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To cite this version:

Enora Gandon, Tetsushi Nonaka, Thelma Coyle, Erin Coyle, Raphael Sonabend, et al.. Cultural transmission and perception of vessel shapes among Hebron potters. Journal of Anthropological Archaeology, 2021, 63, pp.101334. 10.1016/j.jaa.2021.101334 . halshs-03339857

HAL Id: halshs-03339857

https://shs.hal.science/halshs-03339857v1

Submitted on 4 May 2022

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Cultural transmission and perception of vessel shapes among Hebron potters

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1. Introduction

Among the processes underlying human cultural transmission, fidelity copying (action imitation) has been frequently presented as particularly important (Miton and Charbonneau, 2018, Lewis and Laland, 2012; Tennie et al., 2009; Tomasello, 1999). Yet, this process has been recently challenged by empirical evidence from wheel-throwing pottery. Gandon et al. (2020a) showed that Nepalese potters used cultural, cross-cultural and individual-specific hand positions (repertoires and sequences) for the fashioning of familiar pottery types. Their results confirmed that the potters' skills are imprinted by the cultural context in which they have been learnt although these skills are not determined by a cultural model copied during learning (Bril, 2018). A complementary study with Indian Prajapati and Indian Multani potters tracked the vessel morphogenesis defined as the potter-induced morphological changes in the clay body, from its initial pre-formed stage following centring and opening operations, up to the moment that the final form is reached (Gandon et al., 2020b). Results showed that, in both Prajapati and Multani groups, potters reliably followed individual-specific vessel morphogenesis towards culturally homogenous vessel types. This demonstrates that, at the level of the elementary fashioning gestures, individual learning rather than simple model copying of elders' gestures is required for the acquisition of a complex motor skill such as throwing pottery.

This is not, of course, to say that cultural transmission plays a minor role in handicrafts. As highly specialized motor behaviours, handicrafts are unlikely to be acquired on the basis of individual learning alone (Boyd et al., 2011; Bril, 2002). In traditional craft workshops, novices learn by deliberate practicing in socially structured environments (with the presence of typical tools and materials, finished vessels, etc.) under the guidance of elders (Boyer and Bril, 2001; Bril, 1986; Crown, 2014; Lave and Wenger, 1991; Minar and Crown, 2001; Rogoff, 1995; Roux and Corbetta, 1989). The social channeling provided by the - material and human - environments educates the novices' attention towards the useful sensorimotor information for achieving the task (Gibson, 1979). This social bias influencing the learning process of novices' skills corresponds to the cultural transmission of handicrafts and leads to culturally inherited traits (Ingold, 2001a, 2001b). As explained by Bril (2015), the elders and the socially structured environment simply organize the novices' experience, while the novices are alone responsible for acquiring a particular skill. The culturally inherited traits are not *given* through the transmission, they *develop* through the socially mediated individual learning. The skills of

craftsmen are therefore likely to contain both cultural traits inherited from the cultural transmission (i.e. social biased traits) and individual traits resulting from the individual learning, as illustrated in the study with the Nepalese potters (Gandon et al., 2020a). Accounts of handicraft apprenticeship as a process involving both individual learning and cultural transmission is essential to recognize that craftsmen behaviors - and their subsequent object traits - can be modified through their transmission across generations (Mesoudi, 2017; Wiessner, 1983).

While craft apprenticeship can be understood as socially mediated individual learning, the ensuing prediction of individual and cultural object traits within craft communities has so far not been investigated in traditions such as pottery throwing. A major issue remains in that we do not know to what extent the objects produced by learners vary from those of their trainers. Previous experimental fieldwork with modern Indian and Nepalese potters indicated subtle individual and social group signatures on ceramic shapes (Gandon et al., 2018; Harush et al., 2020; Roux and Karasik, 2018). Yet, there is still a lack of systematic analysis of object variations among members of crafting families where the transmission takes place. This lack of knowledge limits the understanding of cultural transmission and evolution, thus depriving archaeologists of a valuable framework for interpreting the variability of ancient objects and their temporal evolution. The first goal of this study is to fill up this gap by measuring the vessel shape variation among members of a pottery-making community including different families.

A related question concerns the visual perception by the craftsmen of the variations in the shape of ceramics. As acknowledged by Crown, it is evident that potters perceive the shapes of the distinctive vessel types they produce: *"The potter then forms the vessel before the clay dries out. These steps require knowledge of culturally appropriate vessel shapes and proportions and the ability to perceive or measure these."* (Crown, 2014: 74). But visually perceiving (without using any kind of measurement tool) the barely discernible variations in same-type vessel assemblages is less evident. If craftsmen do not identify the slight differences between the vessels produced by distinct members of their community, then the process of selection of certain shape variants would not be guided by the craftsmen choice, and the evolution of ceramic shapes would be caused by other factors. Preliminary results from five Nepalese potters indicated the opposite; certain participants perceived the individual signatures

on ceramic vessels (Gandon et al., 2018). The second goal of this study is to verify this preliminary result with an experiment involving a larger sample of craftsmen.

Here we bring an experimental approach to explore these issues, with the aim of providing an assessment of both (i) the vessel shape variations occurring through cultural transmission and (ii) their perception by the craftsmen. We did so by setting up two field experiments with 26 potters belonging to the pottery-making community of Hebron (Palestinian Territories), with a clear identification of the family relationship between them.

In the first experiment participants were asked to throw series of customary pottery types in their familiar conditions of practice. We captured the 2D profiles of their axisymmetric productions. The participants' behavioral reproducibility was analysed by computing the standardization of the vessel assemblages through the coefficient of variation of the vessels' absolute dimensions. We used the Elliptical Fourier method to analyze vessel shape variation among the productions (Gandon et al, 2013; 2018; 2020b; McLellan and Endler, 1998). Following the view of handicraft learning outlined above, our first operational hypothesis is that the complete assemblage of vessels produced by the 26 potters would contain both individual and cultural shape traits, these latter being culturally inherited from the familial transmission unit. If this hypothesis is verified, we could conclude that each transmission (from a trainer to a learner) modifies the ceramic shape, the culturally transmitted traits being combined with new individual traits. Beyond the question of shape variation occurring during the transmission, we also want to understand how individual and cultural shape traits could affect the evolutionary trend of the ceramic shapes. Do the cultural traits propagate through generations of craftsmen or are they diluted in the individual traits resulting from each transmission? We assume that the ceramic shapes evolved through the successive transmissions with the integration of individual traits and the conservation of cultural traits inherited from the familial transmission unit. Hence, our second operational hypothesis is that the shape variations in the complete assemblage of vessels will reflect not only the transmission units but also larger family relationships. If it is the case, it would imply that cultural morphological traits in ceramics propagates through generations of craftsmen at the scale of a pottery-making community including different families.

In a second experiment, we asked the participants to visually identify their own productions and those of five other potters. Based on the preliminary result found with the

Nepalese potters, our third operational hypothesis is that participants will perceive, at least to a certain extent, individual signatures in ceramic shapes. Testing this hypothesis will allow us to evaluate whether potters detect the slight shape variations, and could thus select the individual variant they prefer, notably disseminating it by reproduction. We could then conclude for a possible influence of the potters' choice in the selection and evolution of ceramic shapes.

2. Materials and Methods

2.1. Experimental setting

2.1.1. Cultural context

In the southern Levant, the throwing method as practiced in Hebron dates back to the early Ottoman period (16th century). In the 20st century, the city of Hebron used to be a large center of pottery production. Currently only a few pottery-making families (locally called 'Fakhuri', meaning potters) remain. They constitute learning lineages of specialized craftsmen whose craft has been transmitted over many generations. These families work in the neighbourhood of Hebron, 'Al-Fahs' (Palestinian Territories). Changes in their tradition mainly occurred in the type of containers as a result of market evolution. Contemporary customers demand decorative vessels rather than utilitarian traditional vessels (Table 1). Among the latter, the water jug called "Ebreeq" and the cooking pot called "Fokhara" are still commonly used by the Palestinian population. The main part of the production is represented by flowerpots (from 15 cm to 1 m high) and small tourist vessels (oil lamp, water pipes, incense burners, etc.), sold both in the Palestinian territories and in Israel, very occasionally in Europe or the United-States. All vessels are produced using an electrical wheel which replaced the kick-wheel since the 1980s. Vessels are thrown at high production rates. Potters throw for example 300 small vessels or 30 large vessels in one day. The production is organized in family workshops, with members practicing the wheel-throwing in co-working area (Fig. 1). These family workshops are sometimes in the same compound, this is the case when they belong to a given extended family. They then house the sons and grandsons of the grandfather who originally bought the compound. The different workshops included in a compound can share the clay preparation and drying areas while usually, each workshop has its own kiln. The craft skills are transmitted

vertically from father to sons, the eldest sons can also teach their young brothers. These latter are generally the assistant of their elder brothers and father, they throw vessels occasionally but mostly prepare the clay, participate to simple decoration tasks, carry the vessels from the drying area to the kiln, and help for the firing. The family workshops constitute the transmission units, which change through the lifespan of craftsmen. When the sons become adult, they leave their father's workshop and set-up their own workshop with their own sons, so the roles of learner and trainer are held successively by a craftsman.

Figure 1. Co-working area with elder experts and youngers. Left photo: P8 (Potter 8) with his son P6; right top photo: P4 (left) and his elder brother P13 (right); right bottom photo: P15 (in the middle) with his two sons P1 (left) and P19 (right). Becoming an expert potter requires sitting for hours at the wheel close to those of the elders. While sitting next to his mentor, the apprentice can observe his mentor' fashioning gestures.

2.1.2. Participants

Our study involved 26 participants from the Hebron pottery-making community. The participants belong to three families: HAL (16 participants), NAI (7 participants), and NAF (3 participants) (Table 1, Fig. 2). As shown in the Figure 2, we worked with two generations, unfortunately the first generation passed away. The NAF family is not related to the two other families, it is made up of four brothers working in an isolated workshop (i.e. not integrated to an extended family compound). These four brothers learnt the skill in the same transmission unit (with their father NAF). The HAL and NAI families have kinship ties, the grand-fathers (HAL and NAI) were brothers, the sons and grand-sons are thus cousins. The compounds of

these two families are located a few hundred meters apart. The HAL family members who participated in our experiments are currently distributed between five workshops housing five transmission units made up of the father and his sons (only one father, SAL, did not wish to participate). The five fathers of each workshop are brothers and learnt the skill in the same transmission unit (with their father HAL). In the NAI family, the members who participated are six brothers who learnt the skill in the same transmission unit (with their father NAI), and one son of them (P26) which constitutes (with his father) another transmission unit. The six brothers of the NAI family are currently distributed between three workshops, each of them housing respectively three, two and one brother(s) and their sons (when old enough to work). In total, our dataset encompassed nine transmission units which are labelled U1 to U9 (see caption of Fig. 2). Among them eight transmission units are distributed between two extended families (HAL and NAI's ones) (Fig. 2). The participants were all men, aged from 18 to 72 yrs (37.9 ± 12.4 yrs) and with different wheel-throwing experience (years of practice: 27.8 ± 12.7 yrs) as well as different pottery type specialization (Table 1). The specialization is not fixed but changes over time, depending on the market. As P12 said: *"My brothers HAKA and ISS perfectly know how to throw big flowerpots, but they did not produce them for several years because the demand of customers is mainly for small tourist items."* The level of practice of the participants (young learner, advanced learner, and expert) was defined by the vessel types they usually produce (Table 1). Among the 26 participants, one was a young learner (P12), three were advanced learners (P18, P14 and P26), all the 22 others were experts. The learners P12, P18, and P14 begun to learn the throwing skill early (at 8, 10, and 14 yrs old respectively) but, as the last sons of their family, they mainly assist their elders and do not produce a lot of vessels. The learner P26 also begun early to learn how to throw pots on the wheel (at 7 yrs old) but, as the eldest son of P25, he throws vessels at high production rates for several years. Three participants (P3, P11, P17) were left-handed and the 23 other right-handed. The participants gave their written consent to participate in the field experiments after having been informed through an informative sheet.

N°	Name	Age	Experience	Family	Most usual production
P1	HEL	31	23	HAL	Ebreeq, big flowerpots
P2	HAK	33	23	HAL	Ebreeq, Fokhara, cooking pots, small tourist items (water pipes, incense burners,…), flowerpots in all sizes
P3	HUS	57	43	HAL	Ebreeq, Fokhara, cooking pots, small tourist items (Money-Bank, water pipes, incense burners,…),
P4	ISS	31	21	HAL	Ebreeq, Fokhara, small tourist items (Money-Bank,..)
P5	EIA	34	20	HAL	Ebreeq, Fokhara, cooking pots, small tourist items (water pipes, incense burners,…)
P6	MOH	25	15	HAL	medium flowerpots
P7	SAL	51	44	HAL	Ebreeq, Fokhara, big flowerpots and big water jars
P8	HIS	49	42	HAL	Ebreeq, Fokhara, flowerpots in all sizes
P9	AHM	27	17	HAL	big flowerpots (part 1) and big water jars (part 1)
P10	MUS	35	25	HAL	small tourist items (Money-Bank,..)
P11	MUST	37	26	HAL	small tourist items (Money-Bank,..)
P12	MOH-1	23	15	HAL	small flowerpots
P13	HAKA	40	32	HAL	Ebreeq, Fokhara, small tourist items (Money-Bank,..)
P14	AMM	24	10	HAL	small tourist items
P15	WAH	72	63	HAL	Ebreeq, flowerpots in all sizes
P16	MOH-2	37	28	NAF	flowerpots in all sizes
P17	HAMA	35	23	NAF	flowerpots in all sizes
P18	ALI	18	8	NAF	small tourist items
P19	ANA	40	31	HAL	flowerpots in all sizes
P20	ALA	44	34	NAI	Ebreeq, Fokhara, flowerpots in all sizes
P21	SHU	47	39	NAI	Ebreeq, Fokhara, flowerpots in all sizes
P22	MOH-3	33	18	NAI	Ebreeq, Fokhara, Money-Bank, flowerpots medium size
P23	NUM	39	31	NAI	Ebreeq, Fokhara, flowerpots in all sizes
P24	SHAK	48	38	NAI	Ebreeq, Fokhara, Money-Bank, flowerpots in all sizes
P25	SHA	54	40	NAI	Ebreeq, Fokhara, Money-Bank
P26	HAM	21	14	NAI	Ebreeq (part 1), big flowerpots (part 1)
	mean	**37,9**	**27,8**		
	sd	***12,4***	***12,7***		

Table 1. The 26 participants of the study. Each potter was asked about his age, experience (i.e. years of practice), family (HAL, NAI or NAF), and most usual production. The big flowerpots and the big water jars are produced with the two stages method of throwing (Fig. S1). The most usual production includes the vessel types that the participants were producing during the last months preceding our study. It does not necessarily include the different pottery types mastered by a potter, as the production changes throughout the year, depending on the market demand. For instance, P6 produces mainly medium flowerpots but he also produces Ebreeq and Fokhara in series for exceptional periods. The potters over 40 years old generally master the entire repertoire of pottery types.

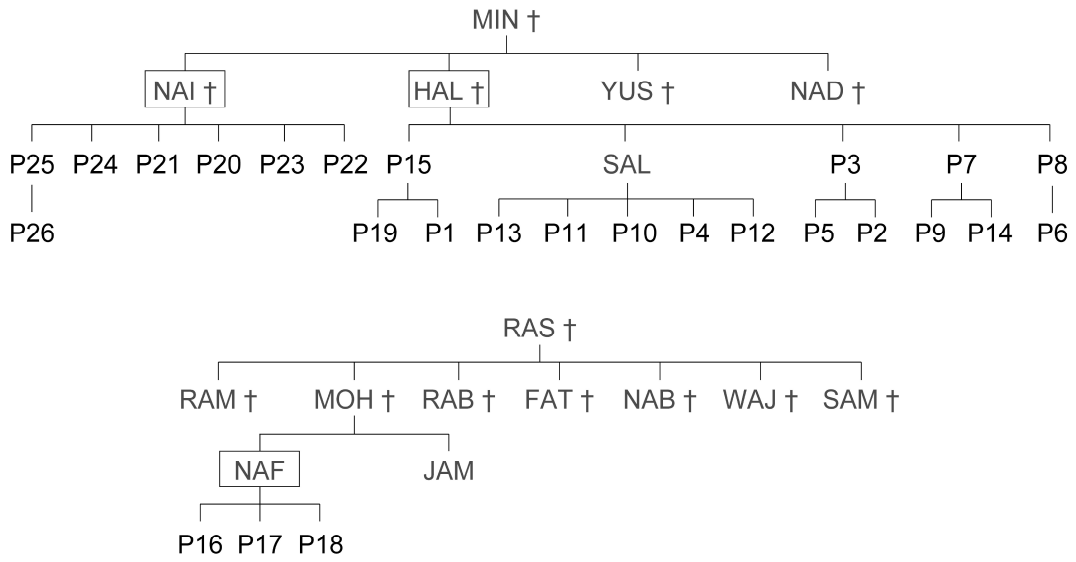

Figure 2. Family trees of the families HAL, NAI, and NAF participating in the experiments. Filial relations are indicated by vertical lines, and sibling relations are indicated by horizontal lines in which potters are sorted in an age-descending order from left to right. HAL and NAI were brothers, so their sons and grand-sons are cousins. Our dataset included nine transmission units (**U1**: consisting of potters P15, P19, P1; **U2**: P3, P5, P2; **U3**: P13, P11, P10, P4, P12; **U4**: P8, P6; **U5**: P7, P9, P14; **U6**: P16, P17, P18; **U7**: P25, P24, P21, P20, P23, P22, **U8**: P15, P3, P7, P8; **U9**: P25, P26). Among them eight transmission units are distributed between two extended families (HAL and NAI's ones). SAL, NAF, and JAM did not participate, NAF and SAL are partially retired, and JAM's workshop is in another area of Hebron. In the different transmission units, only the potters who participated in the study are represented.

2.1.3. Production task

In a first experiment, participants were asked to produce three customary pottery types: Ebreeq, Fokhara, and Money-Bank (Fig. 3, left). The two first types are traditional vessel types known since centuries while the latter is a modern vessel type which dates to the late 20st century. The Ebreeq and the Fokhara were thrown in two stages as potters usually do for those types (Fig. S1). All the 22 expert participants produced the three types. They were all used to them even if they produce each type in different quantities depending on their most usual production (Table 1). The learner P12 did not produce the Ebreeq and Fokhara because he was not advanced enough. The learners P14 and P18 produced the three pottery types with a low level of practice. The learner P26 produced the Ebreeq and Fokhara with a high level of practice for the part 1 of the vessels and a low level of practice for the part 2 (Fig. S1), he produced the

Money-Bank with a low level of practice. To assess the reproducibility of behavior, five replicates were produced in each of the three pottery types, so each potter produced a total of 15 pots (Fig. 3, right). There were some cases where potters produced six replicates instead of five, which were included in our dataset. For each pottery type, a vessel model was presented in front of the potter's working place during the whole fashioning session. The instructions were to make a vessel with the same size as the model, using self-chosen quantities of clay. Potters were not asked to copy the models exactly because we wanted each participant to produce the pottery type following his own way. For seven expert participants (P1, P2, P5, P17, P20, P21, P23) it was the first time they produced the Money-Bank with the specific shape of the model (they usually produce the Money-Bank with different shape variant). Potters used a basin of water to regularly wet the clay during the throwing process, and a metallic scraper during the thinning and/or final fashioning steps. Potters produced the experimental vessels assemblage using their usual wheel and clay, working at their own pace. All finished vessels were marked on one face with numbers indicating the specific potter and the replicate number in the series; then they were put to dry for two days.

Figure 3. The three models of pottery types (left photo) and an example of a complete assemblage produced by one potter (right photo). The three models on the left photo are (from left to right): Ebreeq, Fokhara, and Money-Bank. For the experiment, the Ebreeq was produced without the handle and the spout. The complete assemblage on the right was produced by P8.

2.1.4. Vessel identification task

In a second experiment, we asked 21 participants to visually identify their own vessels and those of five other potters. Among these latter (i.e. the five other potters), one, two, three or four were members of the transmission unit of the participant, and the remaining were members of the extended family of the participant (living in the same compound) or members

of another family. Five participants were not available for this second experiment, they are the three members of the NAF Family (P16, P17, and P18), P24 from the NAI family, and P12 from the HAL family. For this vessel identification task we selected, for each potter and each pottery type, the best three replicates (among the five produced) eliminating vessels with manufacturing defects (for example a fingerprint in the wall, or a little rock in the clay). This was done to prevent a potter recognizing his own vessels because of the presence of a noticeable defect. The vessels were then organized by groups of three vessels per pottery type (x 3 types) and per potter (x 6 potters), thereby obtaining a total of 18 vessel groups including 3 self-vessel groups (one by pottery type) and 15 others-vessel groups (five by pottery type) (Fig. 4, left). Looking at the six vessel groups for a given pottery type, each potter was individually asked to visually identify his own vessels, and those of the five other potters (Fig. 4, right). When performing the task, the potter had the list of the six producers' names (including himself) in his hands. His task was to find which vessels belong to which producers. The vessels were observed from a one-meter distance without manipulation. No feedback or any other type of clue was given. In total, each potter had to give 18 answers (six producers to be identified, for each of the three different pottery types), which were later entered into an Excel file. The participants could also refrain from answering if they were unsure. To close this experimental session, the experimenter (E. Gandon) gave each potter his performance and asked him which clues he used to identify the vessels' producers.

Figure 4. The vessel identification task. Here the experimenter (E. Gandon) is working with P11. For the three pottery types (front line: Money-Bank, middle line: Fokhara, and back line: Ebreeq), potters were asked to identify the producer of the six vessel groups. They were invited to identify the producers starting from the leftmost 3-vessels group and subsequently proceeding rightward. They could change their answers if deemed necessary at the final summary given by the experimenter (photograph by W. Alqaraja).

2.2. Data recording and analysis

2.2.1. Morphology of the vessels

Once the vessels were dried, we used a Canon PowerShot-SX270 camera (resolution 2112 x 2816 pixels) to photograph all vessels. A size-calibration object was placed next to each vessel (as in Fig. 3, left). Two vessels were removed from the dataset because they were damaged (P13, one Fokhara and P8 one Money-Bank). In total, 129, 126, and 136 vessels of Ebreeq, Fokhara, and Money-Bank respectively, contributed to the present analysis.

Using Matlab® software we extracted the x-y coordinates (in pixels) of the complete vessel outline from each vessel photo. A low-pass filter was applied to these coordinates to remove noise from pixellation. The coordinates were then converted from pixels to centimeters using the calibration object present in each photo. The coordinates were subsequently resampled so that the distance between neighboring points was standardized to 1 mm.

We computed the vessel absolute dimensions: base, aperture, height, maximal diameter, and height of the maximal diameter. The base was not computed for the Fokhara which have a rounded bottom. In order to assess the standardization of production we computed the between-trial variation over the five replicates thrown by each participant, for each of the three pottery types, using the coefficient of variation (CV = 100 * standard deviation / mean) computed on the vessel absolute dimensions (Eerkens and Bettinger, 2001; Kvamme et al., 1996). A smaller CV indicates a higher standardization of production. To test if the pottery type (Ebreeq, Fokhara, and Money-Bank) influenced the standardization of production we used an ANOVA with equal variance and t-tests for post-hoc. The effects of the participants' ages and experiences were also tested with a linear regression analysis.

All complete vessel outlines were subjected to an Elliptical Fourier transformation (Gandon et. al., 2013; 2018; 2020b; McLellan and Endler, 1998). The resulting series of 40 pairs of coefficients were normalized with respect to the first coefficients to correct for size differences so that pure shape could be analyzed. For graphical representation of the shape, the size-corrected Fourier coefficients were subjected to a Principal Component (PC) analysis. For

all vessels, over 70% of the total shape variance was captured by the first three PCs. Each vessel shape could thus be represented as a point in a unique three-dimensional PC shape-space, allowing a visual inspection of the variations within and among participants as well as the variations within and among the transmission units. This mathematical shape description also allowed to reconstruct, for each participant and each pottery type, the mean vessel shapes. These mean vessel shapes were reconstructed from the mean Elliptical Fourier coefficients of the five vessel replicates produced by each participant for each pottery type.

Statistical differences among vessel shapes were further examined for each of the three pottery types separately. For that purpose, in a first step we ran nested permutation tests (Anderson, 2001) on the 40 pairs of normalized Fourier Coefficients using the nested.npmanova function in the R package BiodiversityR. This analysis was based on a two-level hierarchical model, in which the individual potters were nested within transmission (family) units. These permutation tests allow us to test our first operational hypothesis, assessing the presence of significant shape variation among individual potters and among the transmission units. Because these tests can be used only with exclusive groups, two rounds of permutation tests were run. The first round tested the presence of significant variation among the transmission units U1, U2, U3, U4, U5, U6, U9 and among the different individual potters (20 individuals for Money-Bank, and 19 individuals for Ebreeq and Fokhara because P12 did not produce these two pottery types). The second round tested the presence of significant variations among the transmission units U6, U7, U8 and among the different individual potters (14 individuals for all three pottery types).

To test our second operational hypothesis, we constructed dendrograms presenting the similarities among the participant's mean vessel shapes (Figs. 8, 9, S2, and S3). The mean vessel shapes were used because showing every vessel replicate would make the diagrams too complex. For each pottery type (Ebreeq, Fokhara, Money-Bank) three dendrograms were made. The first dendrogram provides distinct branch colours for the two families MIN and RAS; the second provides this for the three families HAL, NAI, NAF; and the third provides distinct colours for each of the nine transmission units. While the permutation tests assess the presence of individual and cultural traits inside the global set of vessels produced by the 26 participants, the dendrograms illustrate the transmission of the cultural traits across the two generations of participants, taking into account the combination of individual and cultural traits. If cultural traits on vessel shape were conserved through successive transmissions as we expected, there

should be reasonably strong resemblance between the family trees (Fig. 2) and these dendrograms (Figs. 8, 9, S2, and S3). The resemblance would appear in the dendrograms through a distinction between the branches of two families MIN and RAS, the three families HAL, NAI, NAF, and the nine transmission units. Dendrograms were produced according to the unweighted pair-group mean arithmetic (UPGMA) method using the R function hclust. For permutation tests and dendrograms, the alternative-Gower distance was used as a dissimilarity measure (Anderson et al., 2006), and 10000 randomizations were used to obtain *P*-values. For all statistical tests, the alpha level used was 0.05.

2.2.2. Identification of the vessels

To test our third operational hypothesis, the performance of the participants in the identification task was measured by the number of (i) correct answers, (ii) incorrect answers, and (iii) no answers (when participants refrain from answering). A correct answer was recorded when the vessel's producer was correctly identified by the participant and an incorrect answer was recorded when participant responded another potter instead of the correct one. First, we analyzed if potters correctly identified their own vessels (i.e. self-vessel groups) more than those of the other potters (i.e. others-vessel groups). Then, the Kruskal-Wallis test was employed to test the effect of pottery type (Ebreeq, Fokhara, and Money-Bank) on performance. Pairwise t-tests were used to compare the effect of familial distance (transmission unit vs. extended family) on performance, and linear regression was used to test the effects of experience and age. Results were interpreted in light of the information given by the participants during the interviews closuring the experimental session.

3. Results and discussion

3.1. Morphology of the vessels

3.1.1. Standardization of production

Tables S1, S2, and S3 present the mean absolute dimensions of the vessels (in centimeters) produced by each participant, for the Ebreeq, Fokhara, and Money-Bank respectively. The among-participant standard deviations ranged between 0.5 and 1.8 cm for all pottery types (see last line of the Tables S1, S2, and S3), indicating a rather high standardization of the productions at the level of the pottery-making community in line with earlier results (Gandon et al., 2014a). Table 2 presents the vessel standardization (i.e. CVs) for each participant and each pottery type. The values were in a range of 1.7 to 6.3 %, if one excludes P11, specialized in small items. They are within the ordinary coefficients of variation range reported in previous studies with potters throwing familiar pottery types at high production rates (Gandon et al., 2014a; Gandon et al., 2014b; Harush et al., 2020; Longacre, 1999; Roux, 2003). There was a tendency for the vessel standardization to improve (CV to decrease) with the age and experience of the potter, especially for Ebreeq, and for Money-Bank to a lesser degree. But there was no statistically significant relation between the CVs and the participants age (Ebreeq: $r_{24} = -0.35$, $p = 0.08$, $CI = [-0.65, 0.05]$, Fokhara: $r_{24} = -0.09$, $p = 0.67$, $CI = [-0.46, 0.31]$, Money-Bank: $r_{24} = -0.33$, $p = 0.10$, $CI = [-0.64, 0.07]$), and experience (Ebreeq: $r_{24} = -0.38$, $p = 0.05$, $CI = [-0.67, 0.01]$, Fokhara: $r_{24} = -0.11$, $p = 0.60$, $CI = [-0.48, 0.29]$, Money-Bank: $r_{24} = -0.32$, $p = 0.11$, $CI = [-0.63, 0.08]$). Although the degree to which the vessel standardization is related to the age and experience is somewhat different between shapes, we conclude that, overall, the 26 participants all acquired a sufficient expertise to throw standardized vessels. Finally, we found that the CVs of the Ebreeq were significantly smaller than those of the Fokhara and Money-Bank; the latter two were statistically equivalent ($F(2, 48) = 11.42$, $p < 0.01$) (Ebreeq: 3.5 %; Fokhara: 4.5 %; Money-Bank: 4.8 %) (see Table S4 for post-hoc tests). This difference was small but could indicate that the participants produce Ebreeq with a higher frequency than Fokhara and Money-Bank.

Standardization of production (CVs %)				
Potter	**Ebreeq**	**Fokhara**	**Money-Bank**	**Mean**
P1	3.1	2.2	3.4	2.9
P2	4.4	4.9	3.4	4.2
P3	3.7	2.8	3.1	3.2
P4	2.2	3.3	5.1	3.5
P5	1.9	3.3	4.5	3.2
P6	2.3	3.7	4.9	3.6
P7	1.7	2.7	4.0	2.8
P8	2.7	2.8	3.6	3.0
P9	2.3	5.5	5.1	4.3
P10	4.6	5.3	3.4	4.5
P11	5.7	8.6	6.9	7.1
P12	-	-	4.0	4.0
P13	2.5	4.2	2.8	3.2
P14	5.2	3.5	4.7	4.4
P15	1.9	3.4	4.3	3.2
P16	3.8	4.5	4.9	4.4
P17	4.9	5.8	6.0	5.6
P18	5.7	4.4	6.4	5.5
P19	5.2	3.4	3.8	4.1
P20	4.1	4.6	5.1	4.6
P21	4.1	6.0	5.1	5.0
P22	3.8	5.1	4.5	4.5
P23	2.9	5.8	6.0	4.9
P24	3.0	6.3	6.1	5.1
P25	3.2	6.3	5.0	4.8
P26	3.8	5.3	7.2	5.4
Mean	**3.5**	**4.6**	**4.8**	**4.3**

Table 2. Coefficients of variation of the productions. The coefficients of variation were computed over the five replicates thrown by each participant for each pottery type (Ebreeq, Fokhara, and Money-Bank). They were computed on each absolute dimension of the vessels and subsequently averaged to obtain a mean coefficient per participant and per pottery type.

3.1.2. Individual and cultural traits on vessel shapes

Figure 5 presents, for the Ebreeq, Ebreeq neck, Fokhara, and Money-Bank separately, the morphology of the vessels in the three-dimensional PC shape-space. The shape of each vessel (and Ebreeq neck) produced by each participant is represented as a point in the PC shape-

space, while the distinct transmission units are indicated though different colours. Figure 6 presents the mean vessel shape of the five replicates produced by each participant for the three pottery types. Figure 7 presents the Ebreeq necks photos of the five Ebreeq replicates produced by each participant.

Despite certain overall similarities of the evenly distributed graphical markers, visual inspection of Figure 5-a shows that the Ebreeq vessels produced by the same potter clustered in the PC shape-space, with some participants producing more standardized assemblages (tighter clusters; P7, P8 for example) than others (P16, P10 for example). The specialisation of the participants in certain pottery types (see Table 1) explains the individual differences observed in terms of assemblage standardization: the less a potter is specialized in a pottery type, the less he will produce standardized assemblages for that type. Some of the individual signatures observed in Figure 5-a were detectable in the mean vessel shapes presented in the Figure 6-a: the Ebreeq of P1 were particularly wide, those of P13 had a fine lower part, those of P9 had an oval body, those of P20 had a square outline. Within the five-replicates assemblage produced by each potter, some vessel shapes were different from the others (P3, P23 for instance) (Fig. 5-a), suggesting that a given pottery type can be produced by a single potter with a range of variation (see Photo dataset). A clustering of the vessel assemblages also appeared at the level of the transmission units, indicating culturally inherited signatures which were particularly visible for U2, U4, and U8. In the transmission unit U3, the assemblages of P13 and P4 were close, while those of P11 and P10 were farther apart in the PC shape-space and corresponded to atypical mean shapes (Fig. 6-a). This can be explained by the fact that P11 and P10 are not specialized in the Ebreeq production, they more often produce small tourist items (Table 1). The assemblage of P26 also occupied a different part of the PC shape-space and corresponded to an atypical shape (Fig. 6-a); P26 being still a beginner in producing this pottery type. The Ebreeq produced by the other two learners P14 and P18 were closer to those produced by the experts, yet they had irregular shapes and a low degree of standardization (Photo dataset and Table 2).

As for the Ebreeq complete vessel (Fig. 5-a), individual signatures appeared in the Ebreeq neck through individual clusters in the PC shape-space (Fig. 5-b). Some of these individual signatures appeared clearly in Figure 7, notably two atypical neck shapes produced by P3 and P24, but also the necks produced by P1 which were wider than all others, and those produced by P22 which distinguished through a square-shape lip on the aperture. Some neck

assemblages were more standardized (for instance P7, P8, P13) than others (P10, P11, P17, P5). Individual variants were exhibited in the assemblage of single potter, for example P2 who produced the neck with two different styles of lip on the aperture, one style being used for four replicates and the other for one replicate. The same thing was observed with P20 who produced three necks using one style, and two necks using another style (Figs. 5-b and 7). Similarity between the necks produced by the transmission unit members was observable, indicating culturally inherited signatures (Fig. 5-b). Inside each transmission unit, the higher similarity of the necks did not appear between the necks produced by all members but between those produced by two members, brothers (P4-P13, P20-P22, P18-P16) or father and son (P7-P9).

The Fokhara vessels results were similar to those of the Ebreeq. Individual signatures appeared through systematic clusters of the assemblages produced by each distinct potter (Fig. 5-c). Some of those individual signatures were obvious in the mean vessel shapes: the Fokhara produced by P1 had a wide lower part, those of P13 had an elongated body and a rounded lower part, those of P19 had an elongated body (Fig. 6-b). The standardization of the individual assemblages varied between the participants, for instance the assemblages of P15 and P3 were less variable than those of P10 and P11. The assemblage of P4 exhibited two variants, three vessels were close to those of his brother P13, while the other two vessels were in a different region of the PC shape-space. Two Fokhara produced by P4 were more elongated than the other three vessels in the photos (see Photo dataset). A similarity between the assemblages produced within each transmission unit was observed, and particularly noticeable in U4, U5, and U8. As for the Ebreeq, in U3, the assemblages of P13 and P4 were close while those of P10 and P11 were distant and corresponded to atypical mean shapes (Fig. 6-b). This result is certainly due to the specialization of P10 and P11 in small tourist items (Table 1). The assemblage of P26 stood out from all others and corresponded to an atypical mean shape reflecting that P26 was a learner. Although they were not skilled at producing Fokhara, the vessels of the two learners P14 and P18 had a similar shape to that of the experts' vessels.

Results of the Money-Bank vessels were qualitatively similar to those of the Ebreeq and Fokhara. We observed individual signatures through distinct clusters in the PC shape-space for the different potter assemblages (Fig. 5-d). In Figure 6-c we can see for instance that the Money-Bank of P15 were distinguished by wide shoulders, those of P8 had a narrow neck bellow their bud, and those of P19 had an elongated lower part. Some assemblages were more standardized (those of P1 and P13 for instance) than others (those of P16 and P17 for instance). Individual

signatures did not exclude individual variants, for example we saw that for P7 and P23 the five vessels were separated in two clusters (two vessels being in a distant area of the three others). Similarity at the level of transmission unit appeared for U2, U4, and U6. It appeared also between the four brothers of the U3 transmission unit (P4, P10, P11, and P13), with the fifth brother P12 assemblage being far from the others and corresponding to an atypical mean shape (Fig. 6-c) signing the learning of this young potter. The learning was also observable in the vessels of P14 which were far from those of his father (P7) and brother (P9) (Fig. 5-d) and corresponded to an atypical mean shape (Fig. 6-c). The Money-Bank produced by the learner P18 had also an atypical mean shape (Fig. 6-c) and were in an extremity of the PC shape-space (Fig. 5-d). Surprisingly, in the transmission unit U1, although the assemblages of the father (P15) and the eldest son (P19) were close, the one of the youngest son (P1) was in a distant area of the PC shape-space, this difference being also observable in the mean shape (Fig. 6-c). In the U7 transmission unit, the assemblages of the five youngest brothers were close, and that of the older brother (P25) was distant. The assemblage of P26 (son of P25) was distant from all others and corresponded to an atypical mean shape (Fig. 6-c) signing the learning of this young potter.

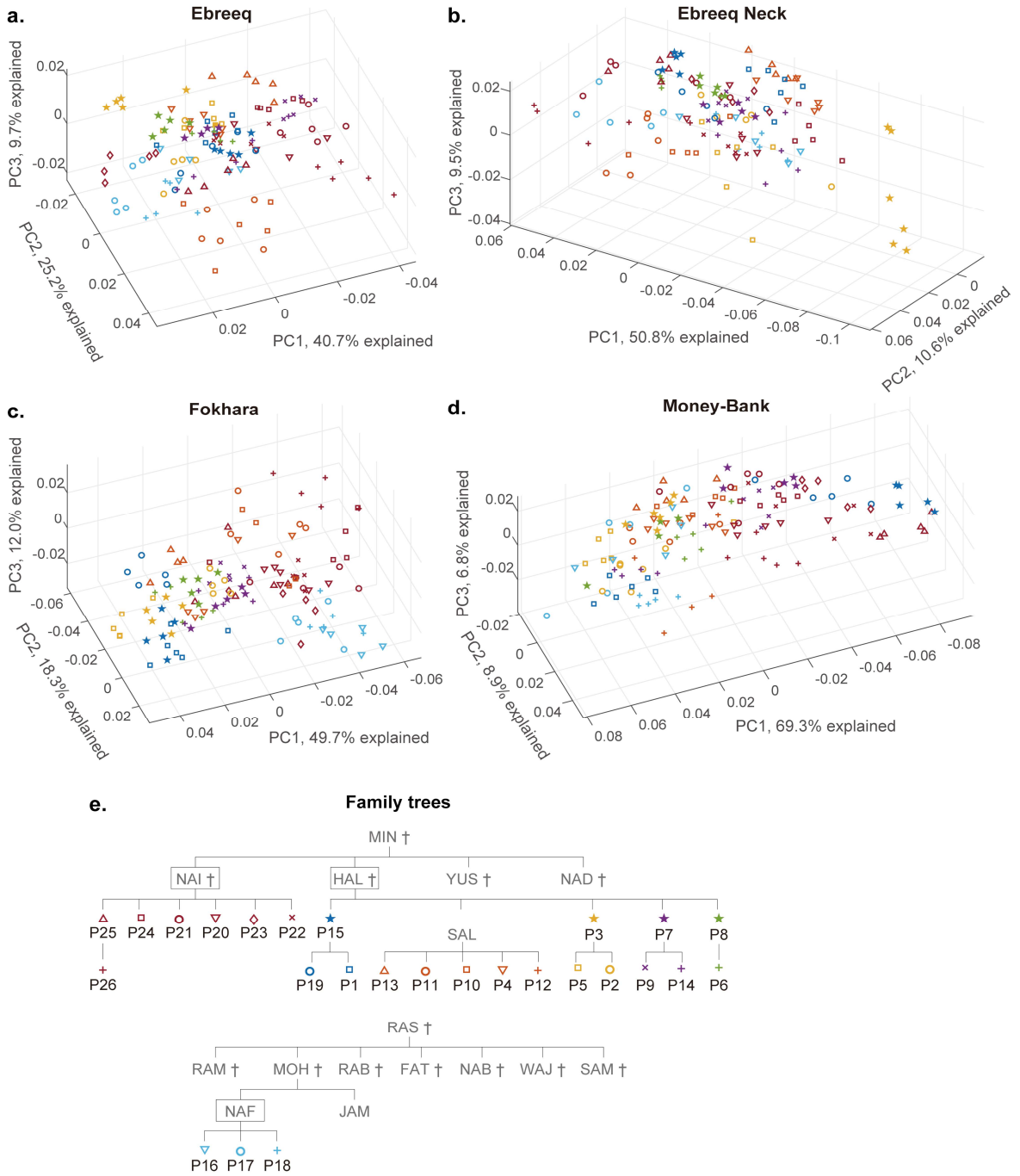

Figure 5. Vessels morphology represented in the three-dimensional PC shape-space. a. Ebreeq, b. Ebreeq neck, c. Fokhara, and d. Money-Bank, e. Family trees. All the vessels produced by the participants are presented. The three principal components (PC1, PC2, PC3) in the x, y and z axis are derived from principal component analysis on 40 sets of Elliptical Fourier coefficients of each pot shape. For all vessels, over 70% of the total shape variance was captured by these first three PCs. Potters from the same transmission unit are represented in the same colour, except those from the U8 who are represented by star-shaped markers. P26 is represented using the same colour as the transmission unit of his father and uncles. Family relations are represented in the bottom panel (e), where filial relations are indicated by vertical lines, and sibling relations are indicated by horizontal lines in which potters are sorted in an age-descending order from left to right. The potters under 25 years of age are represented by the markers "+".

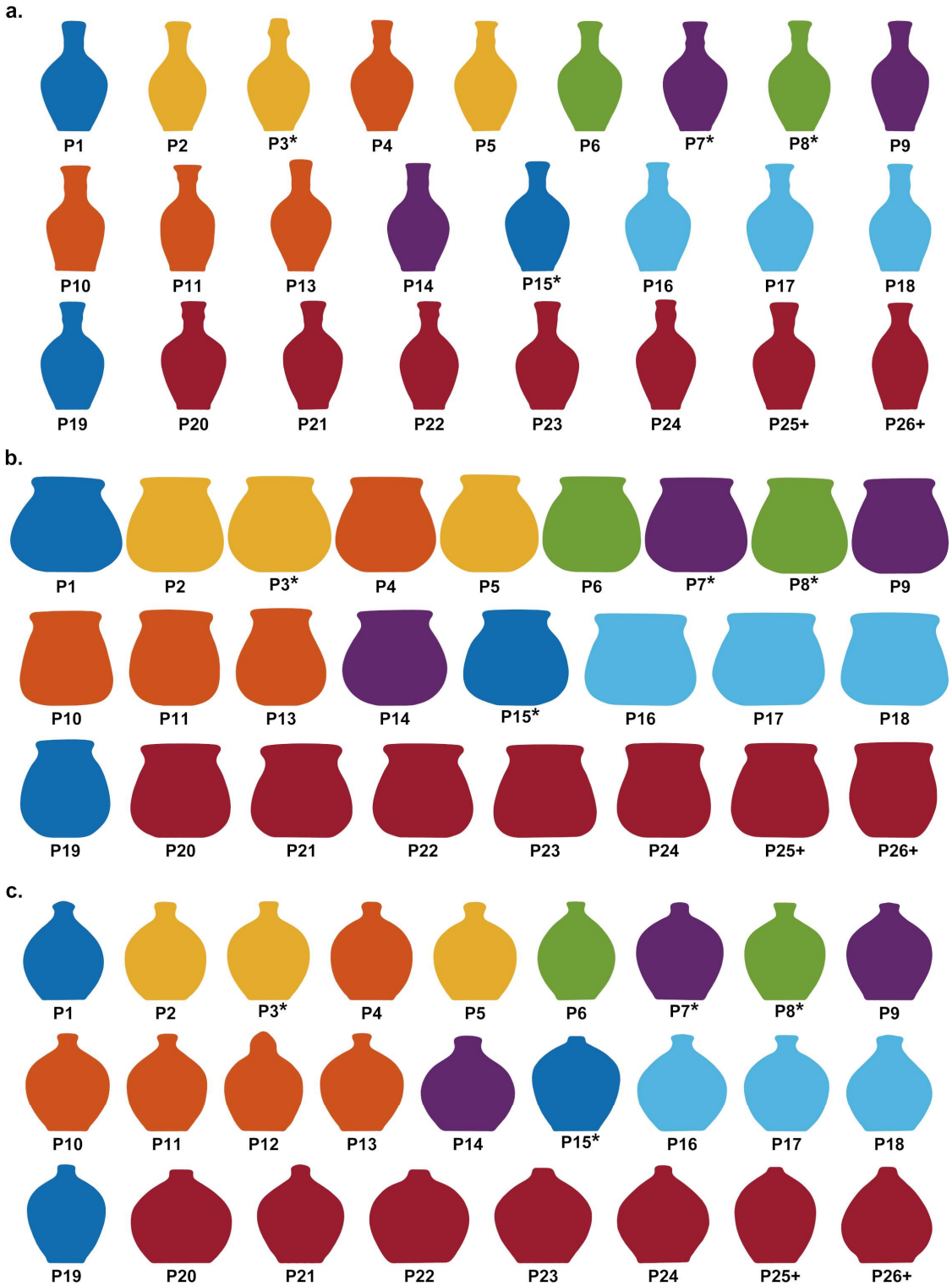

Figure 6. Mean individual shape of the vessels. a. Ebreeq, b. Fokhara, and c. Money-Bank. These shapes are reconstructed from the mean Elliptical Fourier coefficients of the five vessel replicates produced by each participant for each pottery type. Potters from the same transmission unit are represented in the same colour (U1: blue, U2: yellow, U3: orange, U4: green, U5: purple, U6: light blue, U7: red) or by the same symbol (U8: *, U9: +). Family relations are represented in Figure 2 and 5.

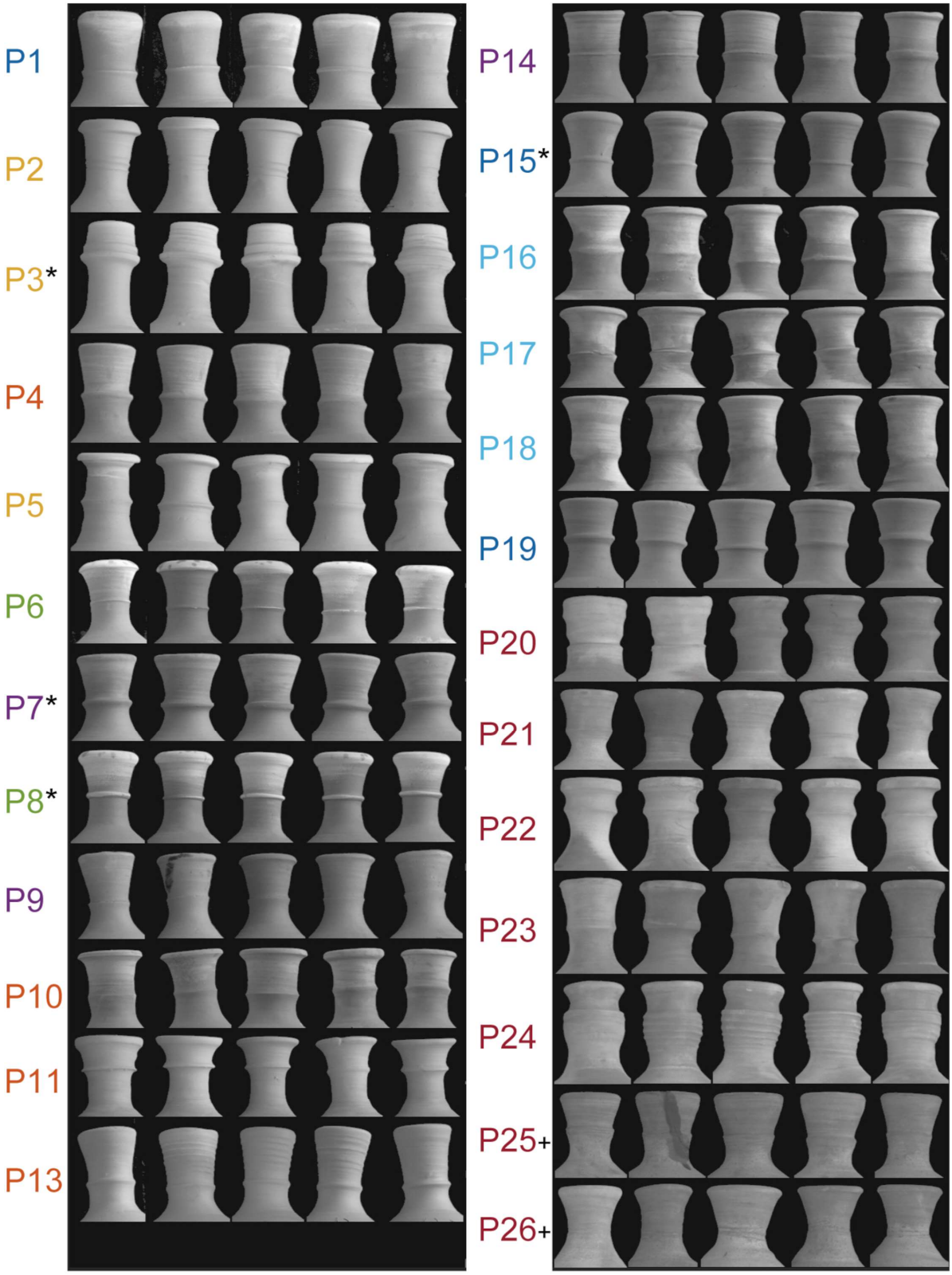

Figure 7. Photos of the Ebreeq necks. All the necks thrown by the participants are presented. The five necks thrown by one potter are presented in a row, with a label on the left side indicating the potter's number. Let's us recall that P12 did not produced the Ebreeq. Potters from the same transmission unit are represented in the same colour (U1: blue, U2: yellow, U3: orange, U4: green, U5: purple, U6: light blue, U7: red) or by the same symbol (U8: *, U9: +). Family relations are represented in Figure 2 and 5.

Hierarchical permutation tests run on the normalized Elliptical Fourier coefficients were used to interpret the results presented in Figures 5, 6, and 7. In line with our first operational hypothesis, these tests revealed a significant vessel shape heterogeneity among individuals and among the transmission units for the three pottery types (Table 3). Hence, even though the standardization of the productions at the level of the pottery-making community was high (Tables S1, S2, S3), there was still room for significant variation. Corroborating the results of earlier work (Roux & Karasik, 2018; Gandon et al., 2018), these results showed that potters left subtle but identifiable individual signatures on ceramic shapes, even on typical traditional pottery types produced for a common consumer market. The presence of individual signatures demonstrated that the vessels produced by the novices are not perfect copies of those produced by their trainers, although the transmission unit also affected the vessels. We conclude that the learning process modifies the ceramic shape, the culturally inherited traits being combined with new individual traits. We should stress that the individual signatures did not prevent individual shape variants within a single pottery type. For the modern vessel type Money-Bank these shape variants most likely correspond to the various customers preferences as explained by the participants; for the traditional vessel types Ebreeq and Fokhara, it is still unclear if these shape variants result from potter personal styles or from the existence of traditional shape variants transmitted by the previous generations of craftsmen.

To our knowledge, our results demonstrate for the first time the existence of familial signatures within the same community of potters made up of a few families of craftsmen. These signatures likely resulted from the social channelling occurring inside the transmission unit during the learning of the skill. In this respect, these signatures represent the cultural part of the potters' skill, which supposedly propagates across generations. Interestingly, these cultural signatures were non-significant for the Ebreeq necks which were marked only by individual signatures (Table 3, Fig. 7). We can then assume that the necks are the more relevant part of the vessel to be analyzed on ancient assemblages in order to detect individual signatures which has also been shown by Harush et al. (2020).

Permutation tests on U1, U2, U3, U4, U5, U6, and U9				
Pottery type	**Parameters**	**Df**	**F**	**P**
Ebreeq	Transmission unit	6	1.50	0.0429
	Individual	13	12.27	<0.0001
Fokhara	Transmission unit	6	3.28	0.0007
	Individual	13	6.83	<0.0001
Money-Bank	Transmission unit	6	2.01	0.0433
	Individual	14	10.49	<0.0001
Ebreeq Neck	Transmission unit	6	1.51	0.09049
	Individual	13	9.38	<0.0001
Permutation tests on U6, U7, and U8				
Ebreeq	Transmission unit	2	1.97	0.0496
	Individual	10	11.46	<0.0001
Fokhara	Transmission unit	2	9.25	<0.0001
	Individual	10	3.64	<0.0001
Money-Bank	Transmission unit	2	2.88	0.0405
	Individual	10	10.59	<0.0001
Ebreeq Neck	Transmission unit	2	0.95	0.5302
	Individual	10	11.57	<0.0001

Table 3. Permutation tests results. Hierarchical permutation tests were run on the 40 size-corrected coefficients resulting from Elliptical Fourier analyses of the vessels. For each pottery type, within-potter effects are based on the five replicates thrown by each participant. The tests were run separately for each vessel type (Ebreeq, Fokhara, and Money-Bank) and the Ebreeq necks. In the first round, the analysis tested the presence of significant vessel shape variation among the transmission units U1, U2, U3, U4, U5, U6, U9 and among the different individual potters (20 individuals for Money-Bank, and 19 individuals for Ebreeq and Fokhara because P12 did not produce these two pottery types). In the second round, the analysis tested the presence of significant vessel shape variation among the transmission units U6, U7, U8 and among 14 individual potters (for all three types).

3.1.3. Conservation of cultural traits through transmission

Figures 8, 9, S2, and S3 present the dendrograms of the participants' mean vessel shapes, for the Fokhara, Ebreeq neck, Ebreeq, and Money-Bank respectively. These graphs indicate that the differences between the two families MIN and RAS, the three families HAL, NAI, NAF, and the nine transmission units varied across the three pottery types. Differences appeared between the two families MIN and RAS and between the three families HAL, NAI, and NAF, especially for the Fokhara and to a lesser extent for the Ebreeq and Money-Bank, corroborating the results of the permutation tests (Table 3). At the level of the transmission unit, the differences were predominantly blurred by the individual signatures on vessel shapes, for the three pottery types. Yet, several clustering units stood out, indicating that the transmission units

still left some traces on the vessel shapes: for the Fokhara the potters from U4 and U6 produced mean vessel shapes similar to each other within each unit, while the mean vessel shapes produced by potters from U1, U2, U5, U7, and U8 were similar to a less extent; and the mean vessel shapes produced by potters from U3 and U9 mainly diverged within each unit. For Money-Bank, contrary to Fokhara the potters from U3 produced similar mean vessel shapes. This can be explained by the fact that the five brothers of this transmission unit produced Money-Bank in a high rate (except the youngest one P12) (Table 1). For the transmission units U1, U2, U5, U6, U7, and U9 a partial clustering was noticeable, while no significant clustering appeared in U4 and U8. For Ebreeq, the potters from U1, U2, and U6 produced similar mean vessel shapes within each transmission unit. By contrast, the mean vessel shapes produced by potters from U4, U7, and U8 were less similar, and those produced by potters from U3, U5, and U9 even less. When we focus on the Ebreeq neck only, although there were a few pairs close to each other from the same transmission unit (e.g., P18 and P16, P22 and P20, P25 and P21, P10 and P11, P4 and P13), most of the neck shapes were distinct between individuals, showing the strong effects of idiosyncrasy in producing the neck of Ebreeq (see also Table 3). Overall, the resemblance between the family trees (Fig. 2) and the dendrograms (Figs. 8, 9, S2, and S3) was present but weak, and the strength of resemblance within each family and transmission unit differ according to the vessel type. For example, the family resemblance found in Fokhara was not apparent in the neck of Ebreeq. And the potters from U3 produced similar Money-Bank shapes, but dissimilar Fokhara shapes. These original findings do not support our second operational hypothesis and we conclude that cultural traits on ceramic vessel shape do not automatically propagate within the transmission chain. While we found with the permutation tests that the variability within each transmission unit was significantly smaller than the variability among the different transmission units, in terms of the distance between each potter's mean shape, some potters from the same transmission unit were similar, while others were not (Figs. 8, 9, S2, and S3). The same pattern of results was visible in the PC shape-space: while some potter's vessel shapes from the same transmission unit were close to each other, others were closer to potter's vessel shapes from other transmission unit (Fig. 5). Hence, even if cultural traits were inherited from the family and the transmission unit, they were diluted by individual traits which came to the fore. As for biological evolution, a given vessel shape is a combination of culturally inherited traits (i.e. the social bias occurring through learning) and both random and non-random effects. Random effects (like genetic drift in evolution) come from random idiosyncrasies among potters, and non-random effects (like natural selection in evolution) come from environmental effects such as the market demand. These observations

predict frequent evolutionary divergence of vessel shapes over time, both within and among potters (Futuyma, 2005; Nielsen and Slatkin, 2013). We also observed on Figure 9 the two atypical Ebreeq neck shapes produced by P3 and P24 (Fig. 7), and on Figure S2 the atypical Ebreeq shape produced by the learner P26 (Figs. 5-a and 6), this latter showing the initial learning difference which presumably is the source of future variation and even evolution of shapes.

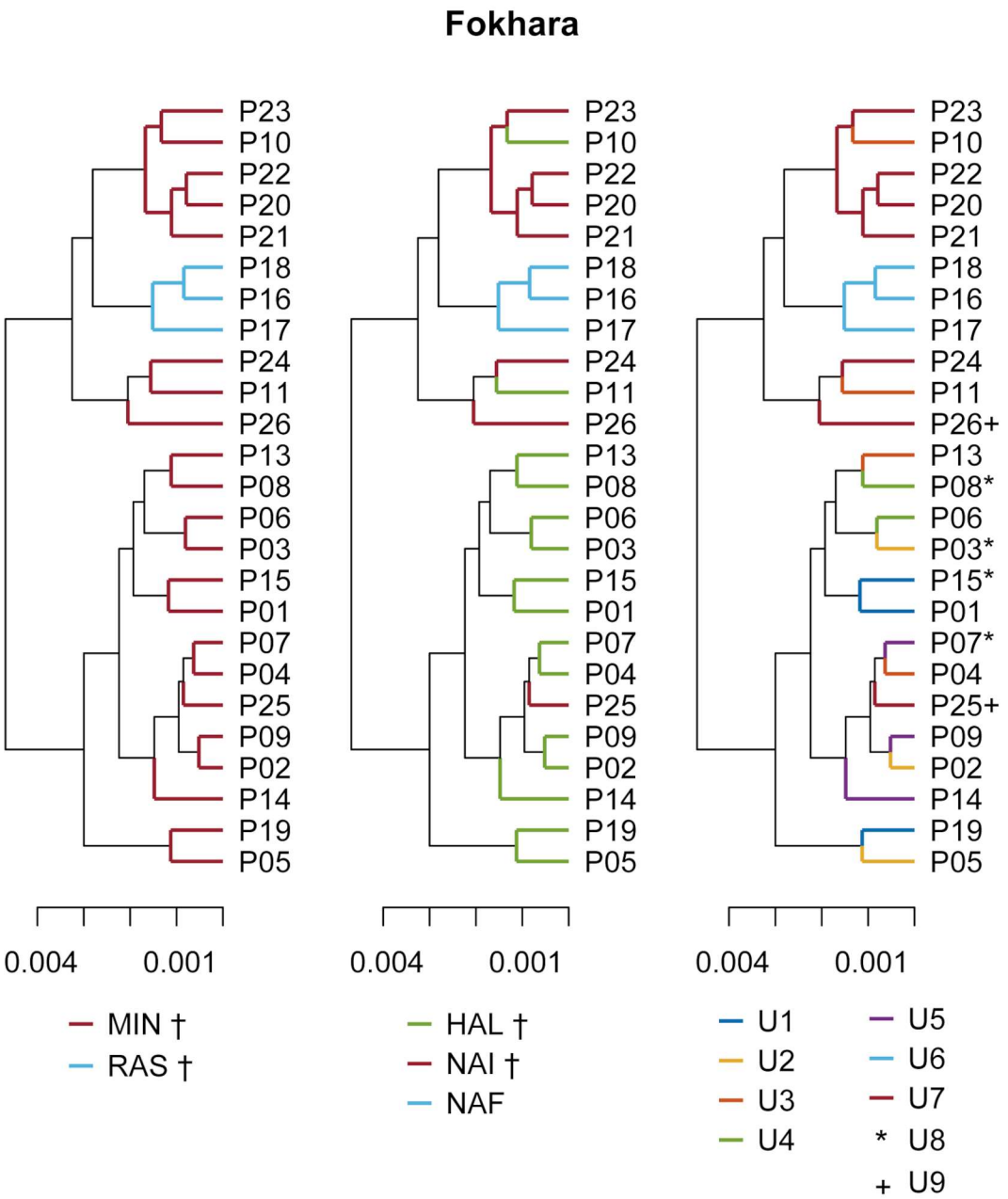

Figure 8. Dendrograms of the mean vessel shapes for the Fokhara. The mean vessel shapes of Fokhara produced by all participants are presented. The similarity between the mean vessel shapes of the different participants is indicated by the point at which the branches diverge. The distance of the divergence between the branches is indicated in the horizontal axis. The further right the diverging point is, the more similar are the mean vessel shapes in the corresponding branches.

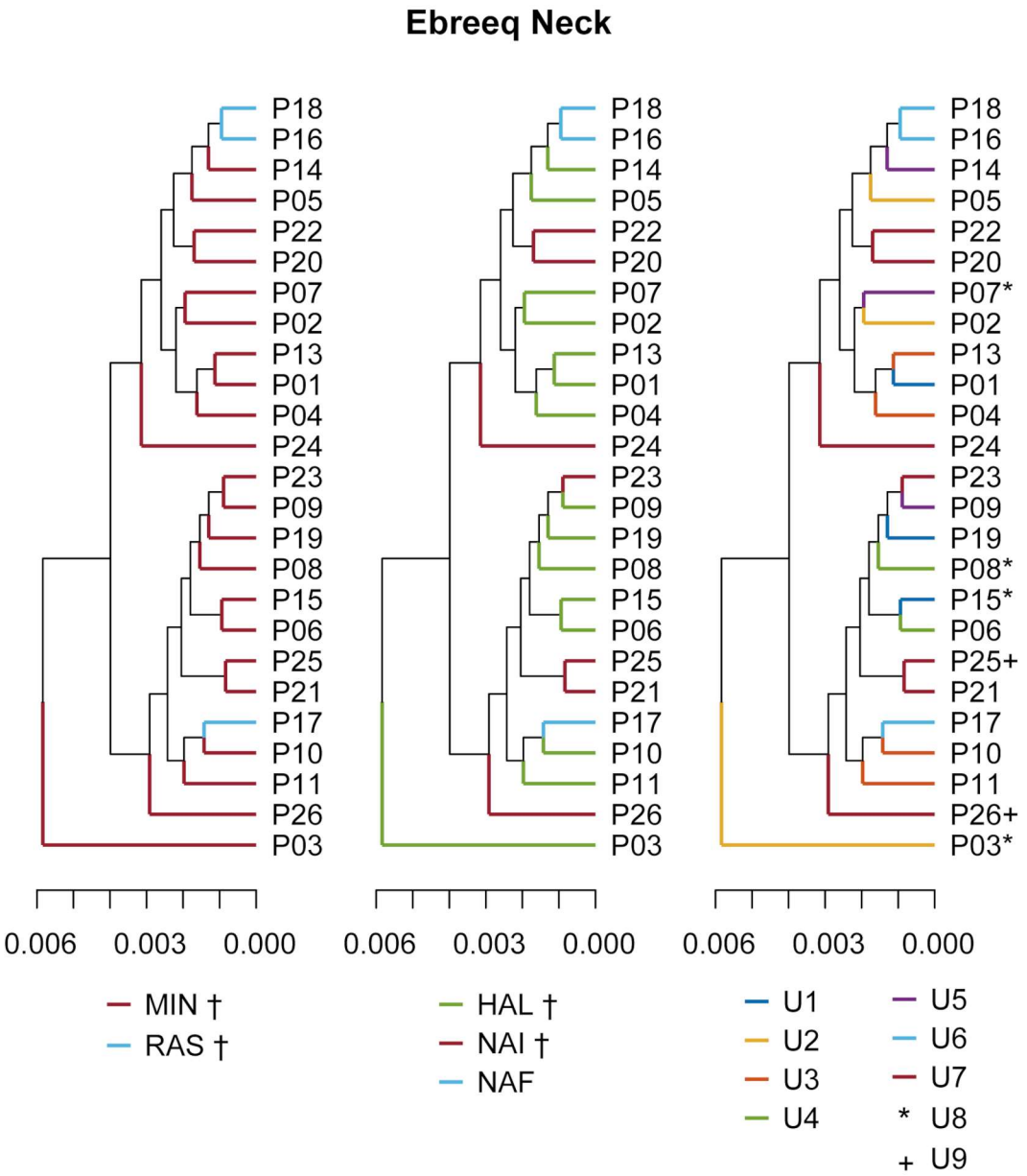

Figure 9. Dendrograms of the mean vessel shapes for the Ebreeq necks. The mean vessel shapes of Ebreeq necks produced by all participants are presented. The similarity between the mean vessel shapes of the different participants is indicated by the point at which the branches diverge. The distance of the divergence between the branches is indicated in the horizontal axis. The further right the diverging point is, the more similar are the mean vessel shapes in the corresponding branches.

3.2. Identification of the vessels

Figure 10 presents the performances of the potters when they were asked to recognize their own vessels and those of their colleagues. The among-participant mean number of correct answers was 11.2 ± *4.4*, which represents more than half of the total 18 vessel-groups examined (62%). Hence, as we expected in our third hypothesis, potters do perceive to some extent the individual signatures on ceramic shapes. Differences among the participants were observed: one potter correctly identified all the 18 vessel-groups, three potters correctly identified 16 vessel-groups, 13 potters identified more than 9 vessel-groups, and four potters correctly identified less than 6 vessel-groups. These performances were not significantly related to the age of the potters ($t(19) = -0.95$, $p = 0.34$), nor their experience ($t(19) = -0.98$, $p = 0.32$) and no tendencies of relation were observed. A factor which could influence the vessels' identification is the potters' personalities, such as perfectionism or curiosity which would enhance the observation of the vessels from the different individual and workshops. For example, P7 explained: *"I like to observe, this is not the case of everyone."* The participants identified their own vessels proportionally better than those of their colleagues: 2.6 ± *0.7* (87%) correct answers in average for a total of 3 vessel groups examined (Fig. 10, bottom panel). Because the sample size of the two groups (self-vessel vs. others-vessel) was different (3 and 15 respectively), we cannot provide a statistical test of this result. Yet, we assume that the identification of self-vessels is easier for the potters because of a longer exposure, as it is easier for pianists to identify their own musical performances (Repp and Knoblich, 2004). Pottery Type did not influence statistically the performances ($KW(2) = 3.54$, $p = 0.17$) (Ebreeq: 4.1 ± *1.8*; Fokhara: 3.9 ± *2.0*; Money-Bank: 3.2 ± *1.7*). But the lower identification score for the Money-Bank is probably due to its limited frequency of production (Table 1). Finally, the transmission unit vessels were not significantly better identified than the extended family vessels: 4.7 (± *2.7*) and 4.0 (± *2.7*), for the transmission unit and extended families respectively ($t(20) = 0.85$, $p = 0.40$). This can be explained by the tight relations existing between members of extended family.

The fact that participants identified to some extent the vessels' producers confirms our third operational hypothesis and leads to the conclusion of a possible influence of the potters' choice in the selection and evolution of ceramic shapes. The interviews done with the potters just after their participation in the task revealed that they detected the vessels' producers through different visual characteristics including the vessel size, the colour of clay, and the shape of the

whole vessel. Other characteristics allowed them to identify specifically each pottery type: Ebreeq were mainly identified by their neck, Fokhara by their aperture, and Money-Bank by their bud. In fact, because of curvature changes and the presence of lips, these vessel parts concentrate morphological information, and thus potential morphological variations constituting possible individual or family styles. Sustaining this interpretation, recent accounts of social group signatures in Indian water jars showed that the distinction between the Hindu and Muslim communities depended upon the jar rim curve length and neck curve (Harush et al., 2020). Participants also noticed the similarity between the vessels of different individuals: *"The vessels of HIS and his son MOH are highly similar"* (P13), *"My vessels look like those of my brother HAKA"* (P4). The vessels aesthetic and the standardization of vessel-groups were also underlined and attributed to a specific potter (P8). In contrast, the vessels with imperfections were attributed to the less advanced potters (P14, P26, and P10 for the Ebreeq). As a test, the experimenter (E. Gandon) performed the vessel identification task under the instructions of her assistant (W. Alqaraja). Because she observed the production of all vessels, photographed them all, and manipulated them for the setup of the identification task, it was expected that she could detect the different vessels' producers. Her performance was 14 correct answers for a total of 18 vessel-groups examined (78%). Overall, these results suggest that an exposure to the vessels in their context of production can be sufficient to recognize their producers, even by outsiders. As P2 and P5 said: *"I recognize the vessels of my father and those of my brother because I'm used to seeing them."* Importantly, this exposure to the vessels of others depends on the life history of potter who can change their usual workshop for economic reasons. For instance, at the end of our field work, P2 left his father (P3) workshop because he did not have enough work and joined the workshop of his uncle P7. The potter P19 also explained that he could easily identify the vessels of his cousin P2 because he worked with him a few years ago.

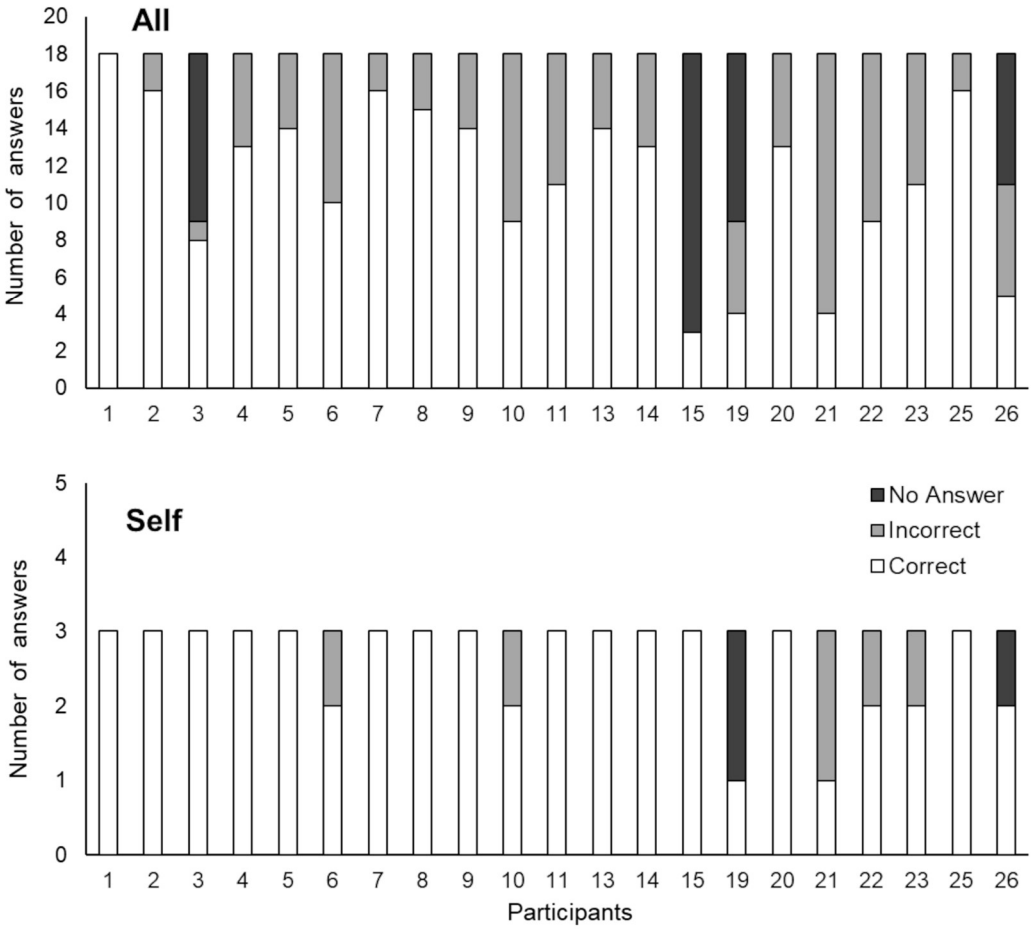

Figure 10. Performances of the participants in the vessel identification task. Top panel (All): number of correct answers, incorrect answers, and non-answers given by each participant when trying to identify the producers of the 18 vessel groups (3 self-vessel and 15 others-vessel groups); bottom panel (Self): number of correct answers, incorrect answers, and non-answers given by each participant when trying to identify his own productions (3 self-vessel groups). The participants P12, P16, P17, P18, and P24 were not available to perform this task.

4. Conclusion

Many studies have addressed the selective forces operating in cultural evolution (Dunnell, 1980), but the production of variation occurring through the transmission has not received much experimental attention. How much are the objects produced by learners different from those of their trainers? Do inherited cultural traits propagate through the successive transmissions across generations? Do craftsmen perceive individual morphological signatures within traditional object assemblages? We tackled these questions in examining the range of variability in vessel shapes produced by 26 potters from the pottery-making community of Hebron. As a long-standing crafting tradition, this community represents a valuable case study.

The participants – all men – belonged to three distinct families and were distributed through nine familial transmission units (Fig. 2). All participants were asked to produce, in controlled conditions, five vessels of three different pottery types (Ebreeq, Fokhara, and Money-Bank), then 21 participants were invited to visually identify their proper productions and those of five other potters.

At the scale of individuals, the coefficients of variation of the vessel absolute dimensions were limited, revealing the high level of practice of the participants in the wheel-throwing skill. This intra-individual variation of the vessel dimensions also revealed the irreducible copying error owing to the sensori-motor limits of human performances (Eerkens and Lipo, 2005), and the existence of individual shape variants inside each pottery type. At the scale of the pottery-making community, the vessel shapes produced by novices differed from those of their trainers, reinforcing the view of a socially mediated individual learning in handicraft. Across generations, traditional vessel shapes are not reproduced as perfect copies but with a combination of cultural inherited traits and individual traits. The fact that vessel shapes statistically differed among the 26 participants proved that these individual variants were not simply due to the human copying error but to the idiosyncratic manner with which each potter fashioned each pottery type. We propose that, for potters, traditional pottery types exist not as fixed templates, but as norms with certain range of variation regarding what is appropriate and what is not. The pool of individual shape variants owing to the learning process constitutes a set of appropriate possible variations allowing potters to adapt each pottery type to the current constraints of their socio-economic environment. For example, the Fokhara could have a flatter bottom for customers using gas stove, and the money-bank could have a limited maximal diameter depending upon the clay's hardness.

Concerning the evolutionary trend of the ceramic shapes, the findings contradicted our assumption that all cultural morphological traits propagate necessarily through artisan generations. Belonging to a familial transmission unit left cultural traits on the vessel shapes but the individual traits prevented the conservation of clear cultural traits across the two generations of participants in the present study. One could say that, from trainers to novices, a transmission of cultural traits exists but is not exclusive, which corroborates the fact that the learning process corresponds more to a socially mediated individual learning than to a fidelity copying. Our quantification of the vessel shape variation indicated that the individual traits

overtook cultural ones, which could lead to divergence of vessel shapes within the transmission chain. Hence, without stabilizing mechanisms, we could predict changes of the ceramic shapes over time, exhibiting evolution disconnected from the social organization of their production. However, when we compared the vessel shapes of a given pottery type (Money-Bank) produced by potters originated from four distinct pottery-making communities (Indian Prajapati, Indian Multani, Nepalese, and Palestinian), we observed that the subsets of vessels produced by each community were distinct from each other's ($F(3, 192) = 24.73$, $p < 0.001$) (Fig. S4). This indicates that ceramic shapes certainly carry inherited cultural traits transmitted through learning lineages. For future research, it would be challenging to develop a more qualitative analysis of the vessel shapes, isolating the various discrete morphological traits interwoven in the whole vessel shape. We hypothesize that certain traits could perpetuate through generations and even historical periods, although they do not constitute the whole shape (Harush et al., 2020). We stress that, if it is the case, our study demonstrated that such cultural continuity in ceramic shapes does not result from fidelity copying in the form of a reproduction, by the novices, of all the trainers' vessel morphological traits. Instead, this shape continuity could result from stabilizing mechanisms such as consumer demand, which directly influences the potters' choice. The results of the identification task supported this view, showing that potters do perceive the subtle same-type vessel shape variations and thereby could select the individual variant they prefer, notably disseminating it by reproduction. Importantly, not only expert potters perceive the morphological variations, but they are also able to produce new shapes without a long training period (Gandon and Roux, 2019). This imply that they can easily modify the shape of a given pottery type following their choice for new morphological traits.

In brief, the Hebron case offered insights into the cultural transmission and evolution of craft objects. The results highlight the individual part of the learning process and of the subsequent developed skills and vessels (Gandon et al., 2018; Gandon et al., 2020a, Gandon et al., 2020b). This study will help archaeologists to interpret the ancient ceramic shapes variation and to better understand how those shapes have evolved. Now, a new avenue of research is opened in order to disentangle the individual and cultural morphological traits. This is essential in order to obtain a thorough understanding of the evolution of morphological types across time and space. Finally, the craftsmen's ability to perceive shape variations certainly plays a key role in the selection and evolution of traditional objects' shapes. We demonstrated that craftsmen practicing in shared or neighbour workshops developed, probably through simple vessels

exposure, the ability to perceive the slight morphological differences characterizing the objects of each individual. The question remains to understand how potters' personalities modulate the development of this perceptive ability.

Acknowledgments

This work was supported by the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 793451 (PI, E. Gandon). It was also supported by the project "Traditional knowledge of the Hebron's potters and Heritage Resilience (Palestinian Territories)", National Geographic Society NGS-398R-18 (PI, V. Roux). We are grateful to Wesam Alqaraja who assisted us during the experiments, and to the potters, particularly to Wahed for welcoming us in his compound. We also wish to thank James Steele for providing project assistance, Patrick Quinn for the interesting discussions, Thom Rynsaard for his administrative support, and the two reviewers for helpful comments.

Dataset reference

The photos dataset is provided in a Zenodo repository link: https://zenodo.org/record/4589147

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Supplement Figures

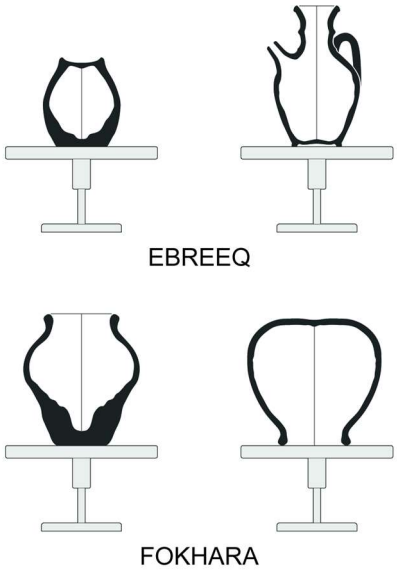

Figure S1. The two stages method of throwing used for the Ebreeq and Fokhara. In a first stage, the potter throws the roughout of the vessel keeping the lower part of the wall thick (left drawing). This roughout is then cut from the wheel and left to dry under conditions allowing the lower part to remain wet. In a second stage, the roughout is placed upside-down on the wheel (sometimes in a chuck, made up of leather-hard ring of clay) for the throwing of the final vessel (right drawing). Starting by the base or the upper part depends on the vessel type. For the Ebreeq, the potter starts throwing the base, while for the Fokhara he starts throwing the upper part. Starting by the base or by the opening depends on the location of the maximum diameter and enables the potter to overcome the risks of collapse while wheel throwing thin walls, from the bottom to the top without further post-throwing operations (drawings by X. Desormeau).

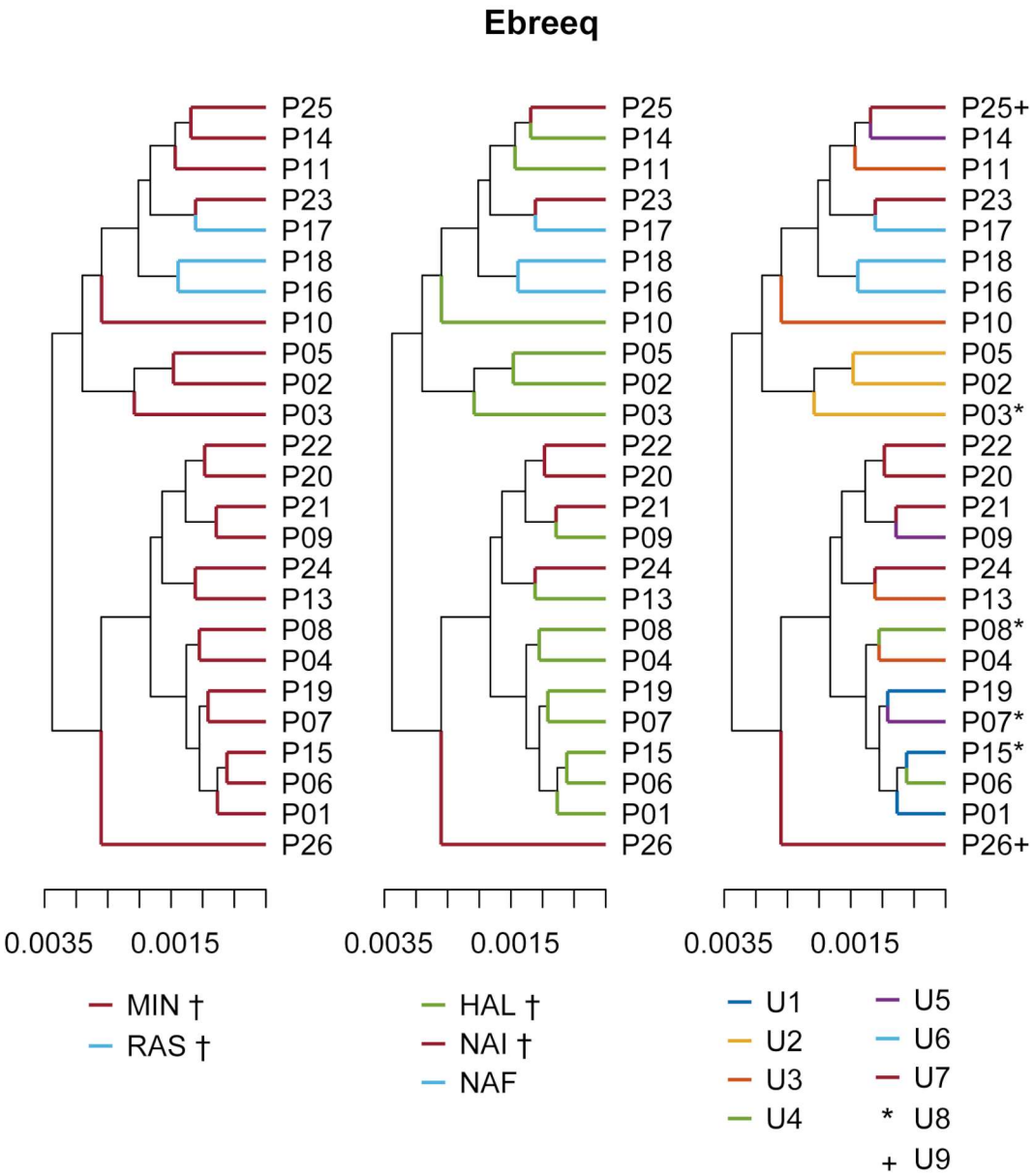

Figure S2. Dendrograms of the mean vessel shapes for the Ebreeq. The mean vessel shapes of Ebreeq produced by all participants are presented. The similarity between the mean vessel shapes of the different participants is indicated by the point at which the branches diverge. The distance of the divergence between the branches is indicated in the horizontal axis. The further right the diverging point is, the more similar are the mean vessel shapes in the corresponding branches.

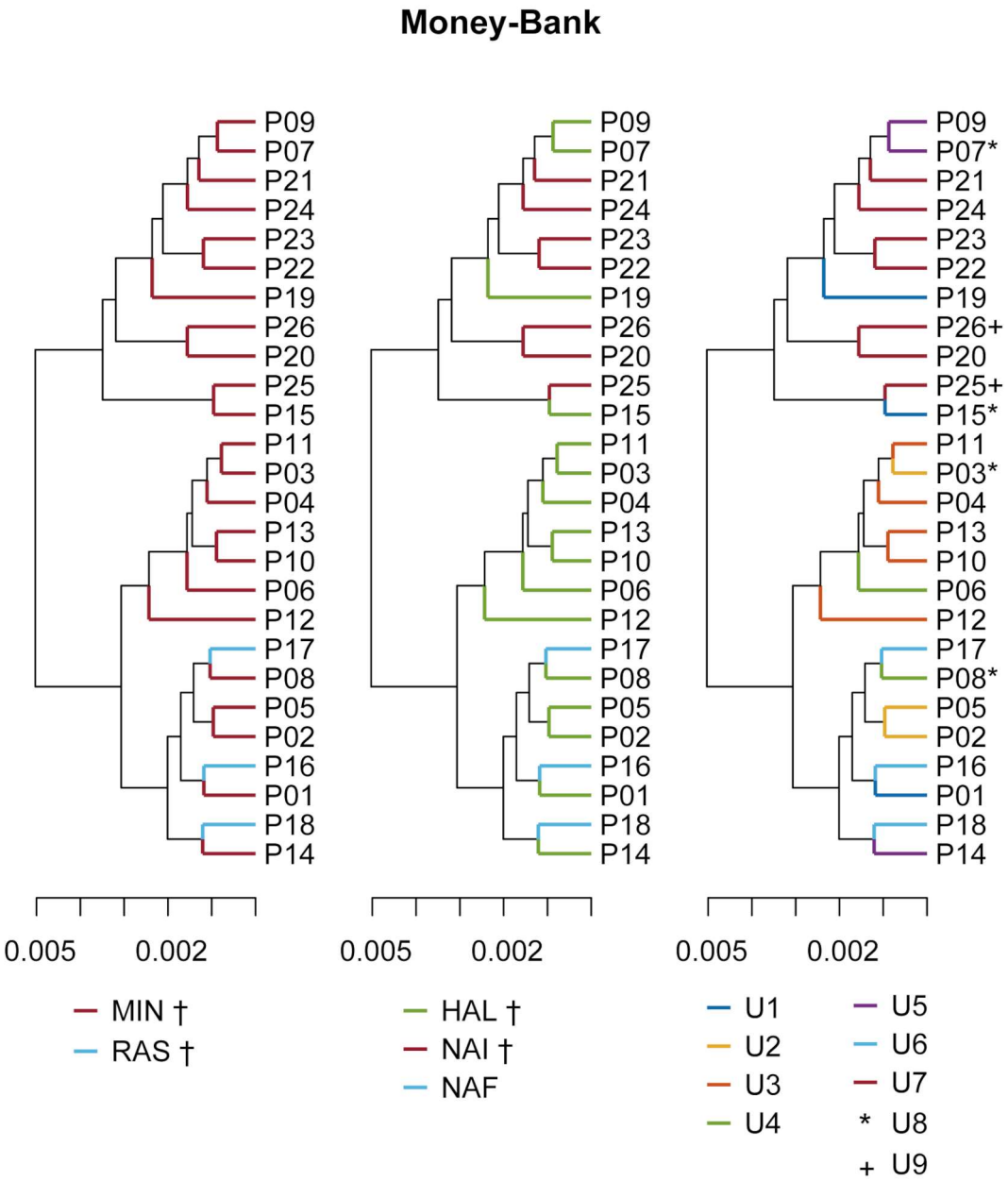

Figure S3. Dendrograms of the mean vessel shapes for the Money-Bank. The mean vessel shapes of Money-Bank produced by all participants are presented. The similarity between the mean vessel shapes of the different participants is indicated by the point at which the branches diverge. The distance of the divergence between the branches is indicated in the horizontal axis. The further right the diverging point is, the more similar are the mean vessel shapes in the corresponding branches.

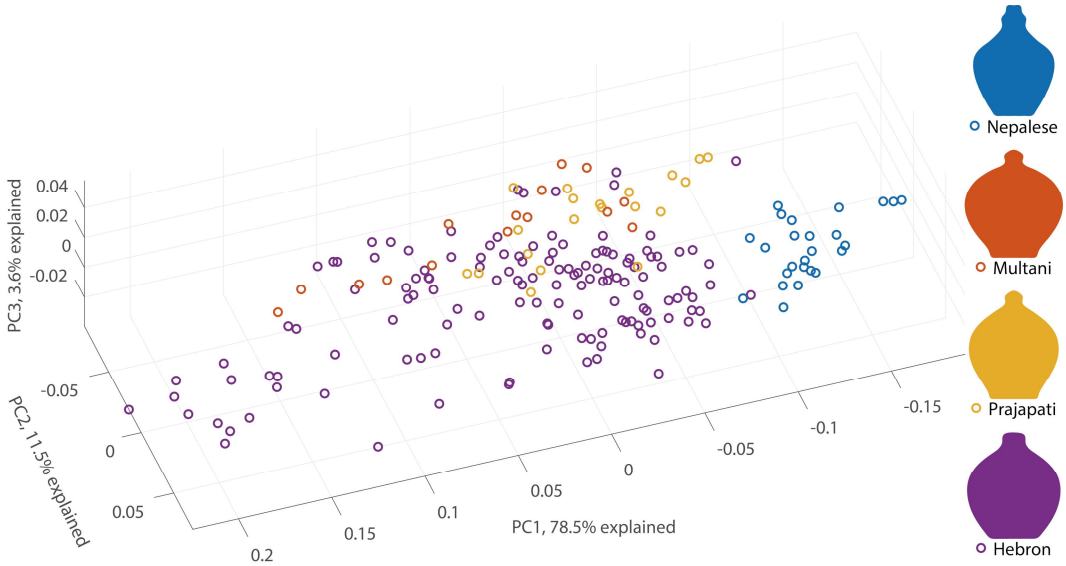

Figure S4. Geometrical distribution of the Money-Bank thrown by potters of four cultures. Indian Prajapati: yellow, Indian Multani: orange, Nepalese: blue, Hebron: purple. The points in the PC shape-space show the variations among potters, for the four groups, and are based upon Elliptical Fourier coefficients derived from every pot shape. The pot outlines (right of the graph) are reconstructions of the shapes resulting from the mean coefficients of each group's production.

Supplement Tables

Dimensions (cm)										
Ebreeq										
	B		H		A		MD		HMD	
Potter	**m**	***sd***	**m**	***sd***	**m**	***sd***	**m**	***sd***	**m**	***sd***
P1	8.8	*0.5*	29.4	*0.4*	6.7	*0.2*	17.9	*0.3*	12.2	*0.4*
P2	7.8	*0.2*	29.6	*0.9*	7.2	*0.6*	15.8	*0.3*	11.1	*0.7*
P3	8.0	*0.4*	30.4	*0.5*	5.1	*0.4*	17.2	*0.2*	11.7	*0.3*
P4	8.4	*0.2*	29.6	*0.3*	6.0	*0.2*	16.9	*0.3*	12.4	*0.4*
P5	7.5	*0.2*	29.2	*0.8*	6.5	*0.1*	16.7	*0.2*	12.1	*0.3*
P6	8.0	*0.2*	29.2	*0.6*	7.0	*0.2*	17.2	*0.2*	12.5	*0.4*
P7	8.4	*0.1*	29.8	*0.3*	7.1	*0.2*	17.7	*0.4*	12.7	*0.1*
P8	8.1	*0.3*	31.5	*0.6*	7.0	*0.2*	17.8	*0.4*	12.7	*0.4*
P9	8.1	*0.2*	31.2	*0.4*	7.2	*0.2*	16.5	*0.4*	14.1	*0.4*
P10	10.1	*0.5*	26.4	*1.0*	8.0	*0.3*	14.7	*0.6*	11.1	*0.8*
P11	8.4	*0.1*	25.6	*0.4*	7.1	*0.3*	13.3	*0.6*	10.1	*1.7*
P13	7.5	*0.2*	31.1	*0.6*	6.7	*0.1*	17.1	*0.2*	13.3	*0.6*
P14	8.0	*0.6*	25.8	*0.9*	6.3	*0.3*	15.0	*0.3*	10.1	*0.8*
P15	8.7	*0.2*	29.9	*0.5*	6.9	*0.1*	17.6	*0.5*	13.0	*0.2*
P16	10.2	*0.7*	30.0	*0.8*	6.9	*0.3*	18.2	*0.5*	12.7	*0.3*
P17	9.1	*0.7*	27.8	*1.2*	7.9	*0.3*	17.4	*0.5*	11.6	*0.7*
P18	10.4	*0.8*	29.2	*1.4*	7.3	*0.3*	17.0	*0.8*	11.3	*0.9*
P19	9.2	*0.8*	29.9	*1.2*	7.4	*0.4*	17.6	*0.7*	12.9	*0.7*
P20	8.2	*0.3*	27.2	*1.5*	6.6	*0.2*	16.3	*0.5*	12.4	*0.6*
P21	8.0	*0.2*	29.0	*1.0*	7.2	*0.4*	15.9	*0.5*	13.6	*0.7*
P22	8.6	*0.3*	30.3	*0.8*	6.9	*0.2*	16.5	*0.7*	12.6	*0.7*
P23	8.7	*0.2*	29.0	*0.8*	7.4	*0.4*	17.0	*0.5*	11.7	*0.1*
P24	7.7	*0.2*	29.7	*0.6*	6.0	*0.2*	16.2	*0.6*	13.4	*0.4*
P25	8.6	*0.4*	26.4	*0.6*	7.2	*0.2*	15.3	*0.3*	11.4	*0.5*
P26	8.7	*0.2*	27.8	*0.6*	6.8	*0.3*	14.7	*0.4*	11.6	*0.8*
m	8.5		29.0		6.9		16.5		12.2	
sd	*0.8*		*1.6*		*0.6*		*1.2*		*1.0*	

Table S1. Ebreeq absolute dimensions (centimeters). The mean and standard deviation are computed over the five replicates thrown by each participant. B: Base, H: Height, A: Aperture, MD: Maximal Diameter, HMD: Height of Maximal Diameter. The two last lines of the table present the among-participant mean and standard deviation.

	Dimensions (cm)							
	Fokhara							
	H		A		MD		HMD	
Potter	**m**	***sd***	**m**	***sd***	**m**	***sd***	**m**	***sd***
P1	16.2	*0.4*	12.0	*0.3*	18.9	*0.3*	8.3	*0.2*
P2	16.1	*0.8*	10.7	*0.1*	15.8	*0.7*	5.9	*0.5*
P3	15.0	*0.6*	12.0	*0.2*	16.5	*0.3*	6.5	*0.3*
P4	14.1	*0.6*	11.8	*0.1*	15.8	*0.3*	6.3	*0.4*
P5	16.6	*0.5*	10.9	*0.2*	17.1	*0.4*	8.2	*0.5*
P6	14.4	*0.4*	11.3	*0.3*	15.6	*0.6*	5.7	*0.3*
P7	16.5	*0.3*	14.9	*0.6*	17.0	*0.4*	6.8	*0.2*
P8	16.3	*0.2*	11.7	*0.2*	16.6	*0.3*	5.2	*0.3*
P9	17.8	*0.5*	13.2	*0.7*	15.6	*0.9*	7.0	*0.5*
P10	13.8	*0.8*	10.9	*0.3*	13.7	*0.4*	3.7	*0.4*
P11	13.0	*0.7*	10.2	*0.3*	12.6	*0.3*	4.7	*1.1*
P13	16.8	*0.4*	10.9	*0.8*	15.7	*0.5*	5.6	*0.2*
P14	12.9	*0.2*	10.4	*0.5*	14.2	*0.3*	4.9	*0.2*
P15	14.5	*0.5*	10.7	*0.4*	16.1	*0.6*	4.9	*0.1*
P16	11.9	*0.5*	12.3	*0.4*	14.6	*0.5*	3.6	*0.3*
P17	12.0	*0.5*	11.8	*0.3*	14.7	*0.5*	4.4	*0.6*
P18	12.1	*0.3*	12.0	*0.4*	14.3	*0.4*	3.4	*0.3*
P19	18.0	*0.5*	11.0	*0.3*	16.6	*0.4*	6.2	*0.3*
P20	13.3	*0.7*	11.6	*0.3*	14.4	*0.5*	4.4	*0.3*
P21	13.1	*0.6*	11.8	*0.8*	14.4	*0.6*	3.9	*0.3*
P22	13.7	*0.6*	11.9	*0.6*	14.8	*0.6*	4.3	*0.3*
P23	13.1	*0.8*	11.1	*0.6*	14.7	*0.5*	3.6	*0.3*
P24	14.4	*0.5*	12.5	*1.1*	14.5	*0.5*	4.9	*0.5*
P25	14.9	*0.8*	11.6	*0.4*	15.6	*0.8*	4.4	*0.5*
P26	15.2	*0.9*	12.8	*0.5*	14.2	*0.7*	6.7	*0.5*
m	14.6		11.7		15.4		5.3	
sd	*1.8*		*1.0*		*1.3*		*1.4*	

Table S2. Fokhara absolute dimensions (centimeters). The mean and standard deviation are computed over the five replicates thrown by each participant. H: Height, A: Aperture, MD: Maximal Diameter, HMD: Height of Maximal Diameter. The two last lines of the table present the among-participant mean and standard deviation.

	Dimensions (cm)							
	Money-Bank							
	B		H		MD		HMD	
Potter	**m**	***sd***	**m**	***sd***	**m**	***sd***	**m**	***sd***
P1	6.6	*0.3*	15.3	*0.4*	12.5	*0.2*	6.0	*0.2*
P2	4.9	*0.3*	11.9	*0.2*	10.0	*0.2*	5.0	*0.2*
P3	4.9	*0.2*	11.9	*0.3*	10.0	*0.2*	5.3	*0.1*
P4	5.6	*0.2*	12.5	*0.7*	10.4	*0.4*	5.5	*0.4*
P5	5.4	*0.4*	11.7	*0.4*	10.0	*0.4*	5.1	*0.2*
P6	5.0	*0.3*	12.9	*0.5*	10.3	*0.1*	5.5	*0.5*
P7	6.0	*0.4*	12.1	*0.5*	10.9	*0.3*	5.8	*0.2*
P8	5.3	*0.2*	12.6	*0.4*	10.5	*0.2*	5.9	*0.3*
P9	6.2	*0.5*	12.5	*0.5*	11.1	*0.4*	5.8	*0.2*
P10	5.2	*0.3*	12.9	*0.1*	11.0	*0.3*	6.1	*0.2*
P11	5.4	*0.6*	13.0	*0.8*	10.6	*0.5*	6.1	*0.4*
P12	5.3	*0.1*	12.4	*0.4*	9.8	*0.3*	5.4	*0.4*
P13	5.5	*0.1*	13.6	*0.3*	11.6	*0.3*	6.6	*0.3*
P14	5.7	*0.4*	10.6	*0.4*	10.4	*0.3*	4.3	*0.2*
P15	5.3	*0.2*	11.5	*0.6*	10.6	*0.3*	6.4	*0.4*
P16	5.3	*0.6*	11.6	*0.1*	10.6	*0.4*	4.9	*0.2*
P17	5.1	*0.4*	12.1	*0.4*	10.7	*0.3*	5.6	*0.5*
P18	5.4	*0.4*	11.2	*0.4*	10.0	*0.3*	4.5	*0.5*
P19	4.7	*0.2*	13.1	*0.6*	10.4	*0.3*	7.1	*0.3*
P20	6.3	*0.3*	10.0	*0.3*	10.7	*0.3*	4.5	*0.4*
P21	4.8	*0.3*	11.1	*0.3*	9.7	*0.3*	5.3	*0.4*
P22	5.7	*0.3*	9.4	*0.4*	10.0	*0.2*	4.4	*0.2*
P23	5.7	*0.3*	10.6	*0.5*	10.8	*0.5*	5.3	*0.5*
P24	5.4	*0.3*	10.6	*0.6*	10.0	*0.3*	4.4	*0.5*
P25	4.9	*0.3*	11.6	*0.6*	9.8	*0.3*	6.1	*0.3*
P26	5.8	*0.2*	10.4	*0.8*	9.8	*0.3*	3.7	*0.5*
m	5.4		11.9		10.5		5.4	
sd	*0.5*		*1.3*		*0.6*		*0.8*	

Table S3. Money-Bank absolute dimensions (centimeters). The mean and standard deviation are computed over the five replicates thrown by each participant. B: Base, H: Height, MD: Maximal Diameter, HMD: Height of Maximal Diameter. The two last lines of the table present the among-participant mean and standard deviation.

Pair	t	df	p
Ebreeq – Fokhara	-3.45	24	0.002
Ebreeq – Money-Bank	-4.21	24	0.0003
Fokhara - Money-Bank	-0.89	24	0.37

Table S4. Post-hoc t-test for the effect of pottery type on the coefficient of variation of the production.