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A Return to the Wheel: Rethinking Experimental Methodologies for the Study of the Potter's Wheel

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A R T I C L E I N F O

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A B S T R A C T

Research into the study of wheel-making techniques has grown, but studies of the tool or the wheel and its properties have remained understudied or considered insignificant until recently. In order to develop this research, the wheel and its practicalities, such as the physics, should be incorporated more into research of making techniques. Through the application of *chaîne opératoire* and experimental archaeology, this research questioned whether different wheel types produce different macroscopic traces on pots produced by the same technique. There are several results presented here that can shed light on the way archaeologists should investigate and understand early wheel potting, in particular the physics of rotation, which has received minimal attention as a result of a predominance for researching techniques over the tool (the wheel). The application of this research is used to better understand pottery and potter's wheels from their adoption and development during the Middle Bronze Age on Crete, c. 2000 to 1500 BCE. A revision of experimental work and methodologies is combined with archaeological experimentation in order to help clarify not only how tools such as the wheel were used but subsequently what roles these craftworkers played in past societies.

1. Introduction

Recent scholarship concerning the analysis of pottery-forming techniques has argued that the tool, in this case the potter's wheel, is not a significant variable affecting the results of analyses on macroscopic traces. However, in the words of Van der Leeuw (1993, p.240), "techniques cannot be studied in isolation, but should [rather] be seen as the arena of mediation between what is materially possible or impossible". Therefore, any investigation into wheel-making techniques cannot exist without analysing the wheel: including its mechanical, physical, and even experiential properties.

For my research, experimental archaeology was combined with the analytical tool of *chaîne opératoire* to interpret the potter's wheel and conical cups from Crete during the Middle to Late Bronze Age when the wheel was introduced, and the technology developed (c. 2200 to 1500 BCE). The *chaîne opératoire* approach was utilised in order to understand and isolate making techniques on the wheel in the production sequence and subsequently for investigating the choices made in terms of techniques and wheels (Dobres, 2000; van der Leeuw, 1993; Roux, 2019). This was then teamed with an archaeological experiment aimed at assessing the variable of the wheel type. Situated between actualistic and scientistic (Outram, 2008), the experiment was designed to incorporate accurate materials (clay) with hypothesised techniques, and pottery wheels propelled by mechanical, electronic or human input.

The conical cup was chosen as the ideal vessel as it was perhaps the most ubiquitous pot from the Bronze Age on Crete, found in a wide range of contexts from "palaces" to domestic, funerary and ritual spaces (Gillis, 1990a and 1990b). Moreover, their simple, open shape and small size means that they require fewer gestures for forming and shaping on the wheel than a taller or closed shape. Their production also embodies the major technological and societal changes happening during the Bronze Age, such as urbanisation and craft specialization (Schoep, 2004, p.262; 2006, p.54; Tomkins and Schoep, 2012, p.6; Weiner, 2011; Hamilakis and Sherratt, 2012; Choleva, 2012; 2018; Christakis, 1996). As such an unassuming vessel type in terms of aesthetics and manufacture, the fact that this complex and highly specialised technology of wheel-making technology

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Figure 1. Conical cup in assemblage from Minoan Unexplored Mansion (Popham, 1984a; SMP.11689; KN.SM.3455). Reproduced with permission from the British School at Athens. Photo by author.

trickled down to or, perhaps, began with the manufacture of these vessels is a testament to their importance.

Observation of macroscopic traces from replica pots produced by the author were used to help inform interpretation of how conical cups of a specific period (Late Minoan IA, c. 1500 BCE) from an assemblage in the South Corridor of the Minoan Unexplored Mansion (MUM) in Knossos, were manufactured on the wheel (Popham, 1984a; Figure 1). The MUM is a large complex located west of the palace of Knossos. Once connected to the Little Palace via a bridge (Hatzaki, 2005), the MUM yielded a number of finds related to industrial activities, including incredibly fine pottery, potter's wheels, as well as large amounts of bronze working materials (Popham, 1984; Christakis, 2019). This particular assemblage contains pottery dating to the Late Minoan IA of Bronze Age Crete, during which conical cups had reached a standardisation in shape, size and manufacture that was not seen in previous phases (Hatzaki, 2007, p.167). The MUM pottery in general remains heavily selected, and as a result the conical cups that were chosen to be kept tended to be complete cups, with only a few being broken.

The experiment presented in this paper was designed to assess three different wheel types following three techniques that scholars have previously suggested were possibly in use during the Late Minoan IA period (*cf.* Jeffra, 2011). The method by which a wheel rotates and the mechanical components which enable rotation can affect traces left on pottery. While an electric wheel provides stable rotation with a motor, a kick or stick wheel delivers rotation through non-motorised means. From this observation, the experiment was designed to isolate the specific variables of how non-motorised wheels rotate and what effects the physics of their rotation have upon macroscopic traces left on pottery. The results suggest that the variable of the wheel, and more specifically the nature of its rotation, should be more seriously reconsidered as a factor that affects macroscopic traces left on pottery.

In this paper I briefly review the current state of knowledge, highlighting the origins of the disparity between studies of the technique and tool, and how they have affected scholarship. Next, I consider the evidence for the wheel on Crete and discuss their characteristics before detailing the experiment conducted at the Centre for Experimental Archaeology and Material Culture (CEAMC) at University College Dublin. A few key results will be presented and then discussed with aspects of the wheel that might be considered within the context of Cretan archaeology, skill from the perspective of the experimenter and the ancient potter, and pottery technologies.

1.1 The study of wheel techniques and tools

Many of the new methodologies for studying pottery technology were developed during the 1980s and promoted the importance of techniques over the tool. They were founded upon on archaeological and ethnographic research by scholars such as Anna Shepard (1956), Hélène Balfet, and others working in places such as Crete (Thrapsano and Margarites; Franchet, 1917; Xanthoudídes, 1927; Hampe and Winter, 1962), the Maghreb in North Africa (Balfet, 1965; 1984), the Netherlands (Van der Leeuw, 1976a) Pakistan (Rye and Evans, 1976) and India (Roux and Corbetta, 1989). Indeed, Sander Van der Leeuw noted in 1993 (p.243) that few scholars had conducted comparative research between forming techniques, with the single exception of Balfet in 1965 and 1984. Yet, it is possible that Van der Leeuw himself is one of the few scholars of the time to discuss and explore the mathematics as well as physics of rotation in his *Studies in the Technology of Ancient Pottery* (1976b).

By the later 1980s, this research coalesced into studies in which the individual potter became the subject of analysis, and his or her techniques became the variables.

Archaeologists sought evidence of combined techniques, distinguishing between primary and secondary techniques (Shepard, 1956, p.351), and what traces these left on the pots. From this distinction, techniques began to supersede the tools as significant aspects for the study of past potters. In *The Many Dimensions of Pottery*, Balfet (1984, pp.188–189) concluded that the tool or the wheel was not sufficient for "giving account of, or identifying, a specific operational sequence" within the production sequence. As a result, the information obtained from the tool is often "ambiguous in the absence of other factors" (Balfet, 1984, p.189). The techniques of throwing and coiling then can be conducted on any device. It was, therefore, pointed out by Van der Leeuw following this paper that the wheel is more of a constraint rather than a determining factor (Balfet, 1984, p.200).

Subsequent research was built upon this assertion. On the cusp of the 1980s, Roux and Corbetta (1989) conducted a learning-study with Indian potters in which they found the throwing technique to be more difficult to learn than coiling, and therefore in the past there must have been an intermediate technique that allowed for increased usage and understanding of using centrifugal force. Thus, it was argued that the development of wheel-thrown pottery in the 4th to 3rd millennia BCE was "comparable to the stages of apprenticeship in wheel-thrown pottery today" (Roux and Corbetta, 1989, p.7). The result of this research was the development of methods for identifying the macroscopic and microscopic traces between wheel made and handmade pots, as well as between wheel-thrown and wheel-fashioned ceramics. Roux and Courty (1998) developed four methods involving the incremental addition of rotational kinetic energy (RKE) to successive stages of coil building.

The methodology soon became established and archaeologists on Crete also began to challenge old dichotomous categorisations of techniques for Minoan pottery (Knapett, 1999). More recently, it was applied rigorously to ceramics from Bronze Age Crete (and Cyprus) by Caroline Jeffra (2011 and 2013). It is one of the most exhaustive studies to date on the techniques of wheel-fashioning. She argued that because older experiments tended to focus on the capabilities of the device rather than the products, studies of tools cannot alone clarify "exact formation techniques", they only elucidate different aspects of the production sequence (Jeffra, 2011, p.55). She went onto write that "utilising" an appropriate wheel device for Minoan vessels without verification that similar devices were available and used in the same way on Crete (or Cyprus) would lead to a disparity in the value of her typeset. Therefore, a modern electric wheel was used for her experiments (Jeffra, 2011, p.105).

Although an electric wheel may act as a controlled variable during an experiment, it is demonstrated here that different macroscopic traces can be produced by this type of wheel when compared to more traditionally powered wheels. Not only does this necessitate a re-investigation into the basic properties of Minoan wheels and how they affected manufacture; it also requires further reconsideration of experimental methodologies involving the wheel for the study of ancient pottery techniques.

1.2 Cretan Bronze Age Archaeology, The Evidence for Potter's Wheels

In Cretan archaeology, few truly engaged with both the tool and the technique until the later 20th century (Knappett, 1999). In the early 20th century, Louis Franchet (1917, p.21) suggested that a technique of hand-building was combined with rotation in the Middle Minoan (MM) II period (circa 1900–1700 BCE). Evans (1921) and Dawkins (1903) also made note of the fact that the wheel was not exclusively for throwing, and yet many publications afterwards only distinguished between hand and wheel made, as Doniert Evely (2000, p.286) noted in his *Minoan Crafts*. Despite the sheer number of ceramic sherds (and studies) from Bronze Age Crete, efforts were concentrated far more on distinguishing stylistic characteristics than manufacture (*cf.* Betancourt, 1984).

Recent experimental research by Jeffra (2011) in Knossos, Myrtos Pyrgos and Palaikastro, as well as Todaro (2016; 2017 and 2018) and Caloi (2011) at Phaistos have begun to clarify the analysis of macroscopic forming traces on Bronze Age Cretan pottery. Simultaneously, pottery typologies have also avoided this dichotomy, and have identified the likely presence of multiple wheel-making techniques such as in more recent publications by Knappett and Cunningham (2012) on Palaikastro, and Choleva (2012 and 2018) on Lerna and other mainland Greek sites. Yet, the tool still remains understudied with the exception of work by Evely (1988; 2000), Morrison and Park (2007) and Evely and Morrison (2008), whose experiments focused on the wheel and its design, drawing heavily from Evely's own research into the Minoan technology and crafts.

Until the evidence was categorised by Evely, early descriptions of potter's wheels often ranged from terms such as "round table" by Hawes (1908, p.42) to being differentiated into the misleading "fast" and "slow" wheels. The catalogue of Evely (1988 and 2000), however, does an excellent job of organising Minoan wheels by their design. The Early Minoan II to III (EM; circa 2400 to 2100 BCE) periods are characterised by using mats made rarely of ceramic, and instead they were likely wood or other organic materials. One of the earliest ceramic examples comes from Room 49 at Myrtos Fournou Koriphi (Figure 2, in which eight "turntables" were found (Warren, 1972, pp.261–262). One *tournette* or turntable had a socket on the underside, and dates to EM IIB or circa 2200 BCE (Warren, 1972, no. 105), and is one of the earliest examples of what Warren called a "freely revolving" wheel. It is possibly a predecessor to later freely revolving designs according to Warren (1972, p.261).

From MM IB or circa 1900 BCE onwards, scholars such as Sinclair Hood (1961–1962; 1966) and Betancourt (1985) argued for the arrival of the so-called "fast wheel". Many of these potter's wheels were grouped into Evely's (1988) Type 3C category. These were the most widespread on Crete

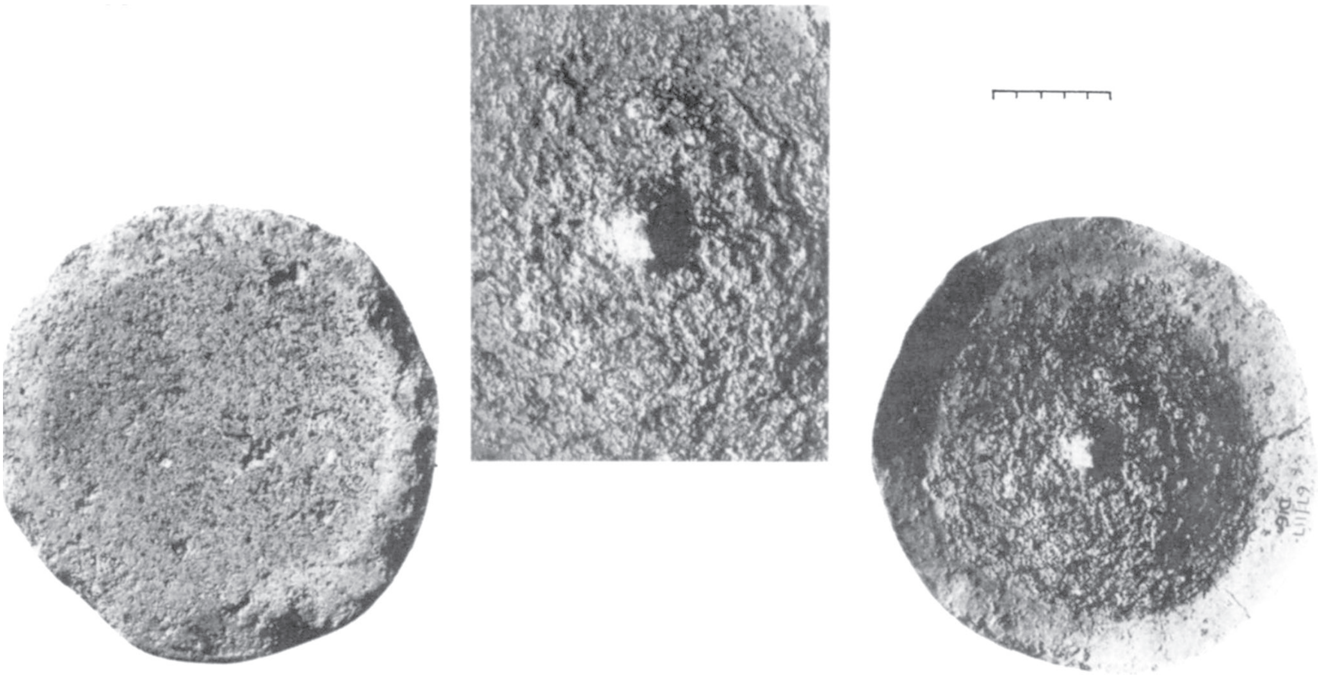

Figure 2. Myrtos Pyrgos wheel no. 105 (after Evely 1988, Plate 11; Warren 1972, p. 261–262) Reproduced with the permission of the BSA and Professor Peter Warren.

during all of the "palace" periods, circa 2000 BCE onwards. They were characterised by flat, plain tops with a socket on the underside. With the addition of a collar, this type of wheel was what Evely called the hallmark and the fullest expression of what was capable at the time (Evely, 1988, pp.100–101; 2000, p.283). Proportions ranged from 30–40 cm in diameter, with some as large as 60–70 cm (Evely, 1988, p.101; Figure 3). Like the EM period much of the device was made of organic materials, which makes interpretation of the design difficult. As a result, archaeologists have tended to rely on ethnographic work and modern potters.

Within the transition from Evely's Type 1 to Type 3C, there seems to be an increase in the development of a wheel design that uses almost exclusively a ceramic wheel head. From the MM I period onwards, the wheel begins to develop new features such as a collar, perforations or at times scalloping on the edges as seen at sites such as Tylissos (Hazzidakis and Franchet, 1921, Figure 39 – MM I), Phaistos (MM I–II; Evely, 2000, numbers 48 and 49; Pernier and Banti, 1956, Figures 234a and 234b; Figure 4), Knossos (Figure 5; Popham, 1984, pp. 84 and P74), and Gournia (MM III to LM I; Hawes, 1908, numbers 32 and 33). Other examples

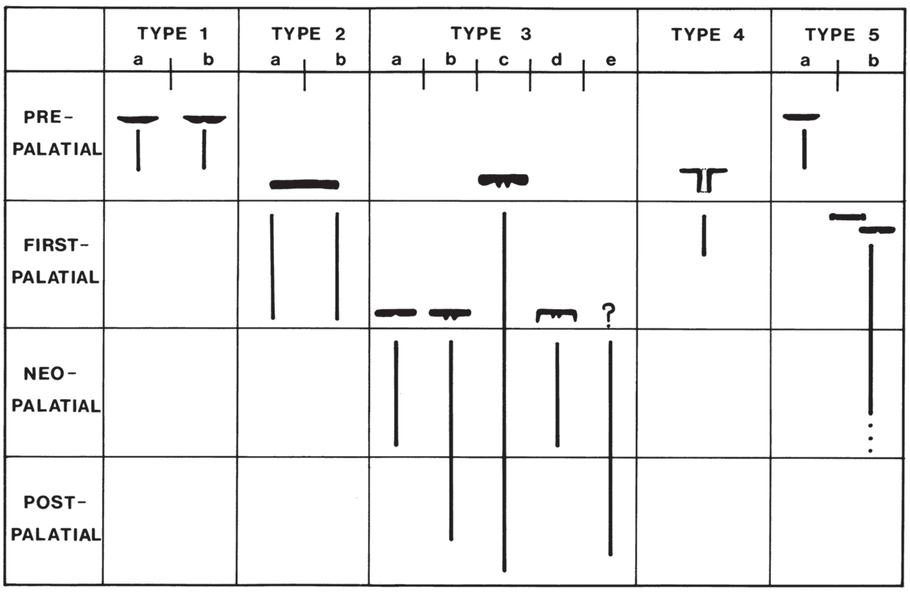

Figure 3. Evely's typology of Minoan wheel-head designs (after Evely 1988, Chart 1). Reproduced with the permission from the BSA and Dr Doniert Evely.

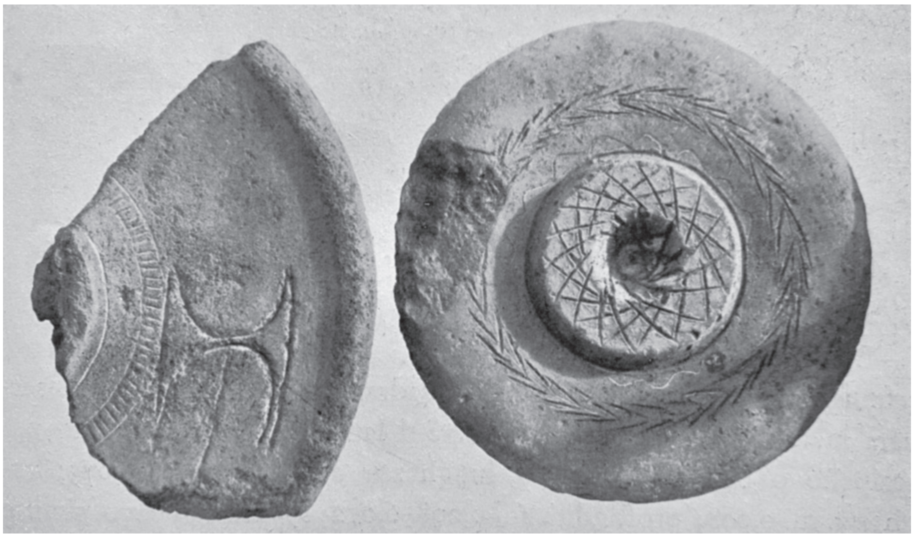

Figure 4. Middle Minoan I–II Wheel heads from Phaistos; the one on the right has a polished top surface as well (Pernier and Banti 1951, p. 268, figure 234a and b). Reproduced with the permission from the Scuola Archeologica Italiana di Atene.

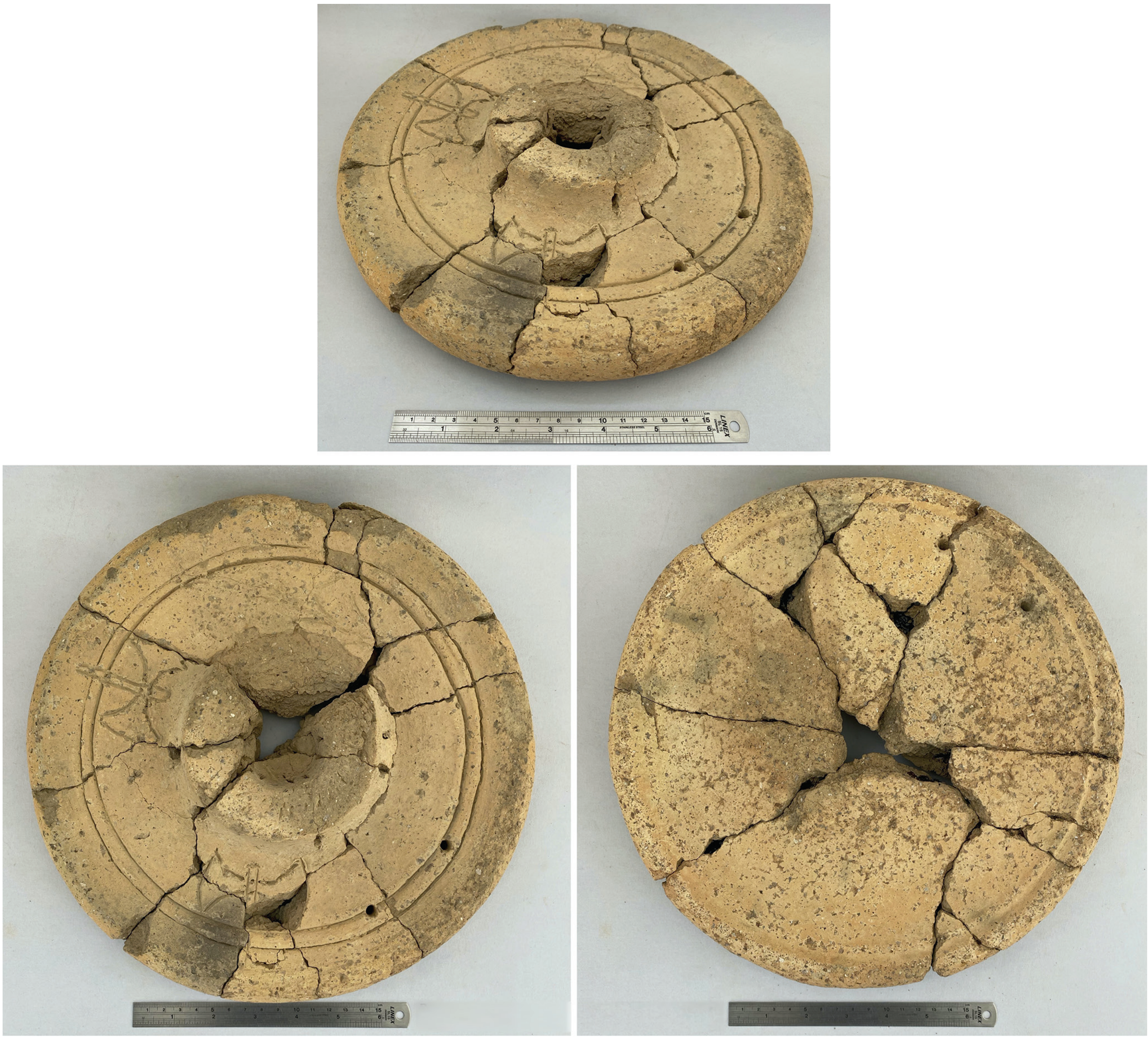

Figure 5. Late Minoan I wheel head from Minoan Unexplored Mansion (Popham 1984, p. 84, no. P74; SMP.656); note perforations through wheel-head. Reproduced with the permission from the BSA. Photo by author.

Figure 6. Late Minoan III wheel head from the Minoan Unexplored Mansion (Popham 1984, p. 299, P17; SMP.738). Reproduced with the permission from the BSA. Photo by author.

come from MM III Ayia Triada (Evely, 2000, number 44), MM III–LM I Vathypetro (Evely, 2000, number 51), Sissi (Jusserat, 2009, Figure 8.3), LM III Kritsa chamber tombs (Evely, 2000, number 61; Kanta, 1980, p.134) and LM III at the Minoan Unexplored Mansion (Popham, 1984, pp.299 and P17; Figure 6).

Despite several pieces of evidence for the wheel heads, the lower portion of the design remains elusive archaeologically. For example, basal sockets are often found and could be part of the shaft connecting to the wheel head, but they might also resemble architectural features (Evely, 1988, p.117). However, in experimental work by Evely and Morrison (2008, p.284) and Morrison and Park (2007), the wheel design was based upon pieces of evidence from a pit at Mochlos which contained a bat (a removable disc to place on top of a wheel head), a basal socket, and stone polishers (Soles, 2003). Their experimental wheel design utilised a crossbar and rotation which was supplied by the potter or an assistant, but their research remains to-date one of the few experiments with Minoan wheels (*cf.* Caloi this volume and 2019). Furthermore, their wheels represent one or variations of one possible design. While ethnographic examples of kick wheels from Thrapsano, Crete demonstrate that a heavy piece of wood can work in a kick wheel design (Hampe and Winter, 1962; Xanthoudídes, 1927; Figure 7), more investigation and experimentation is required to determine whether this was the case during the Bronze Age on Crete.

2. Methodology

The experiment discussed here aimed to contribute to this need for more research. It was therefore directed at the isolation of problems, or in other words, attempted to falsify existing hypotheses which suggest that the wheel or tool is not as significant as the technique (Popper, 1963). Such an approach was guided by the following questions:

1. What effects do different types of wheels and their rotational characteristics have upon the manufacture of pottery?
2. What type of rotation was applied to the production of Bronze Age Cretan pottery?
3. How was this applied to the production of conical cups?

The two methodological tools of this research were the analytical tool *chaîne opératoire* and experimental archaeology, each of which provide opportunities to investigate production sequences and evidence at each stage of production (Lemmonnier, 1986; Dobres, 1999 and 2000; Coles, 1979). They help to elucidate some of the choices made by potters in the past including factors such as the type of clay, technique and, most relevantly, the type of device or tool (Gosselain, 2018). Through an analysis of each aspect of pottery technology, the choices made in each stage of production become meaningful, aiding interpretation of how raw materials are transformed into artefacts (Gosselain, 2018, pp.4–5). Technologies are also social phenomena in which immaterial ideas coalesce with physical materials and become articulated through human action and choice (Sillar and Tite, 2000, p.2; Pfaffenberger, 1988, p.241). With experimental archaeology, the reproduction of past objects, processes, and technologies can then be used as analogies for the study of the archaeological record (O'Sullivan *et al.*, 2014, p.115; Ascher, 1961; Tringham, 1978; Coles, 1979; Reynolds, 1999; Sillar and Tite, 2000). Moreover, *chaîne opératoire* is not only the identification and classification

Figure 7. Traditional potters in Thrapsano, Crete, as shown by Xanthoudídes in 1927 (p. 130, Plate XX).

of processes or stages in production, because each one requires knowledge, experience or, indeed, a skillset that is linked to human action (Pelegrin, 1990). When looking at an archaeological deposit, the identification of gestures and tools that might have led to specific traces left on pots can be hypothesised.

Prior to the experiment, I was able to train for 9 months daily in potting techniques including wheel-throwing, wheel-fashioning, and some hand-making while at CEAMC in UCD. The wheels I trained with were the same wheels used in the experiment. However, I did not have the opportunity or time to train with the Ferrycarrig wheel prior to using it for the experiments. While this was not enough time to master wheelmaking techniques, the level of experience acquired on each wheel can be considered as an opportunity to observe traces from the perspective of an apprentice, particularly in the case of the Ferrycarrig wheel. Given the poor quality of manufacture often ascribed to conical cups, it might also be

Figure 8. Potter's wheels used during the experiment: (from left to right) kick wheel, Ferrycarrig wheel and electric wheel. Photos by author.

Table 1. Methods, wheels and alphanumeric code for the experimental dataset.

Technique/Wheel-type	Electric wheel	Kick wheel	Ferrycarrig wheel
Wheel thrown "off the hump"	1A (1-10)	2A (1-10)	3A (1-10)
Wheel fashioned: Method 3	1B (1-10)	2B (1-10)	3B (1-10)
Wheel thrown: small ball clay	1C (1-10)	2C (1-10)	3C (1-10)

considered just how each variable (clay, wheel, techniques, and the potter) affects the production and macroscopic traces.

During the experimental research, a total of 90 conical cups were produced, ten each for the three wheels and three techniques. The clay for the cups was sourced from Valleymount, Co. Wicklow, Ireland, in the Poulaphouca reservoir where the Liffey and Kings River valleys meet. The clay was processed by hand, sieved through a 1-mm screen, wedged at least 100 times, and left to cure in plastic bags for around two-three weeks before use. Conical cups found at several sites are made up of a range of clay recipes but often they are raw clay tempered with non-plastic inclusions around 1 mm (Day and Kilikoglou, 2001). Once made, all cups were fired to 900 degrees Celsius, studied whole and then broken to analyse the sections.

The techniques employed were wheel-coiling method 3 of Roux and Courty (1998), pure wheel-throwing from a small ball of clay, and "throwing off the hump". It was not possible

Figure 9. Experimental data set with traces highlighted: technique 1C above (wheel thrown on the electric wheel) technique 3C below (wheel thrown on the Ferrycarrig wheel). Photo by author.

or necessary to reproduce and analyse cups based upon more than one wheel-fashioning technique as Jeffra (2011, pp.158–160) argued from her experiment that method 3 was likely the most frequent technique in use between the MM III and LM I period, the date of the archaeological assemblage under analysis here (Popham, 1984; box number KN.SM.3455).

Most importantly, three different types of wheels were used: an electric wheel, a foot-pedal operated kick wheel (Arden Pottery Wheel Company), and the "Ferrycarrig" wheel, which was a kick wheel with a sandstone "flywheel" made at the Ferrycarrig Irish National Heritage Park in Wexford, Ireland (Figure 8; Table 1). Each wheel has its own physical properties in terms of their type of rotation including any associated, optimal gestures or postures. While the electric wheel is steady and designed to maintain rotation under constant pressures during pure wheel-throwing, the kick and Ferrycarrig wheels are powered by foot or hand that necessitates a modification of gestures during the making process.

3. Results

Through a simple experiment, the type of wheel and its rotational properties made a quantifiable difference in the macroscopic traces across three techniques and three wheel-types. The first key result is the observation that cups thrown on the electric wheel and cups thrown on the Kick and Ferrycarrig wheels revealed several features distinct of each wheel type (Figures 9). Tearing at the rim (present across all techniques) and some crevices in the walls occurred on ten cups and only from the kick or Ferrycarrig wheels, but none made on the electric wheel (Figure 14).

Qualitatively, both the electric and kick wheels allowed for rotation to be relatively constant while pressures from the hand were applied. The Ferrycarrig wheel by contrast, could not be used in the same way. The weight and momentum of the stone was relied upon to resist pressures of the hands, or, in other words, there was no input from my foot or a motor to sustain the rotation. In practice, there was little control over the deceleration of the Ferrycarrig wheel due to the momentum of the sandstone. After joining the coils and while finishing the shaping action, inconsistencies and instability in the hands may have caused tearing at the rim. This tearing, which might be called "crevices" (Roux, 2019, p.177), also occurred in the lower portion of the walls and may be a result of the clay's properties. Despite measures to homogenise the clay, crevices were created. Roux has argued that crevices can be a result of stretching "wheel-fashioned pastes" too quickly, or meagre clays with little homogeneity (Roux, 2019, pp.145 and 177, Figure 3.9). This tearing feature can be seen on several Bronze Age conical cups (see Figure 10, bottom left cup).

In the case of the conical cups here, it is likely that non-motorised wheels required opening and pulling out the clay more quickly than on the electric wheel. On the electrical wheel, there was more time to homogenise and centre due to its ease of use. As for the wheel-fashioned cups, the tearing could also be a result of not completely joined coils, which is likely due to Method 3 being less effective for homogenizing the clay despite being a faster method (Roux, 2019, p.84) These features, along with a general lack of symmetry, can be witnessed in both the experimentally produced (Figures 9

Figure 10. LMIA Bronze Age Conical cups from Knossos (After Hatzaki 2001: fig. 5.18). Reproduced with the permission from the BSA.

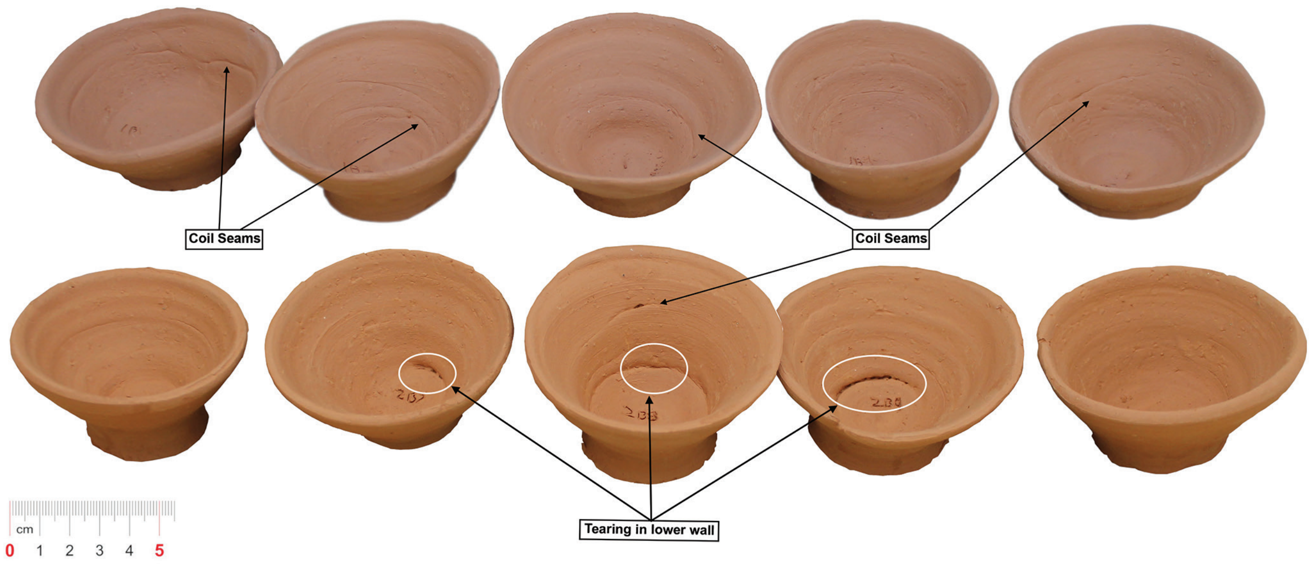

Figure 11. Experimental data set with traces highlighted: technique 1B (wheel coiled on the electric wheel) above; technique 2B (wheel coiled on the kick wheel) below. Photo by author.

and 11) but also some LM IA Bronze Age cups from Knossos (Hatzaki, 2007, p.5.18; Figure 10, Figure 12).

Another key result comes from the wheel-fashioned cups. Joining the coils following Method 3 of Roux and Courty (1998) was more difficult on the electric wheel than the kick-wheel or Ferrycarrig wheel, but the electric wheel allowed for more easily joining coils after the initial join. As joining of the coils was much easier on the non-motorised wheels there was less of a need to provide downward pressures, which perhaps is the reason for this result. With the electric wheel, the inability to join coils from the lack of speed control meant a compression action was needed to ensure they joined properly and so there were no large voids or tearing on the lower interior wall near the base. By comparison, seven cups produced on the kick wheel (2B cups) possessed a large void/coil seam trace near the base and interior wall of the cup (Figure 11; Figure 15). On six of the cups produced on the Ferrycarrig wheel (3B cups), the coil seam is visible in the same locations but lack the characteristic voids. This difference is seen particularly well on cup 3B.3 (Figure 12).

Figure 12. Experimental Cup 3B.3 (Wheel-coiled on the Ferrycarrig wheel), close-up. Note that the coil join at the bottom interior of the cup is noticeable but did not leave a large gap as can be seen in the 2B cups. Photo by author.

Although the electric wheel possessed optimum velocity and momentum, it struggled to work at the slow speed I needed to join coils to the base of a pot. Secondly, the kick wheel had a high velocity but little momentum, which forced me to maintain rotation constantly for certain shapes and gestures. On the other hand, its design made control of the wheel at slower speeds much easier than the electric wheel and even the Ferrycarrig wheel. Third, the Ferrycarrig wheel had high momentum but low velocity. Although winding up the wheel was more exhausting, the momentum allowed for concentration on more easily joining coils and shaping the vessels. Similarly, the kick wheel engages the upper and lower body, forcing the potter in many cases to propel the wheel by the foot and therefore imposing different postures. As the kick wheel required standing, it immediately precluded certain stabilising gestures that worked better for the electric wheel. On the other hand, the electric wheel is a completely steady-state device with little vibration, consistent rotation provided by torque of the motor, and ease of use. Fatigue on this modern wheel is limited primarily to the upper body. The evidence from this experiment suggests that the mechanical constraints, accompanied by a certain pragmatism (due in part to fatigue), played a significant role in the overall manufacturing process. Moreover, the non-motorised types of wheels were quantifiably different to the electric wheel.

Figure 13. Conical cup from Minoan Unexplored Mansion, note unevenness. Also note the internal traces which may point to poor clay quality which may have yielded tearing midway down the cup, or the drag marks from non-plastic inclusions (Popham 1984; SMP11689). Reproduced with the permission of the BSA.

4. Discussion

How ancient potters dealt with the introduction of new techniques, improved wheel designs and the ever-increasing mechanical capabilities of their tools remains complicated to identify and understand. This research has sought to use experimental archaeology to better understand this issue, which inevitably involved thinking about the role of skill, not only from the perspective of the experimenter, and the ancient potter, but also what skill means in the context of making pottery. Skill is a complex phenomenon, consisting of talent, knowledge, and expertise, and which can be defined as non-discursive, tacit, and embodied (Kuijpers, 2018, p.2; Malafouris, 2004; Ingold, 2011, Budden and Sofaer, 2009; Bamforth and Finlay, 2008). It also incorporates an understanding of the properties, limits, advantages as well as a craftsperson's response to raw materials practically and sensorially (Day, 2013; O'Neill and O'Sullivan, 2019). In pottery, knowledge impacts the ordering of time and space (Crown, 2001, p.451), such as knowing when to fire, or how long to wait for clay to cure or dry. Kuijpers (2018, pp. 1 and 2), who set out an empirical method for assessing skill in metalworking, argued that the nature of skill relates to a person's sensory interaction with the materials, and what differences in the quality of an object can be observed from varying levels of skill (Kuijpers 2018, pp.3–5). Given a conical cup, judging quality is complicated as they are generally considered to be easy shapes to make, and the earliest examples of them tend to be described as poor in quality or lumped into categories like "crude ware" (MacGillivray, 2007, pp.130–131). In pottery, actions from the potter are permanently preserved in the vessels through the process of changing clay to its ceramic state. These imprinted traces can be a result of different forming techniques that remain to be analysed and interpreted (Roux, 2019).

From the perspective of the experimental archaeologist, skill in a craft like pottery is an embodied knowledge too (Malafouris, 2004) that can be interpreted and analysed. Skill, then, is intimately tied with know-how of techniques, the construction of tools like the wheel or a kiln, and sensory knowledge, the most pertinent one being touch. How a potter touches or feels the clay at crucial moments during the construction is a knowledge and motor habit that translates into skill. Too much or too little pressure at different points can make a significant and measurable impact on the finished product. Therefore, learning how to make pottery or successfully performing a technique is a vital aspect of skill. For example, Roux and Corbetta (1989, p.16) demonstrated that the earliest stages of learning to throw begin with small conical shapes.

How then do these traces relate to the skill of the potter? For Roux and Corbetta (1989) working in India, skill was associated to a certain extent with the strength of a potter, and thus the larger, higher, and more vertical the walls required an increased level of skill (Roux and Corbetta, 1989, p.52). However, they also point out that transitioning to different levels of skill (1A to 3 to use their categories) involves increasing input from both hands, stability, strength and, of course, precision. In their research, they demonstrate that small conical-shaped vessels were produced much earlier in the learning stages (stages 1A to 1B; Roux and Corbetta, 1989, p.16).

Considering this experiment and the nature of conical cups there is a similarity between the Bronze Age cups and the experimental data that might be best explained from a couple of perspectives. One possibility is that beginner potters were perhaps unfamiliar or inexperienced with proper techniques, and (or) they were new to the type of wheel. Alternatively, it could be postulated that the clay used to produce Bronze Age cups was recycled, and perhaps not "wedged" properly prior to being used on the wheel. A certain pragmatism, derived from the need to produce so many, may have affected the manufacturing process – as it did during the experiment. Recycling clay is a common practice in pottery, and if poorly processed or wedged there can be air bubbles, and hard or unhomogenised pieces of clay that complicate the production.

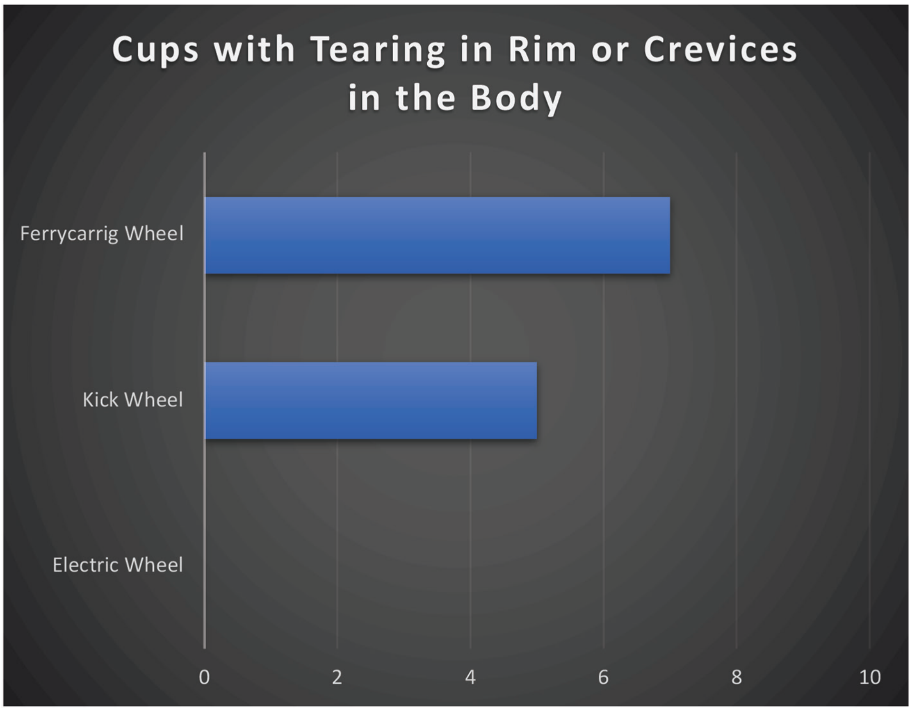

Figure 14. Quantity of tearing or crevices in experimentally-produced cups.

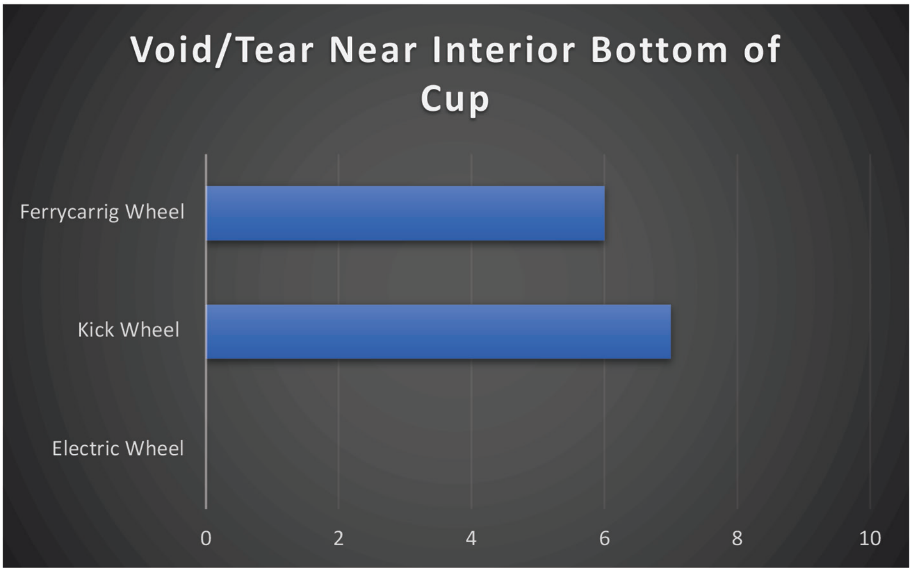

Figure 15. Number of cups presenting coil-seam traces at interior base of cup.

Minoan conical cups often contain some large inclusions in the earlier periods (MM I to MM III), which suggests that the clay recipe may not have been always ideal for the wheel.

Given that there was not enough time to incorporate a second, or master potter, into the experiment, how my own style or skill affected the macroscopic traces must be considered. The aim of the experiment was to address the effect of different types of potter's wheels on the production of conical cups and analysing the macroscopic traces for quantifiable differences. During this experiment there were other variables to consider too, such as to what extent different techniques were affected by motorised and non-motorised wheels. The clay, naturally sourced and processed, was another variable that also contributed to an understanding of how these types of wheels affect the workability of clay during various shaping techniques. Finally, and overlying these variables, is the skill of the experimenter (author). As a potter of approximately 9 months before the experiment, my skill level was that of a beginner to intermediate potter, being capable of producing around 25–30 cm tall, closed vessels by the end of the 9th month. However, my primary ability and focus of training was on the production of small (10–15 cm in height) open and closed shapes. Despite this focus, the incorporation of a second potter would have certainly made assessing skill and style more possible. If another potter of a higher skill level had been involved, the difference might have been detected from macroscopic traces, but this is also an inherently different analytical framework. For instance, recent work completed by Thér and Toms (this volume) demonstrated that with more experimentation and isolation of variables, traces and orientation patterns associated (or not) with skill and style might improve analogies between experimental and archaeological ceramics. Experimental work by Gandon and Roux (2019) also argued that master potters adjust their gestures to suit wheels that are new to them, indicating that future experimental work is still required.

Skill-level permeates techniques and tools, and it conditions decisions made during manufacture in terms of time, angles of the hands, and other material aspects of the shaping process that inevitably have a measurable impact on the macroscopic traces left behind. Therefore, lack of control over early wheel designs and unfamiliarity with new wheel techniques could be reflected in the macroscopic traces of conical cups. Powell (1995), for example, found that velocity and momentum had a direct relationship with the type of pots being produced, such that high velocity and low momentum made possible the production of small biconical and tall vessels (Powell, 1995, pp.333–334). As a result, she suggested that the "obvious solution" of the potter would be to produce wheels that could sustain more momentum, and would be subsequently heavier (Powell, 1995, p.334). While there is some evidence for an increase in the weight of the potter's wheel over time on Crete (Evely, 2000, Volume 2), the lower portion of the wheel is relatively unknown and its role in affecting macroscopic traces should be reinvestigated. Without the lower design, it is difficult to assess the Minoan wheel's capabilities as well as its mechanical characteristics.

The primary evidence for the wheel on Crete derives from the wheel heads that are preserved in ceramic or in rare cases, stone (Evely, 2000). Many of them have channels on the edges, are burnished on the top or have concentric grooves (Evely, 2000, p.283), all of which provide insight into how they may have been used and how the technology developed over time. The channels on the edges, for instance, might suggest they were used for winding up and maintaining rotation by hand, as one wheel from the MUM among others shows (Figure 5 and 6). The effect of utilising a winding up action and deceleration for making pottery versus making pots with constant rotary motion, will have required slightly different bodily gestures, and likely some different skillsets in terms of potting technique. Therefore, conducting more experimentation into changes in the upper and the (elusive) lower portions of the wheel design during the development of wheel technology on Crete could help clarify the emergence of specialised potters experienced or skilled in specific ways of making on Crete.

5. Conclusions

The experiment conducted for this project demonstrated that there are key traces as well as qualitative observations associated with different types of devices and techniques. There were consistent results which warrant a re-examination of how archaeologists employ experimental archaeology for the study of the potter's wheel. Challenges to the technique of throwing have effectively shown that techniques can be variable (Roux and Courty, 1998), and experimental studies concerning devices have explored that some mechanical capabilities can preclude or enable certain gestures (Gandon and Roux, 2019; Evely, 1988; Powell, 1995; Morrison and Evely, 2008). Moreover, O'Neill and O'Sullivan (2019) have argued that the modern experience in a craft such as blacksmithing, in their case, or pottery, as argued here, might dissociate archaeologists from the ancient smith or potter. Thus, I have argued here that the variable of the wheel, particularly non-motorised wheels, should be more seriously considered in the practice of experimental archaeological research.

As a result, experts on the pottery technology of Minoan Crete including Jeffra (2013), Knappett (1999; 2004; 2015) and others (*cf.* Caloi, 2011; Todaro, 2018) have voiced concerns for the need of future experimental investigations into forming techniques (Crewe and Knappett, 2012; Knappett, 2004, p.263 and 2005; Berg, 2007; Morrison and Park, 2007), but few have voiced that call for the wheel. This renewed investigation may also further studies into the regionalisation of potting techniques on Crete. Regional potting traditions are already known, not only in decoration and shape, but also with potting techniques as Caloi (2011) and Todaro (2018) have recently argued. Therefore, might there also be a case for regionality among wheel types? Evely and Morrison's experimental work may represent one type of wheel in use during the zenith of the wheel's design on Crete, but how exactly did this design come about, and was it the only one? What is certain, is that more experimental work is required for addressing these questions. As for the conical cup, examples like the one from the MUM (Figure 1 and 13) necessitate a rethinking in terms of which kind of wheel they were originally produced on as well as how the wheel's (or wheels') characteristics affected the manufacture of these cups when compared to other shapes. Through further investigation into the design of the wheel, conditions of potting in the past, including the technology, tools, techniques, and gestures employed by the potters, might be better understood.

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