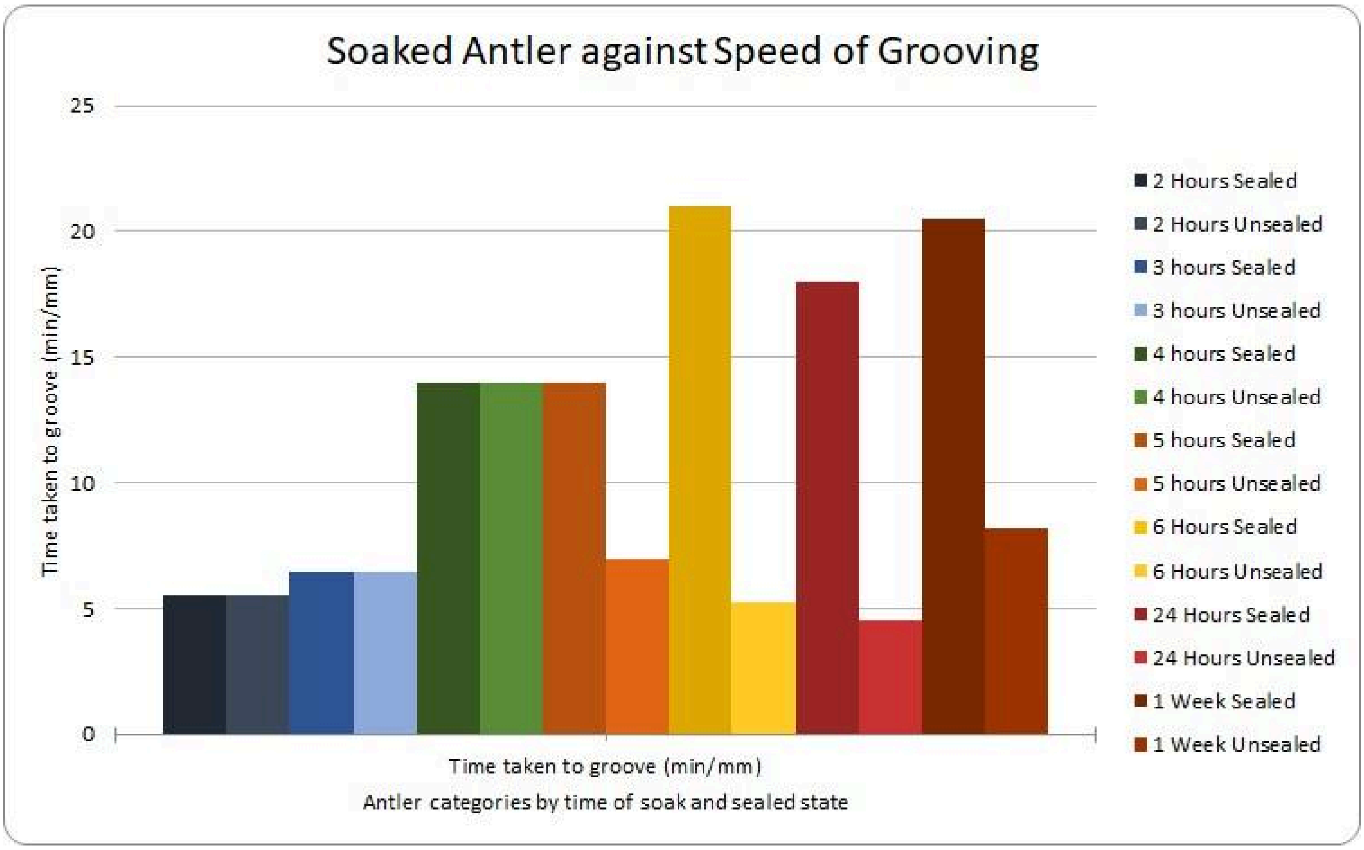

FIG 6. RESULTS OF SPEED OF GROOVING BETWEEN SEALED AND UNSEALED ANTLER SOAKED FOR SPECIFIC INCREMENTS OF TIME, CALCULATED BY TIME TAKEN OVER DEPTH GROOVED TO STANDARDISE THE RESULTS.

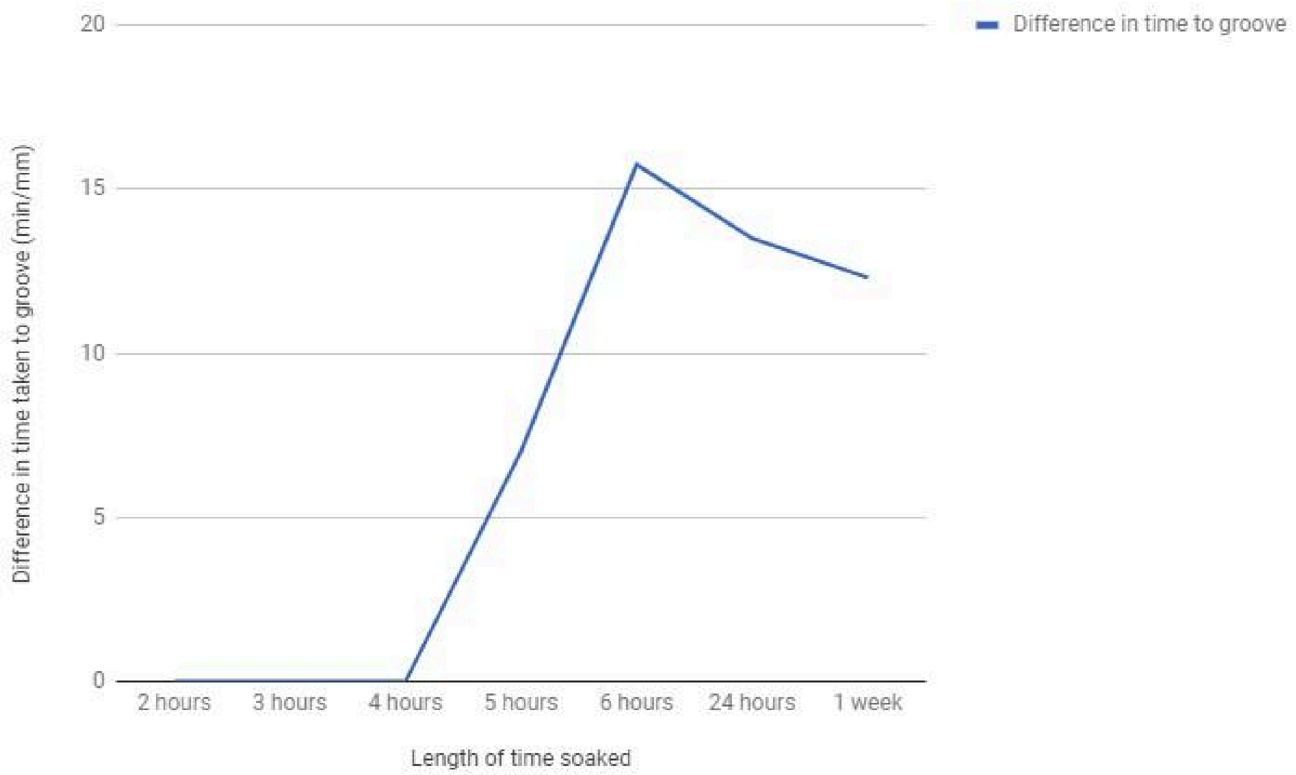

FIG 7. DIFFERENCE BETWEEN THE SPEED OF GROOVING OF SEALED AND UNSEALED ANTLER, BASED ON THE RESULTS FROM FIGURE 4. THIS HIGHLIGHTS THE THRESHOLD CROSSED AFTER 4 HOURS.

FIG 8. BLANK PRODUCED FROM THE DRY ANTLER.

FIG 9. BLANK PRODUCED FROM THE SOAKED-SEALED ANTLER.

FIG 10. BLANK PRODUCED FROM THE SOAKED-UNSEALED ANTLER.