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What a Bead Costs: An Experimental Approach to Quantifying Labor Investment in Olivella Shell Bead Production

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Replicative experiments provide opportunities to assess aspects of past behaviors that are not materially evident. I replicated the Olivella bead-making process to determine the time required to make the various types of Olivella beads that were common during different times in California prehistory. Beads were made using traditional tools and materials. Methods were based on both ethnographic accounts and analysis of archaeological bead-making evidence. The experimentally-derived measurements quantify the production, conveyance, and consumption of shell beads as measures of the time/energy investments they represent, converting bead counts into a "common energetic currency" (Rosenthal 2011:85). This provides a means for (1) quantitative economic analyses of bead wealth between different temporal and spatial contexts, and (2) comparisons between non-subsistence behaviors represented by beads, and subsistence-oriented efforts that are generally measured as time/energy expenditures. Converting beads into time-investment opens the door to novel approaches to assessing changes in the past.

In this paper, I summarize the results of replicative experiments aimed at answering the fundamental question: how much time did it take to make an Olivella bead, and how did this differ by bead type and across time? Beads made by Native California Indians from the shells of *Olivella biplicata* (now *Callianax biplicata*) were used as both decoration and a form of currency.[1] They occur in large quantities in many prehistoric sites throughout central and southern California—and to a varying degree—throughout much of western North America. Olivella beads varied in size, shape, and edge finish, and were sometimes made from different portions of the shell. Archaeologists have constructed and refined temporally and spatially meaningful classification schemes based on these differences (Beardsley 1954; Bennyhoff and Fredrickson 1967; Bennyhoff and Heizer 1958; Bennyhoff and Hughes 1987; Gifford 1947; Groza et al. 2011; King 1990; Lillard et al. 1939; Milliken and Schwitalla 2012). Archaeologists have also long recognized the great variation in labor investment—from beads that were simply whole Olivella shells strung together, to more intensively-crafted types split from the shell, drilled, and shaped into a variety of highly standardized forms (Arnold and Munns 1994; Gibson 1976, 1992; King 1990:106; Milliken and Bennyhoff 1993:337). Given the variety of Olivella bead types that came in and out of vogue over several millennia, the ability to compare the labor investment represented by a given number of beads, as opposed to just the quantity, provides a meaningful assessment of the contribution beads made to the social economies of the particular cultural groups that used them over time. Such contributions likely included indirect access to exotic materials, the ability to mediate resource fluctuations across space and over time, and alliance building—and ultimately, the development of social inequality (Arnold 1992, 2001; Arnold and Graesch 2001; Chagnon 1970; Gamble 2011, 2016; King 1990; Milliken and Bennyhoff 1993; Rosenthal 2011; Vayda 1967). Experimental replication of the bead-making process is an ideal approach for determining the relative labor costs of producing different bead types and providing us with a framework to better address these issues—both as a remedy for the general reliance on inference and guesswork as to how long craft activities may have taken, and as quantitative values that can be incorporated into models that more holistically assess the economics of prehistoric California Indian cultures.

Unlike beads made from whole Olivella shells (e.g., Spire-ground) that can be made by abrading away portions of the shell, or simply be collected from the beach, beads made from the shell wall (e.g., Saucers or Saddles) and beads made from the shell's callus (e.g., Cupped) require a multi-stage process involving reducing the shell, drilling a hole, and finishing the edges—and thus, also require several other tools (Arnold 2011; Gibson 1992). Therefore, it is important to consider not only the quantity of beads produced, but also the time invested to make a given quantity of beads. This is especially important when considering the increases or decreases in the amount of labor required as different types of beads came into fashion. In many studies, archaeologists rely only on the sheer quantity of beads as a differential reflection of wealth or status (e.g., Milliken and Bennyhoff 1993). However, different beads require differing inputs of time and labor. In particular, the use of different portions of the shell with varying thicknesses, as well as the production of beads with different shapes and sizes, requires different investments of time. Bead makers would have to weigh the decision to invest in bead production against other fruitful activities, such as foraging or material procurement. The decision to produce more costly beads at certain times would suggest that beads may have played an increasingly important economic role, eventually evolving into a form of currency (Bettinger 2015; Burns 2019). Here, the baseline cost of production is emphasized over value as it is more directly addressed by the replicative experiments described below. It should be noted, however, that the value of particular beads is subject to numerous post-production factors, such as culturally ascribed value, the distance over which beads are exchanged, the relationship of the giver and receiver, and specific contexts of use.

In order to provide a context to the "cost" of producing different bead types, a number of bead manufacturing experiments were performed, starting with modern, whole *Callianax biplicata* shells. The shells were processed, and bead blanks were shaped and drilled using the same tools and materials that would have been used by pre-contact California Indian bead makers. Though the primary goal was to determine the time required for each stage of manufacture, comparisons between bead types for each of these manufacturing stages produced a variety of both quantitative measures and qualitative insights, not only about the labor required, but also about the variable efficiencies of the techniques, tools, and raw materials that were employed. Observations on raw material consumption and failed splitting and drilling attempts provide a useful baseline for the expectable amounts of waste material and broken beads-in-production that are found at production sites (see Table 1). Average times for each production stage, by bead type, were calculated to provide a comparative table of the varying amounts of production time required for several of the Olivella bead types common to central and/or southern California during the Early, Middle, and Late periods (see Table 2). With these comparative labor 'costs' for each bead type in hand, shifts to stylistically new bead types through time can now be seen in energetic terms, and inferences regarding the economic implications of these shifts in form can be addressed quantitatively. In other words, using time investment rather than simply quantities of beads can more accurately inform us about differential access to labor and wealth between individuals with different quantities of beads, especially for bead types that did not co-occur temporally or spatially. In addition, the time it takes to make various bead types can inform us on general trends of greater or lesser labor investments by bead-making communities over time as popular bead styles shifted—especially in regions that lack a preponderance of direct bead-production evidence (Hughes and Milliken 2007:269; Rosenthal 2011).

BACKGROUND

Replicative data, such as those derived in this experiment, are useful for understanding the actual time investment required to produce the various Olivella bead types that went in and out of fashion through time. These data can also provide a measure of the importance these manufacturing activities held within the overall subsistence economy of bead-producing groups, as well as a measure of the value that these beads may have had either as currency for inter-group exchanges or for intra-group status differentiation. Importantly, without a quantitative measure of the direct or indirect time investments that beads represent, we face the difficult task of incorporating calculations of effort directed

Table 1

QUANTITIES BY BEAD TYPE OF EACH STAGE OF MANUFACTURE PERFORMED AND NUMBER OF FAILURES AT EACH STAGE

Type	Shells Split (n)	Blanks Produced (n)	Failure to Produce Blank (n)	Average Blanks per Shell (n)[a]	Total Drilled (n)	"Experienced' Drilled (n)[b]	Failed During Drilling (n)[c]	Number Shaped (n)	Beads Completed (n)
Wall Beads									
C3 Split Oval	5	3	2	0.6	37.0	22	1	5	5
F2a/F2b Saddle	13	18		1.4				5	5
G2 Saucer	14	33	1	2.4				6	6
L1/M1/M2 Rectangle[d]	5	8		1.6				11	11
Callus Beads									
K1 Cupped	22	19	3	0.9	15.0	7	2	8	8
Other									
A1 Spire Lopped	–							5	5
D1 Split Punched	5	4	1	0.8	4.0	–	–	5	5
C1 Split Beveled	–	–	–	–	–	–	–	5	5

[a]Includes all wall blanks suitable for making the target type. Cupped blanks include three failed attempts to remove a callus blank from the shell.

[b]Excludes all novice attempts and outliers removed using Chauvenet's Criterion (Lin and Sherman 2007).

[c]Drilling time from several failed attempts during the "Experienced" drilling trials is included in average drilling time calculations, as this rate of error is consistent with observations of broken beads-in-production recovered in archaeological contexts (Arnold and Graesch 2001).

[d]Early Period Class L1 Rectangles are morphologically similar to Late Period Class M1/M2 Rectangles, save for differences in thickness, perforation diameter, and shelf presence (Milliken and Schwitalla 2012:63), none of which affected the time spent replicating them in these experiments, so they are combined here.

Table 2

AVERAGE TIMES FOR EACH BEAD PRODUCTION STAGE AND FOR THE TOTAL PRODUCTION TIME FOR EACH TYPE REPLICATED IN THIS EXPERIMENENT

Type	Shell Splitting & Rough Shaping ($\bar{x}$, min)	Drilling[a] ($\bar{x}$, min)	Final Shaping ($\bar{x}$, min)	Total Time (min.)
Wall Beads				
C3 Split Oval	2.4	3.5	3.9	9.8
F2a/b Saddle	2.3		2.8	8.6
G2 Saucer	5.0		6.1	14.6
L1/M1/M2 Rectangle[b]	4.7		3.2	11.4
Callus Beads				
K1 Cupped	9.2	6.6	7.8	23.6
Other				
A1 Spire Lopped	–	–	0.4	0.4
D1 Split Punched	1.2	2.0	0.4	3.6
C1 Split Beveled	2.4	3.5	5.8	11.7

[a]All wall blank drilling trials are combined to calculate average, as final bead shape does not affect drilling rate, except Type D1, which were punched, not drilled. Callus drilling is calculated separately due to the greater thickness of this part of the Olivella shell.

[b]Early Period Class L1 Rectangles are morphologically similar to Late Period Class M1 Rectangles, save for differences in thickness, perforation diameter, and shelf presence, and M2 Pendants only differ from perforation location (Milliken and Schwitalla 2012:63). None of these traits affected the time spent replicating them in these experiments, so they are combined here.(Milliken and Schwitalla 2012:63), none of which affected the time spent replicating them in these experiments.

to their production or acquisition into the quantitative modeling performed by Human Behavioral Ecologists (Rosenthal 2011:85).

A number of researchers in California have called for experimentally-derived data on the labor investments required to produce different bead types (Arnold 2011; Arnold and Rachal 2002:204; King 1990:106; Milliken and Bennyhoff 1993:337). For instance, King (1990:201) suggested that the energy invested in artifacts, such as beads used as currency, is directly correlated with their importance within social systems, and called for replicative experiments focused on determining the time and energy spent on each stage of manufacture. Milliken and Bennyhoff (1993) discussed different hypotheses (including King's) explaining changes in Olivella bead frequencies in burial lots over time. They concluded that "the next step in mortuary bead lot pattern analysis must pay careful attention to variability in types of shell beads and the differing amounts of time needed for their manufacture" (Milliken and Bennyhoff 1993:391).

Some prior research on bead manufacturing proved helpful in approaching the experiments discussed here. Gibson's (1976:82-86) synthesis of ethnographic descriptions of Chumash bead-making techniques, and

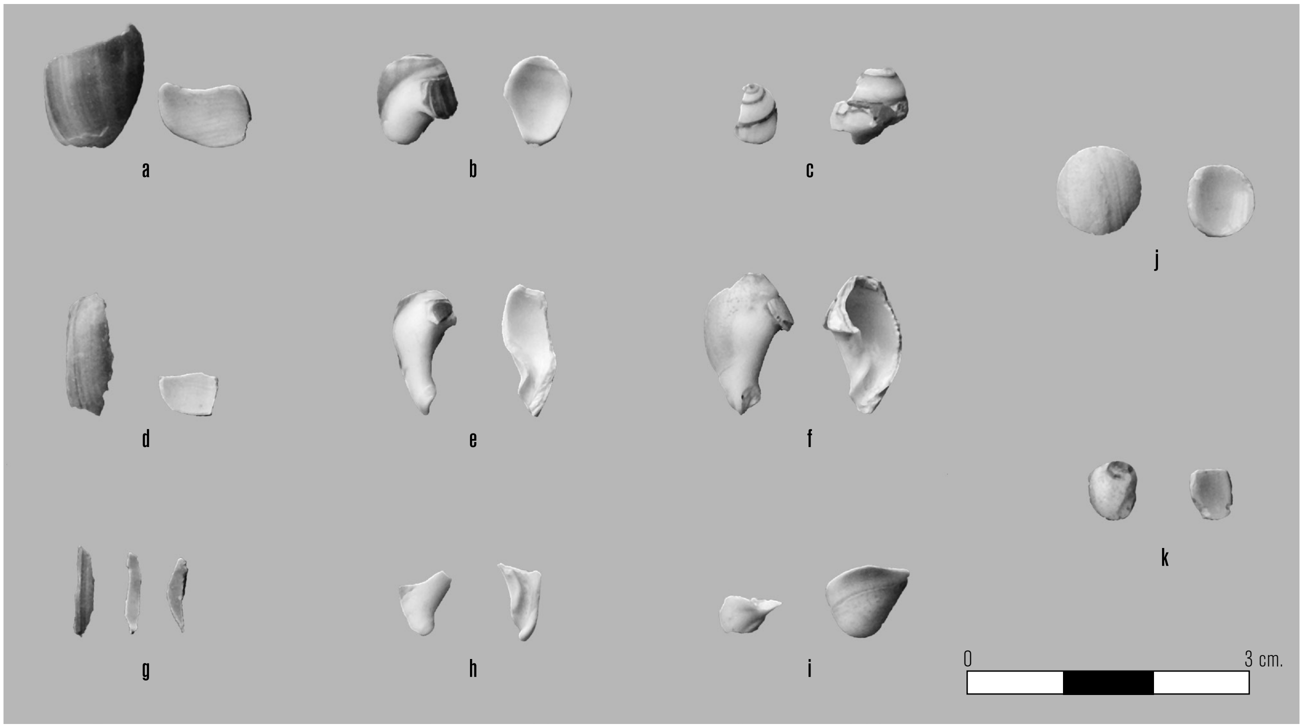

Figure 1. Olivella bead detritus typology created as part of this project, based on analysis of bead detritus from CA-SCRI-240 and CA-SCRI-236: (a) usable wall fragments; (b) upper columella; (c) spire fragments; (d) unusable wall fragments; (e) whole columella; (f) columella with wall; (g) wall splinters; (h) lower columella; (i) fasciole; (j) saucer bead blanks; (k) callus bead blanks.

Macko's (1984) descriptions of the shell-splitting process and classification of bead detritus, were foundational to the development of the methods used in this study. Based on an archaeological investigation of the shell detritus found at the Davis site (CA-NAP-539), Leslie Hartzell (1991) suggested a manufacturing sequence for M1a "sequin" Olivella beads, which proved useful in conceptualizing the stages of the experiment. Preziosi's (2001) analysis of microdrills used by the Island Chumash provided insight into the characteristics of different drill bit forms, specifically the varying strengths of different bit cross-sections.

GOALS

The initial goal of the present experiment was to replicate the prehistoric bead-making process as closely as possible by identifying the general patterns of production evident in archaeological samples of Olivella bead-making detritus. The production sequence and some of the major detritus signatures have been identified by Arnold and Munns (1994), Gibson (1992), Hartzell (1990), King (1990), and Macko (1984). Primarily following Macko (1984), I assessed bead-making detritus from two Santa Cruz Island sites, CA-SCRI-236 and CA-SCRI-240, where over 3,000 years of well-dated strata contained significant amounts of bead-making evidence. I created a detritus typology (Fig. 1) based upon the diagnostic patterns in samples from each period, and through trial and error, "reverse-engineered" a shell-reduction method for each major bead type made at the sites (i.e., Class L Thick Rectangles, Class G Saucers, and Class K Callus) that resulted in similar detritus. This method guided the initial steps of shell-splitting and bead-blank production.

The second goal was to reproduce beads of each type to determine the comparative labor rates involved in different production stages, divided here into shell splitting, drilling, and final shaping (Fig. 2). From this, the overall labor rates could be determined for several of the predominant Olivella bead types used through time in central and southern California, in order to assess spatial and temporal patterns of bead production, distribution, and use in a more economically-relevant framework than simple bead counts alone.

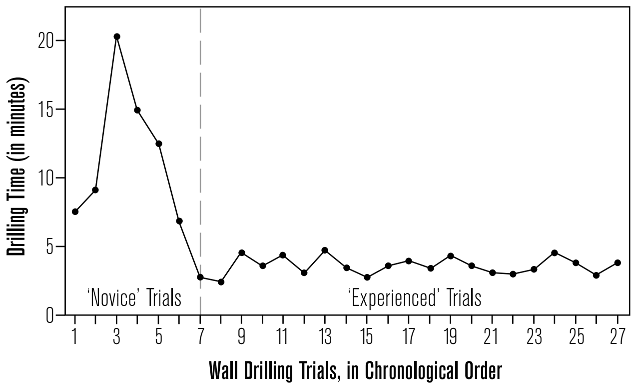

Figure 2. Wall blank drilling trials by one replicator, in chronological order. 'Novice' trials (1–6) were omitted from drilling time average calculation.

Despite the obvious value of increasing our understanding of the bead-making process and its attendant costs—in terms of differential labor investments through time, for example—an important consideration when performing replicative experiments is the recognition that modern experimenters are not perfect analogs for the craftsmen of the past (Ferguson 2010:5; Hansen 2008:70–71). California Indian bead makers were undoubtedly more familiar with the variables and constraints inherent in their traditional practices, such as obtaining high-quality chert, making suitable drill bits, using spindle-mounted stone drills, and assessing the material properties and constraints of the shell itself. They undoubtedly made many more beads in their lifetimes than we did here. In recognition of this, the data collected here were assessed to determine the 'learning-curve' effect; for example, final time estimates for drilling in particular were based only upon "experienced" trials (i.e., those that occurred after the initial learning curve 'flattened' and improvements in skill were no longer apparent). I was the only individual who practiced long enough to achieve consistency in drilling; however, the shell splitting/rough shaping and final shaping times of three other experimenters were included in the labor assessments for those phases, since their times were not appreciably different from my own. The final calculations are also offered as a set to be used in internal comparisons—although the actual time a native California beadmaker spent to make a particular type of bead has not been precisely determined here, the time differences between the types replicated here likely mirror, at least relatively, the differences in time that were actually spent in the past.

METHODS

A small number of the (empty) shells used in these experiments were collected from beaches in northern California by myself, while some were given to me by colleagues. In order to complete the experiment, shells were also purchased commercially. Shells ranged in size from 9 to 14 mm. in width, corresponding to Bennyhoff and Hughes' (1987:117) medium and large sizes. The first stage of replication involved splitting whole Olivella shells in order to produce bead blanks. Following Arnold (2001:77), a bead blank is defined as a fragment of the correct portion of the shell that is of suitable size, condition, and perimeter shape to produce the intended bead type once drilling and finishing are completed. In any given trial, experimenters selected a particular bead type as a goal, familiarized themselves with the dimensions and attributes of that type as described in Bennyhoff and Hughes (1987) and Milliken and Schwitalla (2012), and attempted to produce blanks suitable for that type.

For most trials, shells were split using the "spire-tapping" method, based on descriptions by Macko (1984:10); this involved holding the shell spire-end up on a sandstone anvil and applying percussive force to the spire with a small hammerstone until the shell fractured into two or more pieces. The shells selected generally had intact or nearly intact spires; however, the latter did not appear to expedite the shell-splitting process—even intact spires were shattered within a few seconds of tapping. Following the alternate shell-splitting method described in Macko (1984:10), Class L and M Rectangle beads, Class C and D half-shell sized beads, and a portion of Class K Cups were produced using the "side-tapping" method, in which the shell was laid on its side, the spire was removed using a large chert flake, and the shell was then carefully reduced to preserve the target portion (the callus, in the case of cupped beads, or large, intact sections of wall, in the case of wall beads).

I performed a trial experiment to assess the utility of cutting bead blanks from the shell wall using a chert flake—this was not expedient or successful in producing any blanks, and so was not pursued further. Though some evidence of shell cutting has been seen archaeologically (e.g., at CA-NAP-359; Hartzell 1991:36), this is not described by Fernando Librado (Gibson 1976:83), or is evident in the volumes of Island Chumash bead-making detritus that I or others have analyzed (Arnold and Graesch 2001: Arnold and Munns 1994; King 1990).

Blanks that were produced during the shell-splitting phase were shaped further by laying wall pieces flat and chipping their edges with an antler tine or large chert flake. Heat treatment of the Olivella shells has been described ethnographically and is evident in the archaeological record (Arnold and Rachal 2002; Hartzell 1991); however, due to time constraints, the effects of heat treatment were not addressed in this experiment.

The second stage involved drilling bead blanks, subsequently classified as beads-in-production (Arnold 2001:77). Drills were made of variable-quality Franciscan chert acquired from secondary sources in the central California coast range, and durable, high-quality crypto-crystalline silicates from the Mojave Desert. Suitable drills were hafted to wooden spindles 25–30 cm. in length and 8–10 mm. in diameter made from hardwood shoots (e.g., oak, dogwood, maple). Spindles were custom-notched to accommodate the flake, which was then "hot-glued" in place; I initially used pine pitch and asphaltum but switched to hot glue to minimize the time I spent maintaining drill hafts. Sandstone hammerstones, antler tines, and various types of expedient and formal chert flakes were used for the shell splitting and rough shaping of bead blanks. Sandstone cobbles of varying grit that had relatively flat surfaces were used for the final shaping and finishing stages. No noticeable wear was produced on any of these tools during the experiment. When drilling, the blank was supported by either a tabular piece of sandstone with a small depression pecked into it (i.e., a miniature bead anvil; cf. Gamble 2015: Fig. 12.5) or on a leather pad placed over a small, bead-sized depression in the ground where the experimenter was sitting. Drilling times were significantly reduced as a replicator's experience increased; therefore, the drilling times reported here omit the earliest attempts, which greatly exceeded the average rate that was ultimately achieved.

The final step, finish shaping, was carried out individually on each bead by hand on tabular sandstone abraders. Stringing whole sets of drilled beads-in-production and then finishing them *en masse* would have been ideal, especially for round Saucer and Cupped beads, which are reported ethnographically to have been finished in this way (Gibson 1976); however, for that finishing method to be used, two dozen or more blanks of a particular form are needed. Unfortunately, we were unable to produce that many beads of one type during any of the several separate replication trials that my helpers and I performed in 2011, 2015, 2017, or 2018. Future research will be directed at this issue, particularly for Cupped beads, but my experience thus far suggests that for most wall-bead types, the finishing times would not have been reduced significantly, as some amount of time would be required to get each blank to a similar shape and size before stringing and mass-grinding. However, mass-grinding would be more effective in creating sets of beads that were consistent in diameter.

Information on the total number of shells used, and the number of blanks produced, was tallied independently for each bead type, as were the failures in producing a blank and the failures that occurred during drilling (Table 1). The total time for each of the (1) shell splitting and blank forming, (2) drilling, and (3) final finishing stages was recorded. From this, the average time to make a fully-finished bead of several different types was calculated (Table 2). Calculations include the time spent during attempts in which no usable bead blanks were produced in either the shell splitting and blank forming stage, or the drilling stage. No failures occurred during the final finishing stage.

To provide a contrast between the various formally-made bead types, five A1 Spire-Lopped and four type D1 Split Punched beads were made in order to assess the labor savings of making expedient beads. Spire Lopped beads were rubbed on a sandstone abrader to remove their spires, which accounts for the entire production process for that type. Split Punched trials started with splitting a whole shell and chipping a large section into a blank. A hole was then punched by placing the blank on a sandstone anvil and using a hammerstone with a stout, cylindrical chert point as a punch. Edges were partially finished, as is typical for these beads (Bennyhoff and Hughes 1987:125). The time for each step, as well as the failure rates for each step, were recorded.

Some bead subtypes vary from others in their class primarily on the basis of the additional finishing characteristics present (e.g., type C1, G4, or various incised beads; Bennyhoff and Hughes 1987; Gibson 1992:15). To assess how the extra step of dorsal grinding affects the total finishing time, five trials were performed to determine the additional time required for dorsal grinding for type C1 Split Beveled beads. These are morphologically similar to type C3 beads in silhouette, except that the dorsal surface is ground below the perforation, producing a triangularly-shaped flat section from perforation to edge (Bennyhoff and Hughes 1987:Fig. 4a–c). The trials started with mostly undrilled bead blanks that met the metric criteria for type C1 beads. Dorsal grinding times, as well as the occasionally necessary additional edge-finishing times, were both added to the total average time for type C3 beads.

RESULTS

Shell Splitting and Rough Shaping

The shell splitting and rough shaping phase starts with a whole shell. It is complete when the fragments split from the shell are reduced enough to be suitable for making the target bead type. These fragments are then further reduced into bead blanks. Initial shell splitting using a bipolar spire-tapping method was more reliable in producing certain wall beads, and only marginally effective in producing large rectangle or callus bead blanks. Often, two to three bead blanks could be obtained per shell for Class M Sequin, Class L Thick Rectangle, Class G Saucers, and smaller Class F Saddles, but at a cost of the additional time required to produce more than one blank. The spire-tapping method was ineffective for the reliable production of larger Class F, C, or D blanks, where only one blank per shell can be produced, as it tended to fracture the shell right below the shelf, as well as damaging the canal end of the shell (opposite the spire). The side-tapping method proved more effective for predictably producing wall fragments suitable for making large quarter to half-shell bead blanks, as well as large rectangle, saddle, and callus bead blanks. However, though this method provided more control over the results, it came with the cost of a steeper learning curve for proficiency, and slightly more time was spent per blank than on smaller, rounder beads (e.g., smaller saucers or saddles) that appear to have greater tolerances during shell splitting in terms of the likelihood of producing at least one suitable blank. In other words, larger, more-rectilinear beads often had at least one dimension whose size required that more care be taken during the shell splitting than smaller, rounder bead forms. Though only five shells were split using the side-tapping method to produce eight rectangle bead blanks, more rectangle blanks per shell, on average, would probably be achievable with a little more practice.

Suitable wall fragments that were produced during the shell-splitting phase were roughly shaped into the target blank shape using a chert flake or antler tine to chip away excess material in small increments. This step required working with the ventral side of the bead blank up, and the affected edge had to be carefully supported by the work surface so that the blank did not split at an unintended location. When shaping rectilinear bead forms in particular, long fragments of wall could be snapped off in line with the growth lines of the shell to arrive at a suitable rough size. Though this technique added to the initial splitting and rough-shaping component of rectangle bead production time, it appears to reduce the amount of final shaping required to finish the beads. Round forms such as saucers, however, tended to require a greater amount of chipping time to reach a suitable bead shape, as the fragments split from the shell were rarely round in form (Table 2). No use wear was visible on the tools used to split the shells or rough-shape the bead blanks.

Table 1 shows the sample size, the average time per blank, and the average number of blanks produced per shell during the splitting and rough shaping trials. Unsurprisingly, the smaller the bead, the easier it was to get at least one, and sometimes two to three, blanks from one shell. This contrasts with callus bead-blank production, given that the callus portion of the shell is only of sufficient size to make one blank per shell. Only one blank per shell is possible for larger, quarter to half-shell beads, such as type C3. It is surprising, given how much thicker the callus is than the wall, that only one wall bead-blank fractured during drilling, whereas two callus blanks failed during this step. Failure rates during each stage were higher for novices, especially during early, exploratory trials performed before data collection began, but these are not included in Table 1.

Table 2 shows the varying amount of time required to produce each replicated bead type, as well as the average time required during each stage of production. Notably, the thicker callus portion proved much more difficult to chip, and more progress was often made by grinding the blank into rough shape rather than chipping. A general

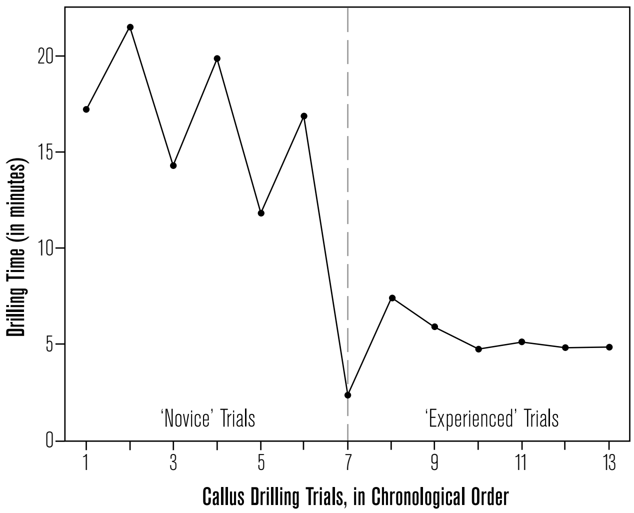

Figure 3. Callus blank drilling trials by one replicator, in chronological order. 'Novice' trials (1-6) were omitted from drilling time average calculation.

trend that is evident in the data is that symmetrically-round beads take significantly longer to both rough out and to finish shaping. Split Oval and Saddle blanks conform more to the natural shape that the Olivella shell wall fractures into during splitting, and so less chipping was required to get these close to a finished form.

Drilling

Based on previous drilling experiments, I hypothesized that callus beads would take significantly longer than wall beads to drill, but I also recognized that drilling would be the same, on average, for all wall-bead types. This is because the perimeter shape of the bead has no bearing on the drilling process; only the thickness of the portion of the shell that was used was pertinent. Therefore, all wall-bead drilling times were aggregated to determine the average wall drilling time (Table 2).

Before calculating the average drilling time for both wall and callus drilling trials, 'novice' drilling trials were separated from 'proficient' trials. Figures 2 and 3 show wall and callus drilling times, respectively, in the chronological order in which they were performed. I drilled a total of 26 wall bead blanks and 13 callus bead blanks over the course of the experiment (Fig. 4). Despite years of prior experience in both making stone tools and using spindle drills, the first six attempts were highly variable for both wall and callus drilling. This primarily represents trial and error in discovering drill-bit material

Figure 4. The author drilling an Olivella "bead-in-production" with a spindle-mounted chert drill.

suitability, improved sharpening of drill bits to maximize durability and effective drilling, and a determination of how much downward pressure an Olivella wall fragment could handle without splitting.

For wall bead drilling, after the six initial trials, a clear leveling-out in drilling time takes place: the average drilling time decreases threefold from 11.9 (SD=5.2) to 3.5 (SD=0.7) minutes per hole (Table 2). The average drilling time for callus beads, also excluding the first six trials, is 6.6 minutes (SD=1.3)—a nearly three-fold reduction from the 16.9-minute average of the first six attempts (SD=3.5). For both wall and callus drilling, the leveling-off during later trials coincides not only with increased experience but also with the decision to use only higher-quality chert drill bits (which required additional forays into the field to find better quality chert!). This is true for both the durability of the material the drill is made from and the cross-section that the end of the bit is knapped into. Generally, a triangular to trapezoidal cross-sectioned bit far outperforms and outlasts a lenticularly cross-sectioned bit. Variation in shell thickness did not appear to affect the remaining variability between the experienced trials—the Coefficient of Variation (CV) of the total callus drilling time during experienced trials was 30%, whereas the CV of callus drilling per mm. was 41%. Shell hardness, drilling technique, and drill bit characteristics likely contributed to the variation seen in trials seven through 20 (Fig. 3).

Final Shaping and Grinding

Shaping the drilled beads-in-production to their final dimensions proved to be a fairly simple and straightforward process for all of the participants in the experiment. A number of sandstone abraders of different grits were available to us. Medium to rough-grit abraders proved the most efficient for rapid material removal without any damage to the bead. Finer-grained abraders were inefficient for rapid material removal, especially after the "pores" of the abrader filled up with shell dust and the surface became smoother. No other use wear was evident on the abraders.

Occasionally an antler tine or chert flake was used to reduce the bead-in-production's size prior to grinding in order to expedite the process. The actual time required to shape a bead depended on the original size and shape of the rough blank relative to the intended bead type, as well as the thickness of that particular blank. The latter appeared to be more substantial between the wall-bead types and type K1 Cupped, but occasionally a particularly thin or thick wall portion would be encountered. In my experience, this is consistent with the variability within bead lots of individual types, so finishing times were not parsed out by bead thickness.

Five type C3 Split Oval beads, five type F2b Oval Saddles, six type G2 Saucers, eight type K1 Cupped, and eleven type L1a Thick Rectangles (morphologically, these also would be typed as M1a) were finished to completion (Table 1). Average times are reported for each in Table 2. Smaller variants of each of the types replicated here likely took more time to finish, though in such cases a smaller initial blank would have significantly expedited finishing. Paralleling my observations during the rough shaping of blanks, the most striking difference in practice was the greater simplicity in finishing a rectilinear bead than a symmetrically rounded bead—one simply ground a side flat, then rotated the bead 90 or 180 degrees and continued until it was finished. To some degree this was true for Saddle beads as well, even though their corners were also rounded off. However, the much greater blank production time for Class L or M rectangle beads makes them more labor-intensive to make than saddles, which took comparatively less time overall.

Evenly rotating round beads, particularly saucers and cupped beads, and achieving a smooth, symmetrical finish proved much more difficult than smoothing the edges of a large oval bead (e.g., C1 and C3), or the flat-grinding or corner-rounding involved in rectangle and saddle bead production. This trend is clearly visible in the differences in average shaping time between each of the replicated bead types. Finishing the edges of saucers takes up to twice as long as it does for the other wall beads. Cupped beads take a couple of minutes more to finish than a saucer, but not double the amount of time; this was unexpected, given that they are nearly twice as thick as wall beads.

Still, the final shaping of callus beads to approximate type K-1 Cupped beads averaged 7.8 minutes (n = 8, SD = 2.0), which was the greatest amount of time spent on the edge-finishing of any of the beads. A high degree of variability in final shaping time was probably due to differences between the starting size and roundness of the callus blanks for each trial. Cupped beads, as with saucers, were likely strung and finished in sets on a large abrading stone, as described by Longinos Martinez in 1792 (Gibson 1976:85), and by J. P. Harrington's consultant Fernando Librado (Gibson 1976:83). This technique would probably reduce edge-finish times and provide a more standardized finish, but it was beyond the scope of this study.

Bead Variants

Type A1 Spire-Lopped Bead Trials. Five whole Olivella shells were spire-ground in order to produce medium (type A1b) and large-sized (type A1c) spire-lopped beads. This whole-shell bead type simply requires the spire of the shell to be removed so that a string can be passed through the shell—no shell splitting, drilling, or further refinement is required. The average time to create an opening of 2–3 mm. in the spire was 0.4 minutes. Many *Callianax* shells are found on the beach with the spire already worn down naturally, which should be taken into account when applying this production rate to type A1 bead lots (Rosenthal 2006). In essence, this is the most expedient form of Olivella bead that could be made or traded, and as such, their manufacture was probably incidental to other economic pursuits, and was often probably less labor-intensive than collecting the shells.

Type D1 Split Punched Bead Trials. Five shells were split using the bipolar percussion method, producing four suitable blanks. One of the four blanks was fractured in half during the punching process. Accounting for the time investment in the failed beads—an unavoidable cost given the expediency of this method—the average splitting, punching, and final shaping times produced a total bead-making time of 3.6 minutes (Table 2), which is less than half of the total production time required to make the most expedient drilled wall-bead type (F2 Saddles) in Table 2. Bead edges were semi-ground, similar to the three illustrated in Milliken and Schwitalla (2012), which contributes to the low overall production time. Smaller, more well-formed punched bead variants probably took additional time to complete, but probably dramatically less time than drilled wall beads.

Type C1 Split Beveled Bead Trials. One bead-in-production and four bead blanks that were suitable for making type C1 beads were ground on the dorsal surface toward the canal end of the shell in order to determine the additional time this Class C subtype would take to make versus the more common members of the class. Blanks were ground parallel to the original axis of the shell (along the bead length) on sandstone abraders of varying grit. A medium-grit abrader produced the best results. Four of the blanks required additional edge finish to return the bead to an acceptable perimeter shape for a Split Beveled bead. The average beveling and edge refinishing time of 1.9 minutes was added to the final shaping time of 3.9 minutes for type C3 Split Oval beads, producing an estimated total average production time of 11.7 minutes for the type C1 Split Beveled bead variant (Table 2). Type G4 Ground Saucers, though not replicated here, are similarly finished but with dorsal grinding focused around the perforation (Bennyhoff and Hughes 1987:133). Based on my analysis of hundreds of ground saucers from CA-SBA-81, I would expect the additional finishing time for the dorsal grinding of Split Bevel C1 beads is probably higher than that required for G4 Ground Saucers, on which the grinding is often minimal, so a type G4 bead would require at most no more than the 1.9 extra minutes on average that the dorsal grinding of type C1 beads requires. Future replicative experiments are needed to verify these estimates.

DISCUSSION

It is worth restating that when assessing the results of replicative experiments, remember that the participants do not have the same level of skill or the same goals as the people they are imitating (Ferguson 2010:5). The current experiment sought data that would be useful in developing hypotheses on the time requirements and associated aspects of Olivella bead manufacturing, hypotheses which could then be applied to the vast quantities of beads in the archaeological record. In addition to determining labor rates for the different stages of manufacturing described above, a number of general aspects of bead production also became apparent during the experiment, aspects which will be useful in anticipating variables that can be either controlled or assessed in future experiments. Some of these may also provide some helpful insights during the analysis of archaeologically-recovered bead lots, particularly with regard to identifying production patterns at bead-making sites.

The Bead-Making Process

During the drilling trials, a number of factors involving tool-stone quality and drill bit design were discovered that had a significant effect on drilling rates. Early in the experiment, an assessment of drill-bit manufacturing and retouch times was abandoned due to the radical variation encountered within the first set of drill bits. The varying levels of brittleness and knapability of the different types of chert used in the experiment affected not only drilling efficiency but drill-bit manufacturing and retouch as well. These variations were most apparent in the significant difference in production efforts between drills; some would produce just a few beads before exhaustion, while other drills of higher quality held up through dozens of perforations with little retouch. Once the proper material to produce the latter was identified, drilling times not

Table 3

CHANGES IN BEAD PRODUCTION TIME-INVESTMENT PATTERNS IN CENTRAL CALIFORNIA BASED ON EXPERIMENTAL RESULTS

Time Period (Groza et al. 2011)	Temporal Range (B.P.)	Predominant Bead Type[a]	Hours per 100 beads	% Change Over Previous
Early	5,000–2,450	L1	19	–
Early-Middle Transition	2,450–2,150	C1	19.5	+3%
Middle 1	2,160–1,530	C3/G2[b]	20.3	+4%
Middle 2-4, MLT[c]	1,530–685	F2/F3[d]	14.3	–30%
Late Phase 1	685–440	M1/M2	19.0	+33%

[a]Predominant types for each period are based on locally-produced types. For instance, Class K were present in Central California during Late Phase 1, but were likely imported from Southern California, whereas Class M were locally made.

[b]Times for Types C3 and G2 were averaged. An assessment of the relative proportion of each type's prevalence is required for a more accurate estimate.

[c]Middle-Late Transition (MLT) is included here for simplicity, though in central California the diversity of bead types increases significantly, with no region-wide "predominant" bead type (Groza et al. 2011:148–149).

[d]Times for F2 were used here.

Table 4

CHANGES IN BEAD PRODUCTION TIME-INVESTMENT PATTERNS IN SOUTHERN CALIFORNIA BASED ON EXPERIMENTAL RESULTS

Time Period (King 1990: Table 1)	Temporal Range (B.P.)	Predominant Bead Type[a]	Hours per 100 beads	% Change Over Previous
Early	5,000–2,450	L1	19	-
Middle 1	2,550–2,150	G1[b]	>24.3	>28%
Middle 2–5	2,150–800	G2	24.3	0
Late 1	800–450	K1	39.3	+62%

[a]Predominant types based on frequencies represented in King (1990:Graph 2).

[b]Type G1 Tiny Saucers were not made during this experiment, but their total manufacture time should be higher than G2 beads due to more extensive edge-finishing.

only decreased and become more consistent, they did so significantly. This result supports the inference that careful tool-stone selection would have been a critical factor for mass-producing beads (cf. Arnold and Munns 1994). Several of the better drill bits used in the experiment were only retouched once every dozen or so beads, thus adding little to the overall duration of the production process. This was quite a contrast from the first few drill bits, which had to be retouched several to a dozen times to finish perforating one bead.

Applying Labor Calculations to the Archaeological Record

Temporal Changes in Labor Investment. The experimental production data presented here can be used to generate testable hypotheses on the amount of labor invested in beads, which can be applied on either an intra-site or regional scale. Tables 3 and 4 show the estimated time required to produce 100 beads of each of the types that predominated during each time period in central and southern California, respectively. The percentage increase or decrease in production times in comparison with the preceding period is also presented and provides some interesting patterns. The most significant change in time-investment in central California appears to be the 30% decrease after Middle Period Phase 1, when saddle beads become more prevalent than saucers and split drilled beads, followed by an approximately equal increase in Late Period Phase 1a, when type M1 Thin Rectangles replaced saddles as the most prevalent bead type (Table 3). Milliken et al. (2007:117–18) suggest these changes in bead types were tied to significant migrations into the region, which in conjunction with increasing population pressure required both technologically and socially adaptive innovations—beads may have played a central role in this regard, serving as a means to bridge the differences in a densely populated region with increasing cultural and linguistic diversity.

In southern California, fewer shifts in the prevalent bead types took place over these periods, but the 62% increase in time investment at the beginning of the Late Period as cupped beads replaced saucers is the greatest change in labor investment in either central or southern California (Table 4). The period of time during which this shift took place has been the focus of a decades-long and still-ongoing debate—one in which Olivella bead production, use, and exchange has played a major role—concerning what drove the rise in sociopolitical complexity and wealth inequality in the Santa Barbara Channel (e.g., Arnold 2001, 2012; Fauvelle 2011, 2012, 2013; Gamble 2011, 2016; Gamble et al. 2001; Johnson 2000; Kennett 2005; King 1990; Raab 1996). While there was a significant increase, it should be noted that during these experiments, cupped beads required no additional knowledge or technical skill for their perforation—in fact, the same drills were used for both wall and callus drilling. However, cupped beads did require a more methodical approach to splitting the shells in order to reliably get a usable blank. Instead of spire tapping, the bead was laid on its side, the spire was lopped off with a chert flake, and the bead was then pried or chipped apart along the wall/callus margin in order to isolate the callus without breaking it. Finally, the portion of the parietal wall that overlapped the callus (and which is not present on cupped beads) was pried and ground off. To roughly shape the callus blank into a cupped bead form, grinding on a sandstone abrader was generally more effective than chipping the perimeter of the blank. This latter process represents the majority of the increased splitting time over saucer blanks—which happens to be the only stage in the process that involves double the amount of time required for saucers. The other key difference that should be noted is that only one callus blank can be removed from a shell, whereas two to three blanks are typically produced during the five minutes spent splitting and rough-shaping saucer bead blanks. Given the difference in blanks produced per shell, cupped beads should produce two to three times more detritus for a given quantity of beads at Late Period bead-making sites. Therefore, the increase in bead production on the Northern Channel Islands during the Late Period may involve only a 200-400% increase—which is still significant, but is not the 600–1,000% increase reported by Arnold and Munns (1994:486).

Valuing Exceptional Bead Lots. As an example of the utility of converting bead-lot quantities to a measure of labor investment, I have converted the bead quantities involved in the largest Middle Period bead lot recovered in central California (Milliken and Bennyhoff 1993: Table 2). Burial 25 at CA-ALA-413 was buried with 28,287 saucer beads, which represent over 6,800 person-hours of manufacturing. This figure includes over 1,600 hours of drilling-related activity alone, without accounting for drill-bit manufacturing or retouch. Although it has long been assumed that saucers were being imported into central California from the Santa Barbara Channel region of southern California during the early Middle Period, recent stable isotopic sourcing research indicates that the saucer beads at ALA-413 and elsewhere in central California originated in both central and southern California (Burns 2019:233–238). No production locations have been identified for early Middle Period saucers in central California (Burns 2019; Rosenthal 2011), but it is probable that thousands of hours were spent by groups in the region to provide for the mortuary goods accompanying this one individual.

Further experimental replication of the various subtypes, as well as replication aimed at matching the particular morphology of specific bead types, could elucidate numerous issues regarding the scheduling of craft production activities, access to interregional networks, and the effect of shifting production methods and intensities on the otherwise subsistence-intensive economies of prehistoric California Indian groups. Clearly, Olivella beads were valuable enough even a millennium ago to divert considerable amounts of material resources and human energy to their production, both in regions where the rise of sociopolitical complexity at a chiefdom level is assumed to have driven such behaviors, and in regions where population pressure, social interaction, and technological innovations are frequently perceived to have been the driver (e.g., Arnold 2001; Milliken et al. 2007).

CONCLUSIONS

The labor rates derived in this experiment allow for quantitative comparisons of the time investment required for the manufacture of several different types of Olivella shell beads. The variation in production costs also provides significant insights that are not revealed by comparing bead counts alone. Still to be determined is whether the differences in labor costs for different bead types map onto the substantial temporal and spatial variations that we see in the archaeological record of California, and whether the shifts in bead types over time correlate with other social, economic, and environmental factors.

Further experiments, such as comparing the finishing methods employed here with economy-of-scale edge-finishing techniques, would be a valuable next step for discovering whether lower production times are possible if the process is approached differently, and how this might affect our interpretations of craft specialization and intensification. Experimental replication may also provide insights into the question of whether different production methods leave identifiable, replicable signatures on both the beads and the production debris, and whether such traits can be used to refine the temporal or spatial components of the archaeological record. There is also much room for further interpretations of what processes drove certain forager groups to put so much effort into bead production at the expense of other pursuits. The extensive social networks through which beads passed and the elaboration of the sociopolitical systems in which beads played a central role represent more than purely transactional relationships; quantifying the energetic investment in bead production helps to make these complex relationships clearer.

NOTE

[1]Despite the gastropod's taxonomic renaming by biologists, I use the longstanding label 'Olivella' (unitalicized) when referring to the cultural uses of *Callianax biplicata* shells and beads, in order to differentiate between them and references to the biological taxon, and in keeping with the extensive body of archaeological research and publication in which this label is already recognized and accepted.

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