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Spinning in Circles: the Production and Function of Upper Palaeolithic Rondelles

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Rondelles are thin, circular disc cut-outs typically made from the blade of the scapula of medium sized ungulates, such as horse or cervid. These are primarily associated with the Late Upper Palaeolithic Magdalenian and focused around northwest Europe. Rondelles are

frequently perforated, with 2 mm - 3 mm diameter holes being common. There are many questions as to the production and use of rondelles. In this article, we discuss experiments on the making of both bone and slate rondelles and their usage.

> Experimental replication has the potential to shed new light on aspects of production and to test the diverse theories raised pertaining to elements of production and the possible use(s) of rondelles. The experimental replication of rondelles presented here takes these varied hypotheses and observations as its point of departure, with experiments designed to test some of the most popular suggested methods of production and two potential uses of rondelles.

The Archaeological Context of Rondelles

Enigmatic circular discs, referred to as "rondelles" are primarily associated with the Magdalenian (Bellier *et al.*, 1991, p.4), a Late Upper Palaeolithic period dating to between 20,500 - 13,000 Cal BP (Fuentes, Lucas and Robert, p.2017) and focused around northwest Europe. Spatially, the Magdalenian is especially associated with Spain and France, regions that were used as refugia during the Last Glacial Maximum (LGM) and from where the culture emerged (Otte, 2012; Straus, 2013). However, sites are also reported as far west as Portugal (Bicho and Haws 2012) and north as the UK (Pettitt, Rockman and Chenery, 2012), Germany (Jochim, 1995; Jochim, Herhahn and Starr, 1999; Street, Jöris and Turner, 2012), the Netherlands and Belgium (Miller and Noiret, 2009; Rensink, 2012), and as far east as Poland (Połtowicz-Bobak, 2009; Wiśniewski, *et al.*, 2012). Rondelles are especially temporally concentrated between 14,000 BP - 13,000 BP (Cook, 2013, p.203), while spatially they are found across much of the Magdalenian range, but in particular southern France and northern Spain around the Pyrenees, as well as to the north and east in Germany and Poland, with clear gaps to the northwest, especially the UK (Fuentes, Lucas and Robert, 2017).

What are Rondelles and What was Their Function?

Rondelles are thin, circular disc cut-outs typically made from the blade of the scapula (Bellier *et al.*, 1991, p.6, p.16) of medium sized ungulates, such as horse or cervid. They are typically circular to sub-circular in shape and small in size, with Bellier *et al.* (1991, p.6, p.15, p.17) reporting a range between 19 mm - 75 mm in diameter, with a diameter of 30 mm - 50 mm being average (Bellier *et al.*, 1991, p.6, p.15, p.17). Multiple cut-outs can be removed from a single scapula and the process leaves a distinctive debitage signature, with multiple circular voids and typically clear working traces, such as at the site of Grotte de Saint-Michel d'Arudy (Bellier *et al.*, 1991, p.20), where three discs have been removed from a scapula in this way. The highly specific working traces that can be preserved in the scapula during working offer some insights into the specific method of rondelle extraction employed, being consistent with marks one might expect if a stone tool were employed in a cutting or incising motion.

While scapulae are by far the most common raw material identified in rondelle production in the archaeological record, alternatives are sometimes used. For example, a small number of possible rondelles have been discovered made from human cranial bones, such as at Grande Salle, Isturitz, France and Maszycka, Poland (Orschiedt, 2013, p.127; Orschiedt *et al.*, 2017, p.435; Pettitt, 2011, pp.223-225). In this case, the thin and broadly flat surfaces offered by the cranium might have afforded a similar working strategy to that used in working scapulae. In rare cases, mammoth ivory has also been used (Bahn and Vertut, 1988, p.81), as well as fragments of mammoth teeth (Bellier *et al.*, 1991). Rondelles are also occasionally made from soft stone - this is typically to the north of the Magdalenian range, especially in Germany, such as at the site of Gönnersdorf where 400 examples made of slate were recovered (Bosinski, 1977). In the case of these latter materials, it is probable that the working strategy employed might be modified or significantly altered to accommodate differences in the specific materials used when compared to that of working with the scapulae of medium sized ungulates.

Rondelles are frequently perforated, with 2 mm - 3 mm diameter holes being common. Multiple permutations are known, with a variant displaying several perforations close to the outer edge being especially common, as well as a variant displaying a single perforation to the centre of the cut-out (Bellier *et al.*, 1991, p.17), possibly suggesting suspension was important in their subsequent use. Rondelles are typically engraved, in some cases only on a single face, while in other examples on both faces, and a wide range of designs have been reported. For example, Sieveking (1971) has noted a number of geometric designs, including a 'type A' motif, with lines emanating from a central perforation; a 'type B' motif, with lines emanating from a circled edge, as well as denticulated edges; and also 'barbed line' designs. The depiction of animals in naturalistic detail is also common, perhaps best exemplified by the rondelle recovered from Laugerie-Basse (Azéma and Rivère, 2012, pp.320-323) where a young chamois was drawn in different postures on each face of the rondelle. While engraving may have been simply decorative in some cases, in others it may have been an integral part of the function, and therefore an important consideration when thinking about both the meaning of rondelles and how they were used.

The full *chaîne opératoire* of rondelle production remains enigmatic, with little detailed understanding of the specific differences in their production across diverse raw materials. Similarly, there is no clear consensus surrounding the use of rondelles; the range of suggested functions is wide. However, work has emerged in recent years that has started to discuss elements of rondelle production and use. For example, in considering production, it has been hypothesised that rondelles made of bone required the use of a round stone to cut around, the stone acting as a stencil or template for the shape of the bone cut-out (Conneller, 2011). Diverse interpretations pertaining to function have also emerged. For example, some have favoured their use as pendants or ornaments (Sieveking, 1971; Conneller, 2011; Cook, 2013, p.203) or as buttons and toggles, based on a human depiction found by Bétirac (1952) on an engraved piece of bone (San Juan Foucher and Vercoutére, 2013, p.126). However, this latter interpretation has attracted criticism due to the fragility of rondelles and how effective they would be as a functional addition to clothing or similar organic items (Bahn and Vertut, 1988, p.81). Others have suggested that if string was passed through the perforations and the disc spun at high speed, the rondelle would act as a thaumatrope, with the images from the different faces blurring into a composite image (Azéma and Rivère, 2012; Cook, 2013, p.203). Further alternate theories have included the rondelle as part of a tool kit that might be used in the creation of string (Stone, 2009; 2011); perhaps even being used as spindle whorls (Soffer, Adovasio and Hyland, 2002, p.237; Soffer, 2004, p.411;).

Experimental replication has the potential to shed new light on aspects of production and to test the diverse theories raised pertaining to elements of production and the possible use(s) of rondelles. The experimental replication of rondelles presented here takes these varied hypotheses and observations as its point of departure, with experiments designed to test some of the most popular suggested methods of production and two potential uses of rondelles.

Introduction to the Experimental Programme

In summer 2017, Experimental Archaeology undergraduate students from the University of York, undertook a "Team Project" aiming to address the following research questions:

1. How were bone rondelles manufactured?
2. How were slate rondelles manufactured?
3. What was the function of rondelles?

Three teams of students worked independently, addressing these research questions through the creation of experimental protocols (See Figure 1). The research presented draws together the experimental results of each groups to address these research questions.

FIG 1. UNIVERSITY OF YORK ARCHAEOLOGY STUDENTS WORKING ON RONDELLE EXPERIMENTS AT THE YEAR CENTRE.

Experimental Design

All experiments undertaken by all groups were carried out at the York Experimental Archaeology Research Centre (YEAR). As with all experimental archaeological research it is important to recognise limitations (Ferguson, 2010). None of the students who designed and executed these experiments had any prior knowledge of working with the materials used; however, occasional instruction by those with expertise (Little, Needham, Langley) meant some of these limitations were overcome when/where necessary as the projects progressed. Many of the specific archaeological materials discussed in the literature were unavailable for use as part of experiments and so close proxies were used as an alternative. Flint tools used during the experiments were produced at the YEAR Centre using Norfolk flint. The bones used for experiments were cow scapula (Bos taurus) sourced from a local butcher, meeting the ethical guidelines for sourcing animal parts, as set out by the University of York. The slate used was commercial domestic tiling slate. Wensleydale sheep wool and poodle fur were supplied by personal contacts and the natural roving was purchased online. Despite these limitations, the use of close proxy materials, along with the availability of expert guidance, ensures the results generated remain informative when trying to understand Palaeolithic rondelles.

Production

To address research questions 1 and 2, the three teams were required to manufacture their own rondelles. Two teams were tasked with investigating the production method itself, with reference to the archaeological evidence. One team focused on bone rondelle manufacture, the other on the production of comparable rondelles made of slate. Specific attention was paid to macro-wear traces relating to production, method and location of perforation, and the shaping of the finished artefact, with both groups aiming to produce rondelles of the circular type. Protocols which led to major deviations from these standards were considered to be unlikely methods of prehistoric production. All methods utilised a combination of scoring or grooving with flint flakes and percussive force, aimed at minimising production time and replicating the manufacture wear traces visible on the archaeological specimens. Three main methods were tested in making bone rondelles, and a single method was tested in making slate rondelles, described in turn below. It is worth noting that these methods are not exhaustive and contain elements which could be rearranged to form multiple variations on the same production techniques. The final methods were selected by the students to be the most expedient and potentially productive.

Making bone rondelles: “Prehistoric compass” method

With circularity in mind, the “prehistoric compass” method was inspired by the contemporary geometric instrument, with the aim of allowing an equal radius from a central perforation, fashioned conceptually from the available materials. This was achieved by drilling a hole into the scapula using a flint borer and then inserting a wooden peg (in this case an unmodified stick), which acted to secure the scapula in place and anchor it to the ground, but also acted as an upright rod, to which string and flint were attached. The flint attached to the string was stretched until taught to ensure the tool remained as close to equidistant as possible as it was rotated around the circumference repeatedly to create a scored mark in the bone (See Figure 2). A loose knot was selected in tying the string to the rod in order to prevent the string from wrapping around the wooden peg with each rotation. The length of the string was closely controlled and any breakages in the string resulted in careful restringing in order to maintain the same radial distance. After deeply scoring the bone, the scored line was deepened further and the blank removed via indirect percussion, using flint as “wedges” to extract the blank. The blank was then subject to supplementary grinding using a coarse rock to achieve a circular shape (See Figure 2).

Making bone rondelles: Stencil method

The stencil method was similarly sensitive to the form of the rondelle, but also the overshoot marks common on many of the archaeological scapulae from which rondelles were cut. An object was chosen as a stencil around which a stone tool could be moved to score the bone. In this case, a rounded stone was first selected, following the hypothesis set out by Conneller (2011), and subsequently a bone rondelle was used as a template for the next. The bone rondelle to be used as a stencil was first ground against a coarse stone block into a circular shape, giving the recursive process a refining quality, as the rondelle stencils became increasingly rounded and circular with each iteration (See Figures 3 a-b). After deeply scoring the bone, the scored line was deepened further and the blank removed via indirect percussion, using flint as “wedges” to extract the blank. The blank was then subject to supplementary grinding using a coarse rock to achieve a circular shape (See Figure 3ab).

Making bone rondelles: Freehand methods

The freehand method involved the use of no additional tools in the initial phase of working and consisted of scoring the bone with a flint tool, using no aides to create the scored edge or maintain or control the desired shape, other than personal skill. Each team attempted a novel from of the freehand technique, resulting in two distinct sub-methods. These two methods resulted in distinct macro-wear patterns on the scapula and are briefly described as two separate production techniques, both for wear evidence and for practitioner efficiency. Sub-method one attempted to carve out a circular rondelle by scoring a continuing curving line. Sub-method two varied subtly by scoring a series of straight connecting lines, producing a hexagonal cut-out, which was subsequently ground into a circular rondelle (See Figures 4 and 5a-d). After deeply scoring the bone, both teams deepened the scored line further and removed the cut-out via indirect percussion, using flint as “wedges” to extract the blank (See Figure 6). The blank was then subject to supplementary grinding using a coarse rock to achieve a circular shape (See Figure 7).

Making slate rondelles

The production of slate rondelles utilised an inverse method as compared to the bone. Bone scapulae were grooved to form the outline of the blank and then indirect percussion and further grooving used to release the blank. In the case of slate, the outline was engraved into the stone using flint in a similar fashion (in this case, using a freehand method) but the surrounding superfluous slate was knapped and struck off using small hammerstones (See Figures 8a-c slate) to reveal the final form. This was because the slate was far more brittle than bone, requiring a different strategy to release the blank.

Perforation and engraving of bone and slate rondelles

All rondelles were perforated after the blank was released from the parent material (See Figure 9-b) and a sub-set of rondelles were engraved, in particular those made in bone, which is an accurate reflection of the archaeological record. In the case of perforation, flint boring tools were used. Where the material was thin, a uniconcial strategy was sufficient, but where the blank was thick, a biconcial approach was adopted. As cow scapulae can be relatively thick, this may have heightened the need to use a biconical strategy. Engraving (See Figures 9c-d and 10) of bone surfaces was produced via the use of sharp flint tools, mirroring the process of scoring the outer edge of bone rondelle blanks, but using different amount of force to achieve different depths and thicknesses of groove, depending on the specific engraving and design.

Function

All three teams made rondelles, but one team also focussed their investigation on the potential function(s). To address research question 3, two published interpretations were selected from the literature to test: 1) the use in textile manufacturing as a spindle whorl and 2) the use of rondelles as thaumatropes.

Spindle whorls

Following Mårtensson *et al.*, (2006) experimental observation that spindle whorls can be effective at spinning yarn at weights as low as 4-18 g, bespoke rondelles were manufactured weighing 14 g each to facilitate their testing as spindle whorls. To test the ability of the rondelles to spin textiles, three fibres were chosen: dog (*Canis familiaris*) fur (5 g), sheep (*Ovis aries*) wool (5 g) and natural roving (pre-spun wool) (2 g). A 100 mm section of horse chestnut wood was carved to fit the central perforation and a 5 mm notch was added to the top to act as a hook to catch the fibres. Two experiments were conducted, one rondelle spinning roving and dog fur and the second roving and sheep wool. The wool and fur were separated into strands and any dirt removed beforehand. The fibres were then drafted into strands and the spindles dropped to spin the yarn; if after five attempts there was no success then the experiment was ended (See Figure 11a-d).

Thaumatropes

Following Azéma and Rivère's (2012) suggestion that rondelles could be used as thaumatropes, two rondelles approximately 50 mm in diameter were extracted from scapulae and perforated with a single central perforation. These blanks were then decorated with images of a juvenile bison and a chamois respectively. The images were engraved to a typical depth of circa 2 mm and were embellished with charcoal sourced from a wood fire to enhance their clarity (See Figure 10). Cordage was fashioned from raffia grass and two lengths of 425 mm were used to loop through the central perforation and act as the rotating element.

Results

The results of experiments conducted by the three groups in all experimental permutations are presented in Table 1. The data evidence appreciable differences in the time taken in working by method and by material, as well as perforation size and location across experimental rondelle permutations, designed for different functions. These specific results are discussed by experiment below.

Rondelle	Team	Bone/ Slate	Weight (g)	Diameter (mm)	Depth (mm)	Perforated	Decorated	Production/ Function	Time to produce (mins)
1	A	Bone	14	~45*	/	Y	Geometric	Function (whorls)	/
2	A	Bone	14	~45*	/	Y	Geometric	Function (whorls)	/
3	A	Bone	16,5	~50*	/	Y	Naturalistic	Function (Thaumatropes)	/
4	A	Bone	16,5	~50*	/	Y	Naturalistic	Function (Thaumatropes)	/
5	B	Slate	/	25	2	Y	/	Production	12
6	B	Slate	/	90	7	Y	/	Production	20
7	B	Bone	/	55	5	N	/	Production	124
8	B	Bone	/	60	8	Y	/	Production	383
9	B	Slate	/	28	3	Y	/	Production	26
10	B	Bone	/	57	4	N	/	Production	1080
11	B	Bone	/	24	5	Y	/	Production	180
12	B	Slate	/	20	2	N	/	Production	72
13	B	Slate	/	21	2	Y	/	Production	15
14	B	Bone	/	30	5	Y	/	Production	74
15	B	Bone	/	50	4	Y	/	Production	368
16	B	Slate	/	26	4	Y	/	Production	14
17	B	Slate	/	25	2	Y	/	Production	12

18	B	Slate	/	76	3	Y	/	Production	14
19	B	Bone	/	/	/	Y	/	Production	367
20	C	Bone	/	~73*	/	Y	/	Production (Compass)	491
21	C	Bone	/	~78*	/	Y	/	Production (Compass)	631
22	C	Bone	/	~56*	/	Y	/	Production (Stencil)	431
23	C	Bone	/	~51*	/	Y	/	Production (Stencil)	332
24	C	Bone	/	~51*	/	Y	/	Production (Freehand)	272
25	C	Bone	/	~50*	/	Y	/	Production (Freehand)	759
26	C	Bone	/	~49*	/	Y	/	Production (Freehand)	296
Total number of slate rondelles			8	* indicates that the diameter is an average between the max and min measurements					
Total number of bone rondelles			18						

TABLE 1. COLLATED DATA OF RONDELLES PRODUCED BY ALL EXPERIMENTS.

Producing bone rondelles

"Prehistoric compass method"

The 'compass' method resulted in relatively large rondelle diameters (~73 mm and ~78 mm) which is due to the nature of the technique; the ability to rotate the string around the rod has a minimum value before becoming impeded by the flint and the hand of the researcher. While the rondelles do fall within the maximum range of archaeologically recovered bone rondelles (Bellier *et al.*, 1991, p.6, p.15, p.17), such examples are rare, with the average being some 20 mm or smaller (Bellier *et al.*, 1991, p.6, p.15, p.17). The mechanical limitations of the technique, along with the average size mismatch, suggest this technique was unlikely to be used during the Pala eolithic.

The rondelles produced by this method took longer as compared to several of the freehand and the stencil method. The technique works the bone from one side only which differed to the other two methods which are capable of working both sides with relative ease, again suggesting this is an unlikely technique.

Another significant finding was that use of a compass produced few deviation marks, with the tool rarely 'skipping' out of the groove, unlike the archaeological example of the scapula from

Grotte de Saint-Michel d'Arudy and similar archaeological specimens where overshoot cut marks made during the marking out of the circular disc shape are clearly visible and very common (Bellier *et al.*, 1991, p.20). Whilst using a compass did enable a higher degree of circularity (variation: 1.7 mm) this was only marginal to that achieved using a freehand method (1.9 mm). It was possible to achieve a virtually central hole by eye without the need for a compass.

Rondelle	Technique	Max. Diameter (mm)	Min. Diameter (mm)	Difference (mm)	Distance of perforation from centre of rondelle (mm)
20	Compass	74,6	72,9	1,7	4
21	Compass	81	76	5	5
22	Stencil	58	54	4	4
23	Stencil	53,4	49	4,4	3
24	Freehand	53,4	49,8	3,6	2
25	Freehand	51	48,1	1,9	1
26	Freehand	51,3	46,2	5,1	0
Circularity and centrality shown by the difference in diameter values and the distance of the perforation from the true centre.					

TABLE 2. DATA COMPARING CIRCULARITY AND CENTRALITY BETWEEN PRODUCTION METHODS.

Stencil method

The stencil method produced shallow groove marks which would be joined to scoring from the reverse side of the scapula. Of note were the natural features of the scapula which made using a stencil uneven and the rondelles produced of different thicknesses. The spine of the scapula made carving particularly difficult and resulted in a visible ridge on one of the rondelles. To compensate, the researchers grooved from both sides of the scapula at various points, sometimes made easier by holding the bone to the light (See Figure 6). Again, the size of the rondelle was mechanically limited, in this case by the size of the stone used as a template, a limitation that was carried over to the bone rondelle blanks that were subsequently used as templates. Given the wide range of sizes encountered archaeologically, it is again unlikely that a stencil was routinely used. Indeed, a template could be feasibly cut freehand and then used directly as a template for the next rondelle blank if a similarity in size was important for some particular purpose, without the need for a stone. While the use of a stone cannot be ruled out, the lack of recovered stones with edge damage from contact by a moving flint tool, along with the mechanical limitations offered by the use of a stone, or the need for several stones of varying sizes to compensate, perhaps suggest that a freehand method is the more likely, in particular as there was only modest differences in the degree of roundness achieved.

Freehand method

The different protocols used for the freehand method showed a high level of variation in the macro-wear patterns produced. Rondelles 1 - 4 were cut out in a hexagon pattern, while rondelles 23 and 26 used a similar connecting line protocol, but deployed a varying number of lines to explore variation, experimenting with a pentagon and heptagon respectively. Although the finished rondelles were rounded and smoothed to remove the linear edges; the waste scapula shows the pattern and would be visible in the archaeological record. While the presence of "overshoot" marks was present using this approach, the shape left after removing the blank was appreciably more angular than archaeological scapulae with blanks removed, suggesting that while freehand is perhaps the most likely method of those tried, this sub-method is unlikely to be the exact technique used during the Palaeolithic.

The second type of freehand pattern used instead created a series of arcing connecting lines that sharply curved to create a roughly circular shape. The resulting macro-wear pattern created a distinctive "Catherine Wheel" like effect, with grooves radiating tangentially from each arc. Once the blank was removed, the resulting void was appreciably more circular in shape than the sub-method which used straight lines, which is more consistent with archaeologically recovered scapulae. Of the two methods, it is this latter sub-method that uses arcing, connecting lines that most closely matches the wear patterns observed in the archaeological scapulae and the shape of the archaeological blank cut from the scapulae. Of all methods of producing bone models, this method matches the greatest number of archaeologically observable variables most closely.

Producing slate rondelles: Freehand method

The creation of slate rondelles acts as an important contrast to the methods used in creating bone rondelles. By creating rondelles in differing materials, there is the potential to learn more about each method through comparison, linked to the specific attributes of the materials being worked. As only a single protocol was trialed in the creation of slate rondelles, and the material used was large industrial sheets, rather than the smaller and/or less regular shaped blocks that might be encountered within a natural setting, the results that can be drawn are necessarily speculative. The results suggest that it is possible to produce slate rondelles expediently, using only flint tools following a freehand method. As slate is brittle, the blank must be excised through a destructive technique that significantly fragments the parent block, leaving a distinctive pattern of debitage. As slate is a relatively soft stone, grinding it into shape was similarly rapid and readily achievable even by experimenters of limited experience. Perforation was similarly rapid and could be achieved via uniconcial drilling in only a short amount of time.

Production: Bone and slate compared

The experiments revealed that the production of rondelles using slate can be very rapid when compared to bone, regardless of the method used in the case of the latter. Even with a smaller sample population; the average and range (See Figures 13 and 14) are significantly different.

However, as the slate method used was destructive in releasing the rondelle blank, more rondelles could be produced from a similar quantity of material when working bone compared with slate. One factor could be the skill level of the researchers; slate is soft and easy to work with stone tools, suggesting that even unskilled working can produce a rondelle quickly, whereas the manufacture of bone rondelles produced a wide spread of times as low as 74 mins and as high as 1080, suggesting the working of bone was more sensitive to experience and technique. With greater experience, slate rondelles might have been spaced differently on the block, designed so as to minimise wastage when the block was broken the release the blanks, which may change the relationship between efficiency and the material used to make the rondelle blank.

Production and the link to function

Once a rondelle blank has been produced, there are a number of variables that can be manipulated, many of which might relate to function. These variables include size and roundness, with grinding being a uniformly effective means of controlling the final size, shape, and weight of the rondelle, regardless of the material used, as well as the location, size and number of perforations. There was no correlation between the technique used and the circularity of the finished result across all experiments. The production methods also failed to correlate circularity with the centrality of the perforation. For example, whilst rondelle 26 showed the maximum difference in diameter, there was no deviation from the true centre with the perforation. The "compass method" showed no significant advantage over freehand in a comparison of circularity, with a difference of 1.7 mm and 1.9 mm respectively.

Function

The results of function experiments are limited to bone, but provide some insight into the potential functional application of rondelles. Whilst the number of rondelles used in testing, and the range of variables tested as a result, are limited, the data produced do hint at the possible functionality of rondelles.

Thaumatropes

	Test Number										
	1	2	3	4	5	6	7	8	9	10	Average Number of Rotations (per second)
Rondelle 3	4,8	4,3	4,2	4,8	4,4	4,3	4,5	4,6	4,6	5	4,5
Rondelle 4	4,8	5,1	4,2	4,5	4	4,9	4,7	4,3	4,6	4,9	4,6

TABLE 3. DATA OF ROTATION ATTEMPTS AND SPEEDS FOR THAUMATROPE TESTS.

For a thaumatrope to function successfully, the device must rotate fast enough for the human eye to maintain persistence of vision; the image can be retained at a speed of 0.232 seconds (Ferry, 1892). In testing, the rondelles managed an average rotation of 4.6 per second, or 0.217 seconds per side. This suggests that rondelles, decorated with appropriate imagery, are capable of acting as thaumatropes. Further testing is required to establish if the size and shape of the rondelle, the raw material used, as well as the specific placement and number of perforations, makes a significant difference to rotation speed, and so functionality as a rondelle. Given the diversity in the size, shape, weight, and perforation location of bone rondelles in particular observed in the archaeological record, there is scope for future experimental research to explore this possible function in more specific detail to further contextualise the results. That rondelles could be made to function as a rondelle without particular sensitivity to these criteria perhaps suggests that a diversity of shapes, size, weights and peroration configurations could be made to function effectively in this way.

Spindle whorls

Rondelle	Material	Attempt Number	Weight of textile fibre (in grams)	Time spun for before breaking (in seconds)	Length (in millimeters)
1	Wensleydale Sheep Wool	1	2	319,6	274,1
	Roving	1	2	181,3	810
2	Dog Fur	1	5	1,1	0
	(Poodle)	2	5	0,38	0
		3	5	0,21	0
		4	5	0,34	0
		5	5	0,02	0
	Roving	1	2	127	190
		2	2	376,6	908

TABLE 4. DATA OF SPINDLE TESTS SHOWING LENGTHS OF YARN AND TIMES TAKEN.

As highlighted in Table 4, the rondelles were capable of producing a spun yarn from sheep wool, but not from dog fur. This is probably a result of the length of the fur used and the unfamiliarity with the procedure on the part of the researchers. In principle, longer dog fur should be capable of producing a spun yarn. Similarly, the time taken is likely to fluctuate with the skill of the experimenters. With the successful completion of a length of wool, there is a positive proof of concept that rondelles are, in fact, capable of acting as spindle whorls. Further experimentation will be required to extend this line of enquiry to test realistic quantities of fibre and to investigate results when using period specific materials. Materials such as horse hair, mammoth hair, or plant fibres, might provide different results to the proxies used for this experiment. In keeping with the result for rondelles, a greater quantity of experiments, using a range of rondelles that fluctuate by material, size, weight, and perforation quantity and location would also be valuable in expanding the results.

Discussion

The experimental archaeological research presented here focused on understanding both bone and slate rondelle production techniques, as well as exploring two commonly proposed theories surrounding their function: as thaumatropes or spindle whorls.

Several participants, organised into teams, worked on replicating manufacture techniques using different methods: compass, stencil, and freehand.

Compass vs stencil

The experimental data produced suggests that whilst technically possible, the compass method is the least likely to have been used archaeologically. This method was cumbersome to execute, resulting in greater time taken in producing each rondelle, and with frequent breaking of the string compounding this, as well as limiting the control over the rondelle size produced, resulting in a minimum diameter. Conversely, it created greater control over the execution of the engraved lines, producing highly regular circles with greater ability to achieve a centralised hole, albeit marginal to that which can be produced by eye with the freehand method. If the manufacture marks visible on the Grotte de Saint-Michel d'Arudy are representative of how most bone rondelles were produced, then it is highly unlikely that a stencil was used as this method does not produce the same overshoot cut marks, best described as looking like "Catherine Wheels", when carving out the circular disc form.

Slate vs bone rondelle production

Whereas bone rondelles took on average 405.54 minutes to make, even accepting the fact the makers were unskilled in rondelle production, it is clear that rondelles made from this material took considerably longer to produce than their slate counterparts. In fact, our experiments would suggest that slate rondelle manufacture can best be described as expedient. Interestingly, the manufacture of slate rondelles is, in effect, the inverse of that of bone rondelles, with their form realised through a process of reduction of "unwanted" slate, gently hammering out a circular form; not unlike production techniques identified for Mesolithic shale beads from Star Carr (Needham *et al.*, 2018).

Function: Spindle whorls

The results from the function experiments testing use of rondelles as spindle whorls certainly suggest these objects were capable of spinning a length of sheep wool into yarn, although not dog fur. Given that the whorls rotate centrally around an axis, it is important to their function that they sustain a rotation for a period of time which requires symmetry in the rondelle shape. This ability, to stay in rotation around the axis, is a function of the mass and the distance of the rondelle from the axis, also known as the *mass moment of inertia* (Keith, 1998). Thus, to prevent oscillations, the whorl needs to possess symmetry, both centrally and in its diameter, which makes these variables crucial in the production method. Maintaining symmetry can be difficult to attain where the material is naturally uneven across the surface, such as bone.

Figure 12 shows the relationship between the centrality of perforation and the circularity of the rondelles across different production methods. Interestingly there is no correlation between centrality and circularity, with freehand showing both the greatest and least divergence. This suggests that knowledge of spindle whorl function, the identification of the crucial technical requirements and the skill to produce the whorl is more important than any one particular production method. Further investigations could utilise different materials, such as stone, in order to increase the mass of the rondelle.

Whilst a broad variety of functions has been previously proposed for rondelles, our experiments were limited to exploring just two. Previous research has made a strong case for rondelles functioning as thaumatropes (Azéma and Rivère, 2012); results from our research support this theory, with carved figures taking on an animated appearance when the rondelles were strung and spun. However, rondelles can serve as functional spindle whorls, and thus their utility in spinning fibres cannot be ruled out as possible function.

Future Directions

The results generated highlight the value of using an experimental approach to test amongst a diverse range of theories pertaining to the production and use of rondelles. Future research might involve microwear analysis of used replicas which could be compared against wear traces on better preserved archaeological specimens, helping elucidate information on their function(s). The use of further permutations of experiments, in particular manipulating variables in the rondelles used to assess function, could aid in this high-resolution analysis, by providing highlights of specific comparative data sets. This expansion in the range of variables manipulated in the assessment of function would further aid in establishing if sub-elements of rondelles are particularly sensitive to functional constraints, or perhaps if elements of rondelle morphology reflect cultural choice.

While the study has highlighted potential differences in the production method for rondelles made in bone and soft stone, it is less clear whether selecting different materials reflects changes in function. It is feasible that material properties afforded by stone versus bone were considerations in their intended use. However, the marked spatial patterning in their distribution, with slate examples being especially common in Germany (Bosinski, 1977), may hint at a divergence in the material selected being linked to cultural differences by region. While the experiments presented here focused on the testing of two theories of how rondelles might have been used - as thaumatropes and as spindle whorls - there are further possibilities to test, especially in relation to their potential role in personal ornamentation, and functional and/or decorative elaboration to clothing, such as a button or toggle (Bétirac, 1952). Here microwear/experimental archaeology would be important methods to utilise in facilitating high-resolution comparison of the experimental objects produced against the archaeological specimens.

Conclusion

The experimental results suggest that rondelles could be made freehand with no need for a stencil, as has been suggested in previous studies. Similarly, use of a “prehistoric compass” method has been shown to be not only unnecessary for achieving circularity of the disc or centralisation of the hole, but unlikely due to the limitations this method proposed on achieving a smaller rondelle. Whilst questions remain about the function(s) of rondelles, with a likelihood that these objects may have served a variety of functions, we have established that in addition to performing well as thaumatropes, use as spindle whorls is a strong possibility. That rondelles could be made to function as either rondelles or spindle whorls without specific control over many of the variables, such as number of perforations, or size, perhaps suggests a cultural role for at least some of the variances observable in the archaeological record.

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stone

Country United Kingdom

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Gallery Image

FIG 1. UNIVERSITY OF YORK ARCHAEOLOGY STUDENTS WORKING ON RONDELLE EXPERIMENTS AT THE YEAR CENTRE.

FIG 2. PHOTO SHOWING “COMPASS METHOD” IN ACTION.

FIG 3AB. STONE AND RONDELLE STENCILS.

FIG 4. FREEHAND TECHNIQUE - “CATHERINE WHEEL” WORKING TRACES PRODUCED IN THE PROCESS OF SCORING THE EDGE AND EXTRACTING THE RONDELLE BLANK.

FIG 5A-D. FREEHAND TECHNIQUE - “HEXAGON”.

FIG 6. REPLICA RONDELLE BLANK WITH DEEP SCORING TO DEMARCATE THE EDGE BEFORE WEDGING WITH FLINT TOOLS TO RELEASE THE BLANK.

FIG 7. A SERIES OF SHAPED/GROUND BONE DISCS.

FIG 8A. REPLICA SLATE RONDELLE PRODUCTION SEQUENCE.

FIG 8B. REPLICA SLATE RONDELLE PRODUCTION SEQUENCE.

FIG 8C. REPLICA SLATE RONDELLE PRODUCTION SEQUENCE.

FIG 9. PERFORATION AND ENGRAVING OF REPLICA BONE RONDELLE.

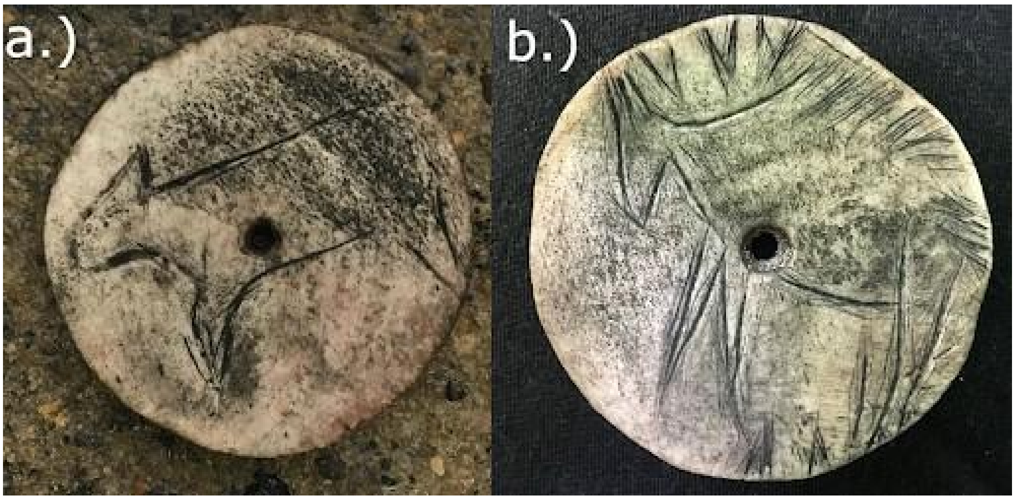

FIG 10. ENGRAVED REPLICA BONE RONDELLES.

FIG 11A-D. REPLICA RONDELLE USED EFFECTIVELY AS A SPINDLE WHORL.

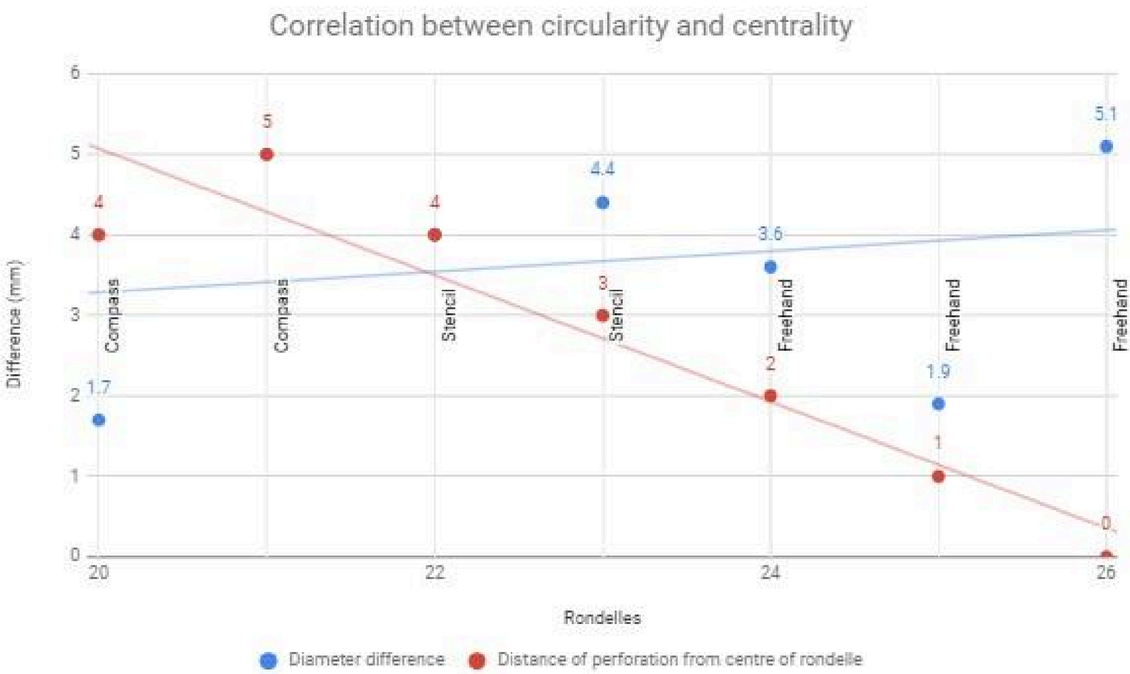

FIG 12. GRAPH SHOWING CORRELATION BETWEEN CENTRALITY OF PERFORATION AND THE CIRCULARITY OF DIFFERENT PRODUCTION METHODS.

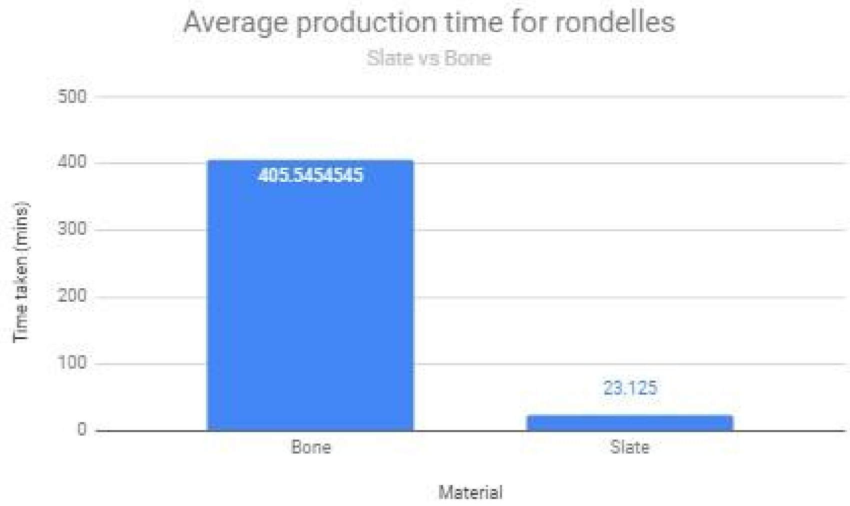

FIG 13. GRAPH DISPLAYING AVERAGE PRODUCTION TIME OF SLATE AND BONE RONDELLES.

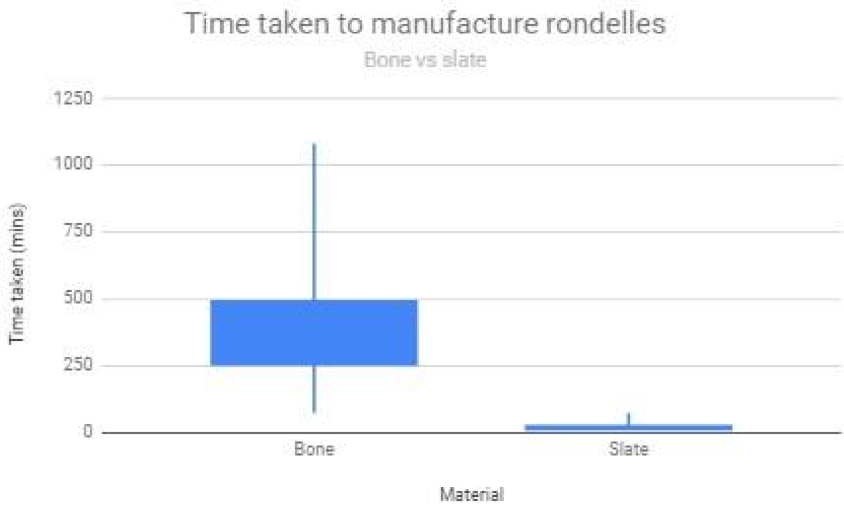

FIG 14. GRAPH SHOWING RANGE OF PRODUCTION TIMES OF SLATE AND BONE RONDELLES.