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Stone knapping

the necessary conditions for a uniquely hominin behaviour

Edited by
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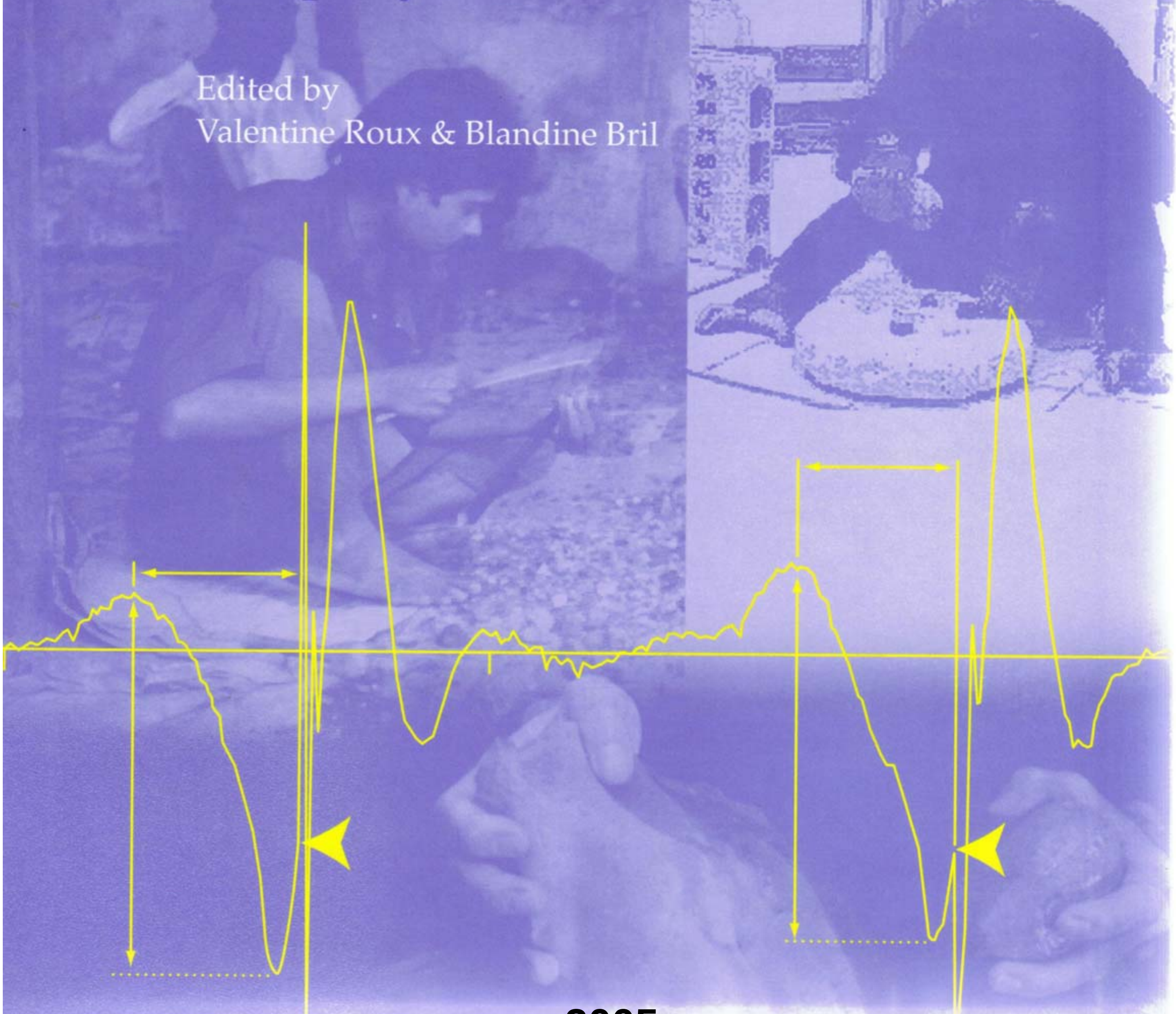

2005

Section B

Stone Knapping: Characterizing the Skills Involved

Skills Involved in Stone Knapping

Chapter 4

Stone Knapping: Khambhat (India), a Unique Opportunity?

Blandine Bril, Valentine Roux & Gilles Dietrich

Cambay is one of the very rare places in the world where the stone-knapping technique still responds to the principles of the conchoidal fracture. The technique practised is an indirect percussion by counter-blow and is used for making stone beads. This technique is a recent one in the history of techniques. It can provide, however, an appropriate reference situation to study the skills involved in stone knapping. In effect, given that for all stone-knapping techniques, the stable parameters of conchoidal fracture must be controlled, we can assume then that similar skills are involved. In order to characterize the skills involved in stone knapping in Cambay, a program of field experimentation was developed. At Cambay, the knappers are distinguished according to different levels of competence. In psychology, studies of apprenticeship are often based on transfer tasks. We tested the following hypothesis: the degree of success attained in modified situations reflects the capacities of adjustment, flexibility and planning of the artisan. A highly-skilled artisan should be capable of transferring his planning and motor skills to new situations. In addition, we would expect the differences that characterize distinct expertise levels to be amplified in the context of transfer tasks. Modifications were introduced into the knapping activity of the artisan, varying the nature of the raw material to be worked (glass versus stone) and the objective to be attained (bead dimensions and shapes). We worked with 12 artisans distributed equally among two levels of expertise: a high-level, and a low-level. The participants were instructed to produce superior-quality beads. The ensemble of fabrication processes of each bead was recorded with a video camera and an accelerometer attached to the head of the knapper's hammer in order to analyze the succession of actions realized, as well as the characteristics of the elementary movements and their sequencing.

Our results emphasize the critical role of the elementary movement and as such raise the question of the complexity of the elementary gestures produced by first hominins when knapping stone and their specificity as compared to the technological gestures produced by non-human primates. We make here the hypothesis that the knapping gestures reveal cognitivo-motor skills proper to hominins.

Our understanding of stone-knapping skills depends on the possibility of working with people who have the ability to knap stone, producing flakes characterized by a conchoidal fracture (see J. Pelegrin this volume). The main characteristic of stone knapping is that flaking must obey the conchoidal fracture. A simple fracture of the cobble would make the whole process of knapping totally out of control (Pelegrin this volume). Consequently split breaking cannot lead to a controlled shape.

This chapter relates an experimental field study on stone knapping with Indian craftsmen (Khambhat, Gujarat). The aim of this study was to find out what distinguishes expert knappers from less expert ones (Bril *et al.* 2000; Roux *et al.* 1995). The rationale of the study was the following: if we assume that the con-

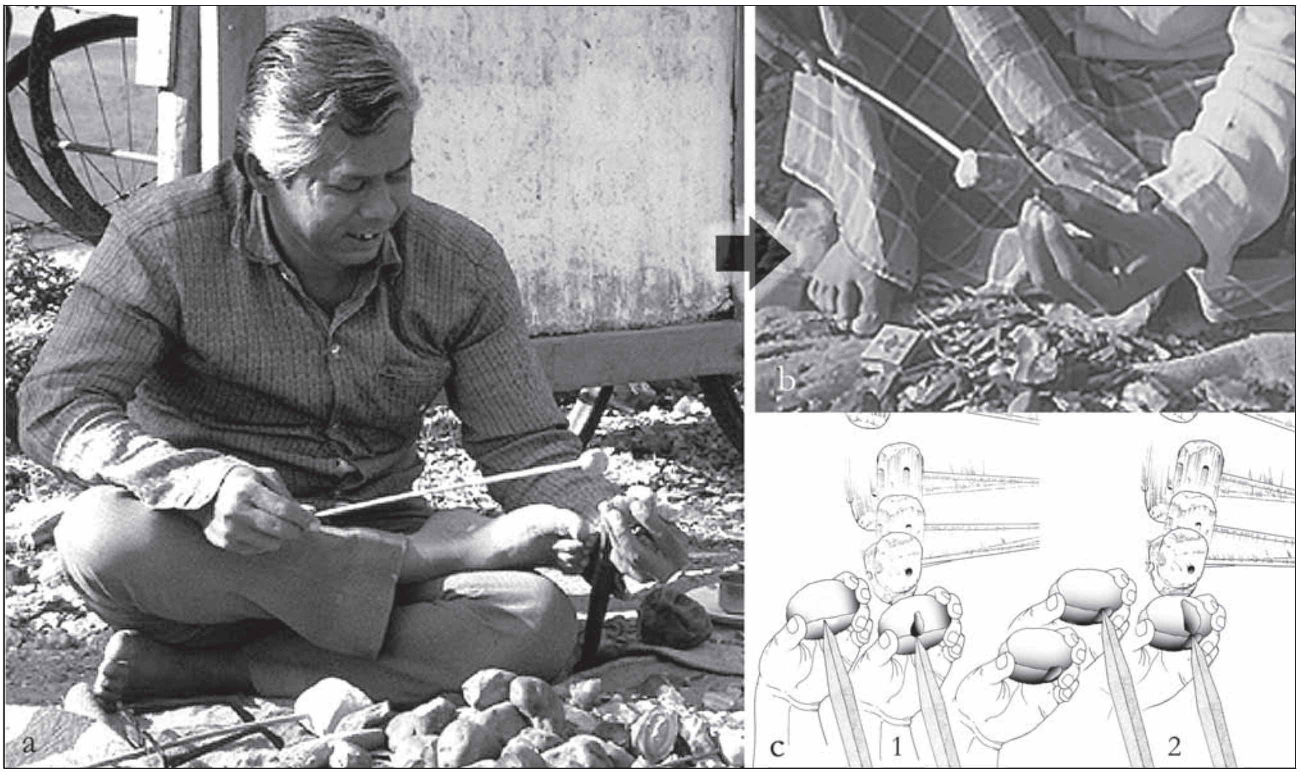

Figure 4.1. *Stone knapping in Khambhat: a) a craftsman knapping a stone bead, using a buffalo hammer and an iron bar as anvil; b) counter-blow technique; c) two successive flake removals.*

choidal fracture by itself imposes the characteristics of the action, then we can assume that regardless of the technique used to produce such a fracture, the necessary skills involved have much in common. Furthermore, the study of different levels of expertise should help understand what kinds of abilities are involved and consequently what kind of abilities have to be developed during the learning process.

Now, if we accept this groundwork, we may hypothesize that an analysis of any present-day technique that produces flakes (detached by means of a conchoidal fracture) will shed light on our understanding of the necessary capacities involved in stone knapping regardless of the historical period concerned, and regardless of the technique involved.

Apart from modern experimental knappers reproducing prehistoric techniques, only a handful of people around the world still knap stone as a common task (see Stout this volume). Khambhat is one of the very rare places in the world were the stone-knapping technique still follows the principles of the conchoidal fracture. However, although the technique used in Khambhat uses indirect percussion which differs from the direct percussion that characterized ancient prehistoric lithic technologies (Pelegrin this volume) or the last human stone toolmaker technique in New Guinea (Stout 2002; and this volume), the task at hand is analogous, i.e. making a final product having a specific shape well-defined in advance.

In this chapter, following a description of the technique and methods of knapping stone used in Khambhat, we shall discuss the theoretical framework referred to in our analysis of expertise in stone knapping, and then present a field experiment designed to work on the question of the 'nature' of the skills involved depending on the level of expertise.

Stone knapping: why is Khambhat a unique opportunity?

Nowadays, knapping stone as a regular craft activity is exceptional. In Khambhat, more commonly known as Cambay (name given before India's independence), craftsmen still manufacture carnelian and agate beads using a technique that meets the conchoidal fracture constraints. The production of beads is in the hands of workshops which produce either superior-quality objects or objects of a lower quality. We saw this organization of production as a unique opportunity to carry out a study of stone-knapping skills. Before moving into the study, we shall describe the *technique*

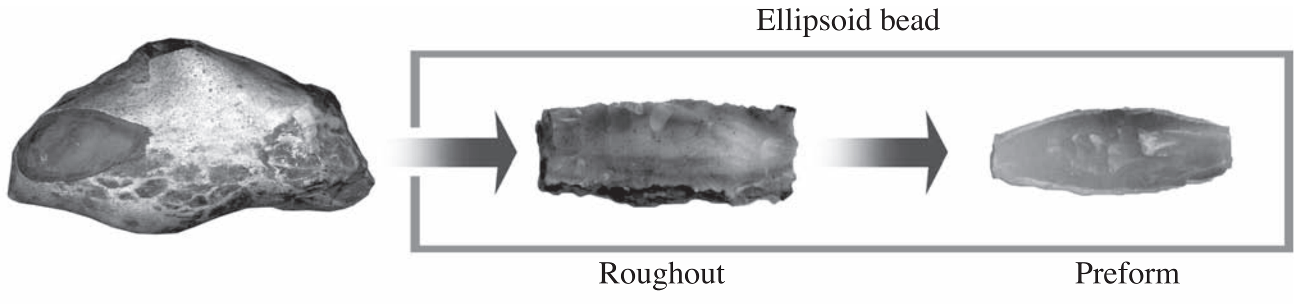

Figure 4.2. *The two stages of bead fabrication, from cobble to roughout, and from roughout to preform. The second stage only is discussed in this chapter.*

used to detach a flake, and the *method* employed to produce beads of different shapes.

The* technique*: an 'indirect percussion by rebound'

The knapping *technique* in use in Khambhat employs an original principle. It has been described as an 'indirect percussion by counter-blows' (Pelegrin 1993; 2000). The knapper, sitting on a rug on the ground, uses two tools jointly (Fig. 4.1):

- a sharp-pointed iron bar about fifty centimetres long and two centimetres thick, stuck obliquely into the ground in front of the knapper;
- a buffalo-horn hammer mounted on a thin wooden stick.

To detach a flake, the knapper holds the piece of stone to be knapped between his fingers and applies the edge of the piece against the pointed tip of the iron bar. The hammer held in the other hand strikes the piece to detach a flake from the point of contact with the iron bar. This technique makes it possible to detach flakes of various shapes, sizes, and thickness. The craftsman uses hammers of different sizes and weights depending on the size of the core and of the flake to be detached. The weight of the head of the hammer varies approximately from 15 to 50 grams. The head of the hammer gets worn quite rapidly and is replaced after a few dozen hours of use. The stick, which is quite flexible, weighs between 7 and 10 grams. The upper point of the iron bar is sharpened from time to time.

The method of knapping

The *method* of knapping is an orderly set of functional operations that must be undertaken to obtain the desired shape, starting from the raw material (see Fig. 4.2). Bead knapping is a two-staged process. First, in an initial reduction phase, a roughout blank is produced (see Roux & David this volume). The roughout displays its basic geometric characteristics which are determined by the intended final shape — i.e. the roughout for a spherical bead is a cube; for a cylindrical or ellipsoidal bead a parallelepiped roughout is knapped. The second phase changes the roughout to a preform, which is then ground, drilled, polished and buffed (for more details see Roux 2000).

For example, to knap a ellipsoid preform, you need to start with a roughout whose shape is a parallelepiped with four crests; and the following operations must be performed (Fig. 4.3):

- *calibration of the crests*, final shaping of the roughout and regularization of the crests through transversal removals in order to achieve successful fluting;
- *end preparation*, preparation of micro-platforms prior to crest fluting or axial removal;
- *crest fluting*, axial removals of the crest from the end;
- *axial removals* from the end, bladelet-like;
- *reduction of the residual crest* through very short transversal flakes;
- *end finishing* by shorter axial removals.

Each operation, or sub-goal, is achieved by chaining a succession of flake removals, which characteristics are dictated by the operation.

Figure 4.3 describes the succession of operations required to produce a truncated ellipsoid preform. It shows the succession of steps required as a previous condition for the next step, i.e. for example, end preparation is a prerequisite for fluting — i.e. preparing the micro-platform to achieve successful fluting. Once the prerequisite is met, the sequence of operations may be unfolded in various ways that we call strategies. The calibration of the crest may either be performed successively from the first crest to the fourth, with end preparation performed next, and so on; or after the first crest calibration, the craftsman may decide to prepare a micro-platform to perform the fluting of that crest, and then resume calibration of the second crest, and so on. Figure 4.4 summarizes the four main theoretical strategies that can be chosen to produce an ellipsoid preform from a parallelepipedic roughout.

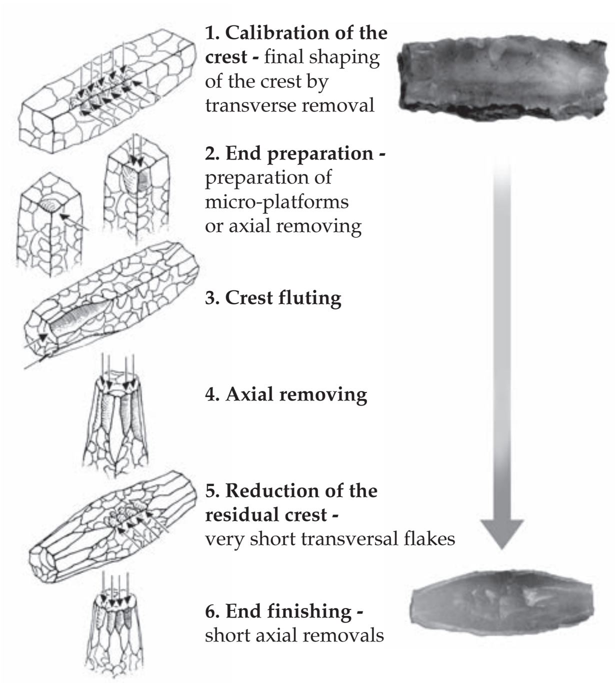

Figure 4.3. *The different sub-goals necessary to transform a parallelepipedal roughout into a ellipsoidal preform.*

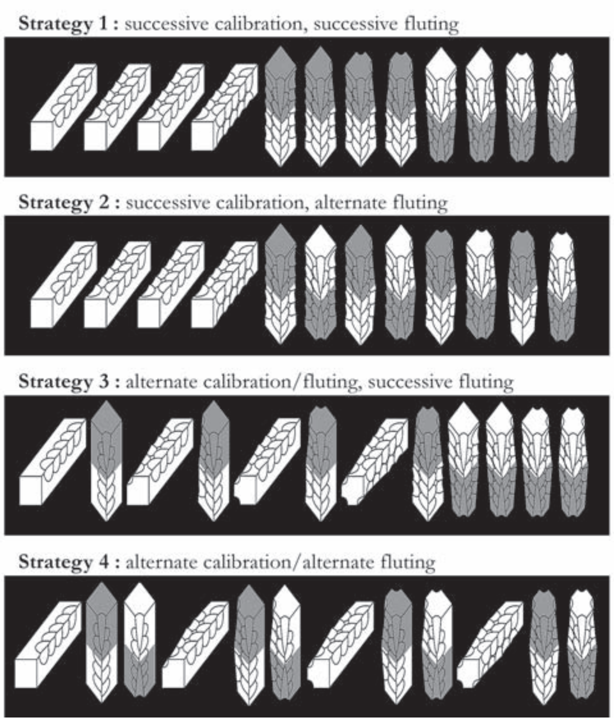

Figure 4.4. *The four theoretical strategies summarizing the different paths from calibration of the crests to the fluting of the four crests.*

Knapping a bead: from goal to movements to end product

How does the wish to knap a specific shape from a piece of raw material give rise to a sequence of movements, resulting in a piece of stone of a specific shape? In other words, what is the process that causes the desired goal-oriented action — knapping a specific shape — to be used? And what are the mechanisms called upon to give rise to this process?

Reaching this aim obviously requires some knowledge of the task at hand. Once again, what does this mean? Or how can we bridge the gap between the idea 'I want to make a small regular spherical bead or a long ellipsoidal one' and the behaviour that will allow the production of such a bead? What are the prerequisites to succeed, that is what 'knowledge', 'skill' and 'dexterity' must have been acquired to be able to perform such a task?

How is the goal of the action, here a piece of stone of the desired shape 'the knapper has in mind' (Pelegrin this volume) determined by its 'geometric objective', reached through a sequence of movements? What brings the 'template' — the 'image' — into existence?

The first issue here is to define a complex motor skill that clearly differentiates an action from the movements that allow this action to be carried out. An action may be referred to along two dimensions: the goal, referring to the intentional aspect of the action, and the means, that is the operational aspect of it, in other words, the way the goal is reached (Connoly & Dalgleish 1989):

1. In stone knapping, the goal is the production of a stone of a certain shape. It may be either a chopper with a cutting edge as for the Oldowan choppers, or a whole shaped object such as the tools described in this volume by Roche and Pelegrin, or the beads of various qualities knapped by the craftsmen in Khambhat.
2. The means correspond to a succession of operations performed to reach the goal. This process corresponds to the 'actualization' of the method. Each craftsman may have his own way of working out the succession of operations necessary to reach the desired shape: this process is designated by the *course of action*. The method, and consequently the sequence of operations, vary according to the shape to be produced (Roux & Pelegrin 1989; Pelegrin 2000). The sequence of actions performed by the craftsman, that is the *course of action*, corresponds to the 'actualization' of one of the basic strategies used in Khambhat to obtain beads of different qualities and shapes. According to our terminology, the course of action is composed of a

sequence of sub-goals. A sub-goal corresponds to the actualization of an operation, that is when and how a craftsman carries out an operation.

Such a definition helps differentiate planning 'What to do' *vs* planning 'How to do it'. Here again difficulties arise. The process of performing an action, once the goal is set, is not easy to describe. An operational way to split up a complex sequence of actions is to refer to the three levels put forward by Richard (1990) among others.

1. The first level concerns the overall organization of the task: the way the method is actualized in a succession of functional actions in order to complete the task. It is referred to as the *course of action*. In other words, the course of action corresponds to the way each craftsman carries out the different operations to produce the intended shape, that is a chaining of sub-goals.
2. The intermediate level expresses the way the operations are actualized, that is how the sub-goals are carried out. Most of the time — but not always — carrying out a sub-goal requires performing a succession of elementary actions — the third level. For example, as we have described, calibration is an operation that may require dozens of flake removals. On the other hand, fluting may be achieved with a single strike. In addition, calibration may be performed in different ways: either by a succession of adjacent strikes along one edge, going one way, and then back along the crest but from the other side, or carried out by a succession of alternate flaking along the crest (Fig. 4.5).
3. The last level, the elementary action, concerns any goal-oriented action that cannot — functionally — be split into parts. In the case of knapping it refers to the removal of one flake typified by the conchoidal fracture. This level corresponds to the *actualization* of the technique, that is the way a craftsman performs the movement that allows the action to come into existence. The characteristics of the flake can be manifold and are determined by the operation to be carried out. In the case of calibration for example, the flake is very thin and more or less disc-shaped. On the other hand, fluting corresponds to a thick, long flake, and axial removal to a long, bladelet-like flake. End finishing is characterized by small, thin flakes. All of these respond to the same technique. Performing any of these strikes, however, requires adapting the movement in such a way as to successfully produce the proper removal. Indeed it is not the movement itself that must be examined but what the movement allows for, that is the exact relative position and force ratio of the stone, the hammer and the anvil. As we can see, to be effective the actualization of the technique necessitates a very high degree of flexibility.

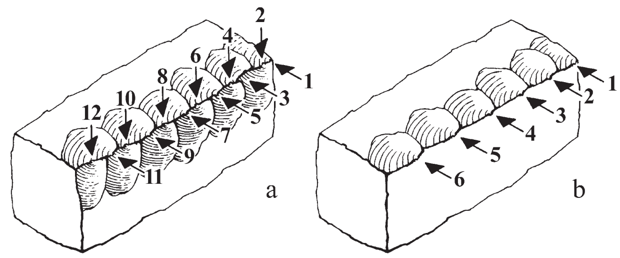

Figure 4.5. *Two ways of actualization of the calibration operation: a) succession of alternate flakings along the crest; b) succession of adjacent flakings along the crest.*

The interesting point here is the following: when planning is alluded to, to which level does it refer: the planning of a succession of sub-goals, the planning of the succession of strikes necessary to carry out a sub-goal or the planning of the striking movement? To answer this question, we need to clearly differentiate the level referred to. The different action planning theories usually refer to a level of action, rarely to all three levels simultaneously. Yet, if one wants to understand what a skilled behaviour refers to, what expertise means, a theory linking together the three levels of action as defined here must be used.

As discussed in the introductory chapter the first theoretical approach, often referred to as the 'motor-system approach', emphasizes an information-processing perspective, the existence of a kind of 'central representation', 'internal models' and 'motor commands'. The second theoretical approach, referred to as the 'action-system approach' stresses the reciprocal role of the organism and the environment acting as a set of constraints from which behaviour emerges. Three types of constraints may be considered (Newell 1986; 1996): the organism, the task and the environment (see Fig. 4.6). Any change in one of these three sub-system may produce a different outcome. This is particularly explicit in the case of tool use. Depending on the type of hammer (element of the environment) used for example, the constraints on the hammering movements will be different due to the weight of the head of the hammer and/or the length of the handle. As a consequence the outcome will be different.

A skilled action combines precision, flexibility, adaptation, smoothness, regularity, optimization and swiftness (Bernstein 1996; Ericsson & Lehmann 1996). In other words, an expert is able to carry out an action in any situation and under all conditions. The level of expertise refers to the degree attained by each of the qualities of action listed here.

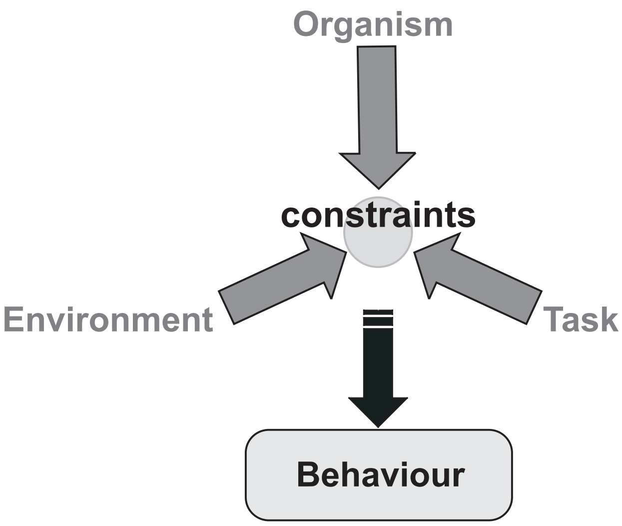

Figure 4.6. *The three main types of constraints that set up the work space (adapted from Newell 1986).*

How can we characterize the abilities of a high-level expert compared to a low-level expert? What specific capacity or aptitude or ability does the expert possess that the less expert does not have? Does the expert have a better 'mental representation' of the action of the goal to be reached? Or does the expert have an extensive capacity to detect the appropriate information resulting from the ongoing course of action coupled with the ability to incorporate these into his action?

To investigate such questions it is necessary first to more clearly outline the different components such a task entails. These questions about expertise were at the origin of the field experiment reported in this chapter.

A field experiment

The experiment described in this chapter was designed to uncover the features that might distinguish high-level experts from lower-level experts. Our aim was to tentatively disentangle the different dimensions of expertise, i.e. the underlying abilities, controlled factors, skills and knowledge involved.

Experimental setting

The motivation of the experiment was twofold. First, the craftsmen should be in a situation as close as possible to their everyday activity. Second, the data obtained should allow for analysis of parameters usually studied in laboratory experimental situations. To satisfy these criteria we considered an experimental paradigm based on the capacity of transfer and generalization. We assumed that the higher the dexterity of the craftsmen, the higher their capacity of transferring to new situations.

The experiment was based introducing new situations to the craftsmen. They had to transfer their knowledge to a new raw material and to knapping shapes that were unknown or at least unusual to them.

The new raw material chosen was glass. Three reasons justify this choice:

1. As far as knapping is concerned, the mechanical properties of glass are the same as chalcedony (conchoidal fracture).
2. Glass is not as hard as chalcedony, presenting a basic difference with the raw material commonly knapped.
3. Glass also provides a homogeneous raw material and the possibility to start from a roughout of exactly the same size and weight for all the craftsmen; consequently glass as a raw material allows for a more reliable interpretation of the results obtained.

The main hypothesis was the following: the participants' ability to transfer their knapping knowledge to the new raw material and new shapes indicate their level of dexterity.

Participants

The choice of participants of different levels of expertise derived from the existence in Khambhat of workshops specialized in the production of objects of different quality. Indeed, the bead-manufacturing workshops are divided into two categories: those specialized in high-quality beads, and those specialized in low-quality beads. The craftsmen who produce high-quality beads are able to knap all kind of beads of various shapes and sizes. The duration of their apprenticeship period is about ten years. The craftsmen who produce low-quality beads knap beads with irregular shapes and of small size — less than three centimetres. Their apprenticeship lasts approximately three years. It was, therefore, reasonable to map the two levels of expertise with the two types of workshops.

The experiment was carried out with six craftsmen accustomed to knapping high-quality beads — referred to as group 1, and six craftsmen knapping low-quality beads — referred to as group 2. It is important however to note that craftsmen from both groups are experts, though with different levels of expertise.

Methods and recordings

The choice of the data recorded depends on quite a few parameters. As mentioned earlier in the chapter, we consider that a field experiment must provide data similar to those recorded in the lab. It also depends, however, on the type of technical devices available and, naturally for a field experimentation, which are easily transported. It is not necessary here to list the differences between a university lab in Europe or elsewhere and a workshop in a small Indian town.

The technical devices used in this experiment had to allow us to analyze the course of action and the elementary action (Fig. 4.7). The course of action was recorded using a video camera with a sampling rate of 50 frames per second. The camera was located in the axis of the movement, and recordings of the whole knapping activity were carried out.

The elementary action was recorded using a uniaxial accelerometer affixed to the not-used end of the hammer head. The choice of the accelerometer as a means of recording was dictated by several considerations. What is important in knapping is not the movement in itself, but the fracture that is produced due, at least in part, to the hammer's movement (displacement, velocity, force of impact). The forces produced being proportional to the acceleration, the hammer acceleration was considered a good parameter characterizing the elementary action. In addition, the small dimension of an accelerometer makes it easy to transport. The accelerometer which was designed especially for this experiment, had the following characteristics: range, ±250 g; natural frequency, 3000 Hz; accuracy, ±0.2 m/s^2. It was connected to a portable Toshiba 600 computer via an ADC (analogue-to-digital converter, sampling frequency, 200 Hz; 12-bit resolution). It gives the acceleration of the hammer along the progression axis, i.e. according to the hammer's reference axis. The recording programs were developed by the third author.

Protocol

As noted earlier in the chapter, this experiment concerns the second step of knapping a bead, i.e. going from a roughout to a preform (Fig. 4.2). Each craftsman had to knap 10 preforms of four different shapes, using the two raw materials, chalcedony and glass, for a total of 80 preforms (Fig. 4.8). The stone roughouts were prepared in advance. They were made of chalcedony, the raw material commonly knapped in Khambhat. They had been made by the same craftsman in order to obtain, as best as possible, the same dimensions for all the roughouts. The glass roughouts were orange, a colour close to chalcedony. They have been manufactured by a French corporation, Saint Gobain.

The following four shape preforms were to be knapped: two slightly bitruncated ellipse-shaped preforms of two different lengths, one spherical-shaped preform, and one bitruncated ellipse-shaped preform with a quadrangular section.[1]

The experiment was held in a workshop which was quite calm as only one craftsman producing high-quality beads was working there. Each craftsman came to the workshop for a whole day, as the experiment lasted around six to seven hours.[2] After a trial in order to get used to the new raw material and the experimental situation, each participant was asked to knap the different preforms in the same order, first the glass preforms, then the stone ones. The first two preforms of each type were eliminated from the study as we considered that they might reflect the need to familiarize oneself with the task.

Figure 4.7. *Experimental setting, data recordings: 1) a video camera is situated in the axis of the movement; 2) an uniaxial accelerometer is attached to the head of the hammer, and data are recorded via a portable computer.*

Data reduction

The analysis is based on three types of record: the preforms produced, the video records and the time series of the hammer acceleration.

Analysis of the preforms produced: The preforms that we brought back to our laboratory in Paris, have been analyzed one by one. All the preforms have been filmed with a video camera, from eight different angles in order to systematically analyze their contour. For this purpose, each view was digitized. A pattern-recognition program, developed by the third author, automatically analyzes each contour. The different parameters chosen are based on three criteria: techno-economic (i.e. refers to the economy of raw material as it is economically important not to

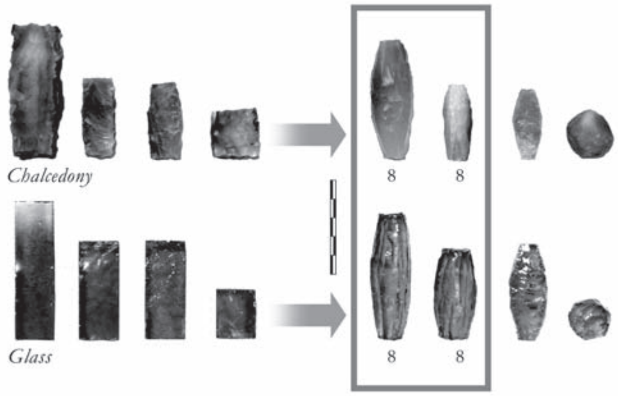

Figure 4.8. *The different roughouts to be knapped into preforms.*

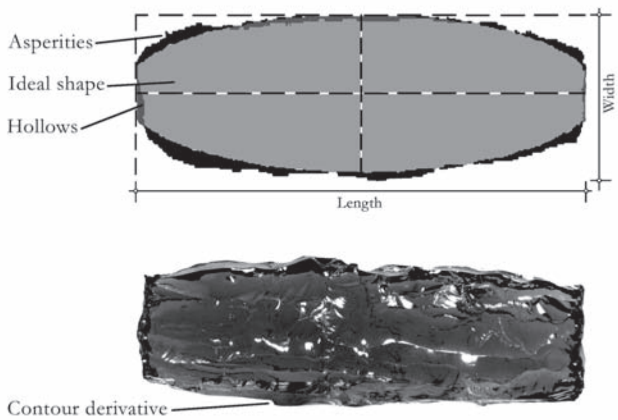

Figure 4.9. *Modelling of a stone: comparing the bead produced to the ideal shape. The different shaded areas correspond to a) a lack of material, b) to a surplus of material, and c) to the good shape.*

waste raw material), morphological (i.e. indexes the geometry of the knapped pieces, sphericity and symmetry), and technological (i.e. indexes the regularity of the shape, bumps and holes).

The general idea underlying the computation of most of the parameters, was to compare the knapped product to an 'ideal' shape.[3] These parameters index (a) the overall shape of the preform produced, (b) the symmetries along the longitudinal and transversal axis of the preform, and (c) the contour of the preform in terms of regularity or smoothness (for more details see Bril *et al.* 2000).

The behaviour of the craftsman knapping a preform: The three levels of action described earlier have been investigated:

a. The course of action (level 1)
We systematically analyzed the different paths taken by the craftsman as far as sub-goals are concerned — the course of action — that is, the organization of the sequences of sub-goals to reach the goal. The analysis was performed using Kronos software initially designed for ergonomics studies (Alain Kerguelen CNAM).

The succession of sub-goals was noted, as was their duration. From this coding procedure, two different types of parameters were analyzed for each condition:
1. the number of different 'strategies', or more precisely 'sub-strategies', including non-coherent ones;
2. temporal parameters such as total duration of the task, or total duration of sub-goals corresponding to one operation.

b. The sub-goal: chaining of elementary movements (level 2)
Level 2 of the action was considered from the point of view of the characteristics of the chaining of elementary actions (i.e. chaining of strikes). The dynamics of the succession of elementary actions was analyzed, from the accelerometer time series, using two types of analysis:
1. *Power spectral density analysis of the accelerometer signal* (Fourier analysis), provides information on the timing of the actions and on the preferred striking frequency.
2. *Harmonic modelling*. Harmonic analysis is a tool for observing the structure of the dynamics of a movement with a limited number of parameters (Fourier coefficients). The procedure consists in 'constructing' a harmonic model of the signal by gradually increasing the number of coefficients (number of harmonics). At each step, a higher-order harmonic is added until the best fit is found between the model and the signal being studied. The output is a curve representing the distance (in fact, the standard deviation) between the signal and the model, depending on the number of harmonics. Here, we took a given number of harmonics (300) and computed the distance between the harmonic model and the signal. Since the acceleration of the hammer is proportional to the forces exerted, small distances between the source signal and the model correspond to more harmonic behaviour, and consequently less energy expenditure (Cordier *et al.* 1996).

We restricted the analysis of sub-goals to one subpart of the total sequence of sub-goals, starting with the first end-preparation and ending 50 seconds later. In most cases, this included at least the four first flutings, and usually more. Many different equivalent paths are possible here, all leading to the fluting of the four crests.

c. The elementary action (level 3)

In analyzing the elementary movement, we focused on the fluting movement, whose weight is critical as far as the shaping of a ellipsoidal preform is concerned. We chose to analyze the first fluting of each crest, for a fair comparison, since all crests are of approximately the same length at that point of the preform knapping process.

The coding of the course of action (KRONOS) was used to locate the exact timing of flutings. Once the instant of the fluting was determined, it was possible to calculate the variation of acceleration produced for each individual fluting strike (Fig. 4.10). From the acceleration curve we computed the variation in acceleration during the movement, from the positive peak prior to the impact of the hammer on the stone up to the time of impact.

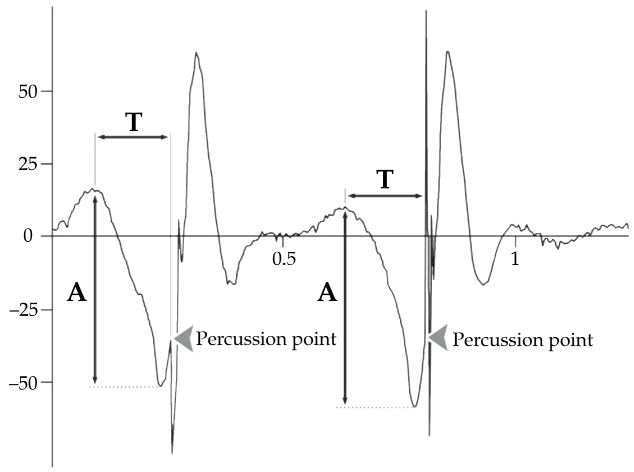

Figure 4.10. *Graph of the acceleration of the hammer (from the accelerometer) for two consecutive fluting movements. (A: maximal amplitude of the acceleration of the hammer).*

Results

Our results concern the knapping of large and small ellipsoid preforms, except for the power spectral analysis and the harmonic analysis, which were performed on large ellipsoidal preforms (stone and glass) and spherical preforms (stone and glass). This was dictated by the fact that the small ellipsoidal stone preforms were much smaller than the glass ellipsoidal preforms, making a comparison between glass and stone difficult. Spherical preforms were knapped from stone and glass roughouts having the same dimensions, consequently any comparison is legitimate.

The product of the knapping process: the preforms

A look at the pieces produced by the craftsmen of both groups makes it easy to tell the difference. For the purpose of objectivity, however, we decided to quantify this qualitative but reliable perception of the differences. This task proved to be extremely difficult and complex. The eye considers and integrates a large number of different indices that are often difficult to isolate.

Figure 4.11 shows an example of the pieces knapped by one craftsman from group 1 and one craftsman from group 2. The production reveals a clear disparity of dexterity. The top row of both stone and glass products are more equal in shape and dimension suggesting a higher level of skill. Furthermore, the glass pieces from the craftsman of group 2 are far from a truncated ellipsoid with a circular section. The parallelepipedal roughout has barely been knapped. As hypothesized, the use of glass as a new raw material increases the differences between the two groups of craftsmen.

Parameters taken from the three criteria defined earlier significantly distinguish the production of the two groups. The results concerning the parameters that better distinguish the two groups are given here: sphericity (morphological criteria), bump (i.e. the excess of raw material compared to the ideal shape), and the derivative of the contour of the preform (technological criteria). Sphericity is significantly higher for group 1 when compared with group 2. In addition, while in group 1, the sphericity values are approximately the same for both stone and glass products, this is not true for group 2. The production of the craftsmen of this group is significantly less spherical for glass preforms (see Fig. 4.12a). The analysis of the bump parameter is very instructive. It highlights the difference between the production of group 1 and group 2, highlighting the difficulties for the craftsmen of group 2 in transferring their knapping skill to the new raw material, glass (Fig. 4.12b). Stone production does not differentiate the two groups. While for group 1, however, the bump values are 48 per cent higher for glass than for stone, the difference rise to 128 per cent for group 2. Similar figures appear for the small preforms. While there were major differences between the craftsmen in both groups, this result clearly suggests a lower transfer ability for the craftsmen of group 2.

The last parameter reported here evokes once again a clear difference in skill between the two groups. The smoothness of the contour of the produced preform to the contour of the ideal preform, shows that, in all cases, the craftsmen of group 1 are better than the craftsmen of group 2. When the production of both stone and glass are compared, the values show that when glass is concerned smoothness deteriorates significantly more in group 2 than in group 1 (Fig. 4.12c).

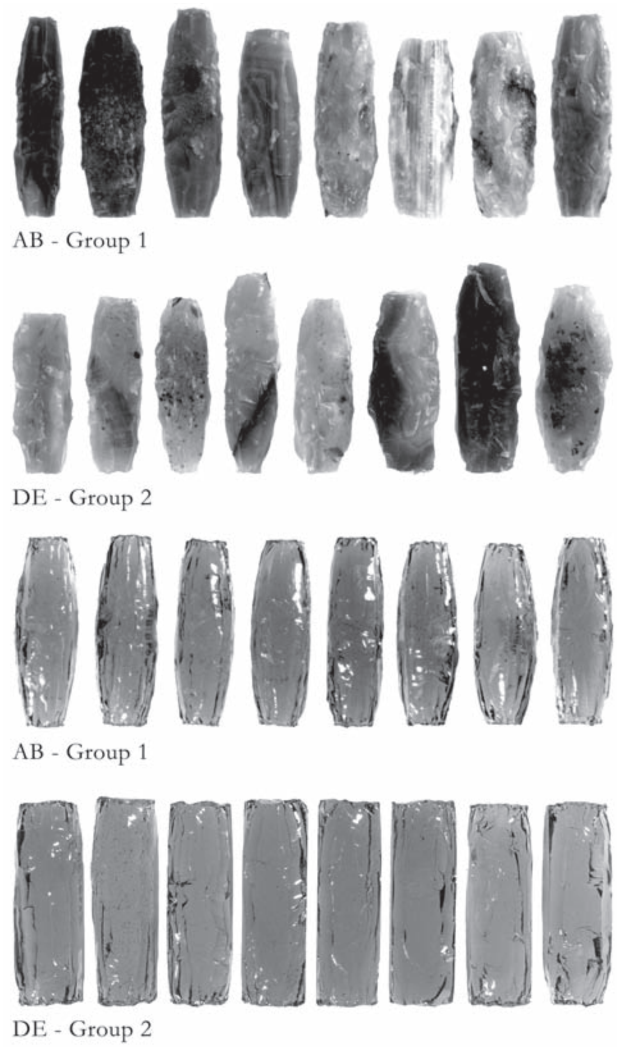

Figure 4.11. *Examples of the production of a craftsman of group 1 and a craftsman of group 2: a) stone preforms knapped by AB (craftsman of group 1) (top row) and by DE (craftsman of group 2) bottom row; b) glass preforms knapped by AB (craftsman of group 1) (top row) and by DE (craftsman of group 2) bottom row.*

The action plan

The course of action corresponding to each preform produced has been systematically coded and analyzed using the KRONOS software (Fig. 4.13). This analysis provides information on how the method was adjusted to produce an ellipsoidal preform. Two main aspects of the course of action were analyzed. The first concerns the strategies or sub-strategies used by the craftsmen, that is how the sub-goals are sequenced to make a preform. The second deals with the temporal structure of the course of action.

The overall strategy: adjusting the method: A comparison of the course of action displayed by each knapper for each preform shows two important aspects of the craftsmen's plan of action.

1. The craftsmen of group 2 rarely perform calibration or regularization of the crest for successful fluting. Only two of them (SU and DE), sometimes perform calibration; it is interesting to note that shortly before the experiment, SU had spent a few months at a higher-quality workshop.
2. Apart from calibration, all the craftsmen's courses of action, from both group 1 and group 2, match two of the four basic strategies. Of the four theoretically possible strategies (see Fig. 4.4) the first two are used most of the time. The third one was applied systematically by one craftsman from group 1 only, and occasionally by two others. The fourth has never been observed. It must be noted, however, that what has been described as one strategy is not rigid and that sub-strategies, i.e. variations on a strategy, have been often observed.

There is major variability both within and among participants (Fig. 4.13). The number of sub-goal paths performed by each craftsman corresponding to different sub-strategies, is shown in Table 4.1. On average, the number of different sub-strategies used is slightly lower for group 2 than for group 1. In the same way, the number of sub-strategies used to produce glass preforms is lower than those used to produce stone preforms. A few craftsmen systematically follow the same path, i.e. use only one strategy (IN, HA from group 1 for large ellipsoidal stone preforms, SU for group 2), but other craftsmen may display as much as five to seven different paths while making eight preforms in sequence (HU from group 1 for stone large ellipsoidal preforms, or NA from group 2).

The glass condition seemed to reduce the average number of paths in both groups, although not significantly. This is coherent as the stone is not homogeneous, unlike glass. It is therefore understandable that a less homogeneous raw material leads to a necessary adaptation to the contingency of the raw material. However the high variability exhibited by some craftsmen from both groups is difficult to explain. Why IN from group 1 and SU from group 2 exhibit only one sub-strategy while HU from group 1 and NA from group 2 exhibit more than five sub-strategies, is still not clear. IN is recognized as the best craftsman in Khambhat, but HU also produced high-quality beads.

The temporal structure of the course of action: The duration of the entire knapping process is far greater in group 1 than in group 2 (Table 4.2), which confirms the previous study by Roux & Pelegrin (1989). This difference reflects the absence of calibration for craftsmen in group 2. But when considering the duration

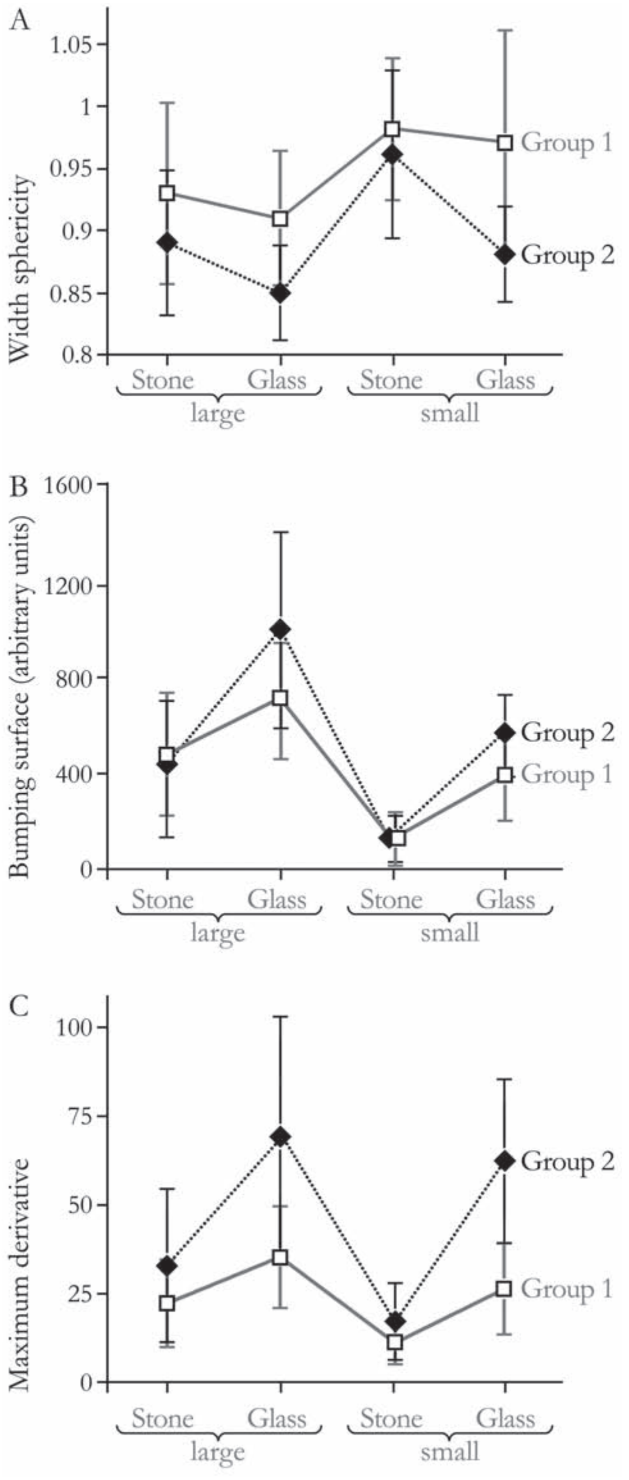

Figure 4.12. *Values of parameters indexing morphological and technological criteria of a good product: a) spericity; b) bumping; c) contour smoothness.*

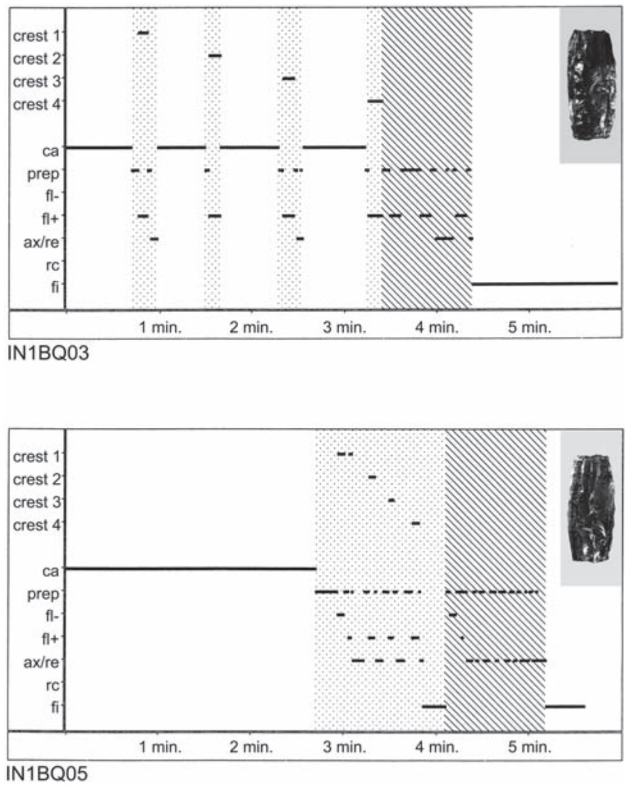

Figure 4.13. *KRONOS diagram representing the course of actions corresponding to the knapping process of an ellipsoid preform.*

of partial knapping, that is, not including calibration and finishing, group 1 and group 2 spend approximately the same time on each preform. On average, for both group 1 and 2, the time spent knapping glass preforms was higher than the time spent on stone preforms (see Table 4.2). The partial number of sub-goals, however, is higher for craftsmen of group 1 compared with group 2. This could mean that the craftsmen of group 2 skip some operations (i.e. end preparation), a behaviour which is less frequently observed in craftsmen of group 1.

When the relative number of sub-goals is computed, that is the ratio of the number of sub-goals to the total duration of the knapping process, it is higher for the craftsmen of group 1 when glass is considered. The opposite is true when stone is considered: the relative number of sub-goals is higher for the craftsmen of group 2. In other words, the duration of a sub-goal (inverse of frequency) is longer for the craftsmen of group 2 working on glass preforms than for the craftsmen of group 1; the opposite being true for stone preforms where the craftsmen of group 1 spend more time on each sub-goal while knapping a stone preform. The shorter time spent on each operation by the craftsmen of group 1 when knapping glass suggests that they take advantage of the homogeneity of the glass raw material, while the craftsmen from group 2 have more difficulty adapting to the new raw material.

In spite of the significant differences between the two groups of craftsmen described in this section, major variability appears between the craftsmen within each group. The total duration of the process of knapping a large preform of glass may vary between 299 seconds and 533 seconds in group 1, and between 92 seconds and 347 seconds in group 2. The same extreme variations are observed for the partial number of operations a craftsman performs, varying from 19 to 43 in group 1, and from 8 to 36 in group 2.

Table 4.1. *Number of different sub-strategies displayed by craftsmen of both groups depending on the raw material and the shape of the roughout to be knapped.*

		STONE		GLASS	
		LARGE	SMALL	LARGE	SMALL
GROUP 1	RA	3	3	2	4
	HU	7	5	4	5
	HA	1	5	1	3
	IN	1	2	1	1
	AB	2	3	1	1
	RN	3	5	5	2
GROUP 2	DE	2	2	2	2
	SU	1	1	1	1
	SA	2	2	1	1
	NA	5	5	3	2
	AS	1	–	1	1
	HK	3	6	3	2

Table 4.2. *Temporal characteristics of the knapping process: total duration, partial duration (total duration – calibration and finition), relative frequency of operations.*

	Total duration	**Partial duration**	**Relative frequency of operations**
Large Stone			
Group 1 ($n = 48$)	330.88 (93.34)	179.12 (89.87)	0.17 (0.05)
Group 2 ($n = 48$)	159.04 (58.71)	117.72 (44.61)	0.21 (0.05)
Large Glass			
Group 1 ($n = 48$)	382.02 (110.64)	140.88 (65.23)	0.23 (0.15)
Group 2 ($n = 48$)	210.71 (95.73)	129.60 (69.02)	0.16 (0.10)
Small Stone			
Group 1 ($n = 48$)	180.25 (63.17)	79.79 (31.51)	0.26 (0.06)
Group 2 ($n = 48$)	99.57 (47.07)	67.03 (28.19)	0.28 (0.09)
Small Glass			
Group 1 ($n = 48$)	294.4 (43.51)	114.68 (42.73)	0.27 (0.06)
Group 2 ($n = 48$)	196.77 (92.39)	99.90 (31.52)	0.21 (0.05)

The dynamics of elementary movements

Power spectral density analysis (large ellipsoidal preforms): The range of frequencies is between 1 and 5 Hz; Figure 4.14 gives the average power spectral density curve for the eight preforms for stone and glass large preforms. The curves are not different in the two situations for all participants (group 1 and group 2).

For all participants, the power spectral density curves present one peak at 3.5–3.7 Hz, regardless of the raw material — glass or stone.

The power spectral density curves show specific characteristics for each group. All the craftsmen from group 1 have a non-symmetrical pattern, in the low frequencies. On the other hand, most of the participants of group 2 present symmetrical curves. SU's curves, however, are more like the curves of group 1 than group 2. The interesting point here is that SU had spent some time working in a workshop producing superior-quality beads.

Harmonic analysis: Figure 4.15 shows an example of the original signal and of the model using the first 300 harmonics. Figure 4.16 summarizes the harmonic analysis. For both group 1 and group 2, it gives the average distance between the accelerometer signal and the reconstructed signal based on the harmonic model. This graph clearly shows that the craftsmen from group 2 have higher values than the craftsmen from group 1, regardless of the condition, suggesting a more harmonic behaviour for subjects from group 1.

Compared with the stone condition, the values are always lower in the glass condition for the craftsmen of group 2. This is true, however, for the craftsmen of group 1 for spherical roughouts but not for the large ellipsoidal ones where there is no difference between conditions (stone and glass). This suggests that the raw material affects the harmonization of the behaviour, except for the large roughout in group 1.

The interpretation is not obvious. The smaller values for glass may be interpreted differently for group 1 and group 2. If we take into account the product (the roughout characteristics) it has been shown that group 2 craftsmen hardly modified the roughouts, although the preform is far from an ellipsoid shape. It could be that the sequence of actions was more stereotyped and less flexible resulting in a less energy-consum-

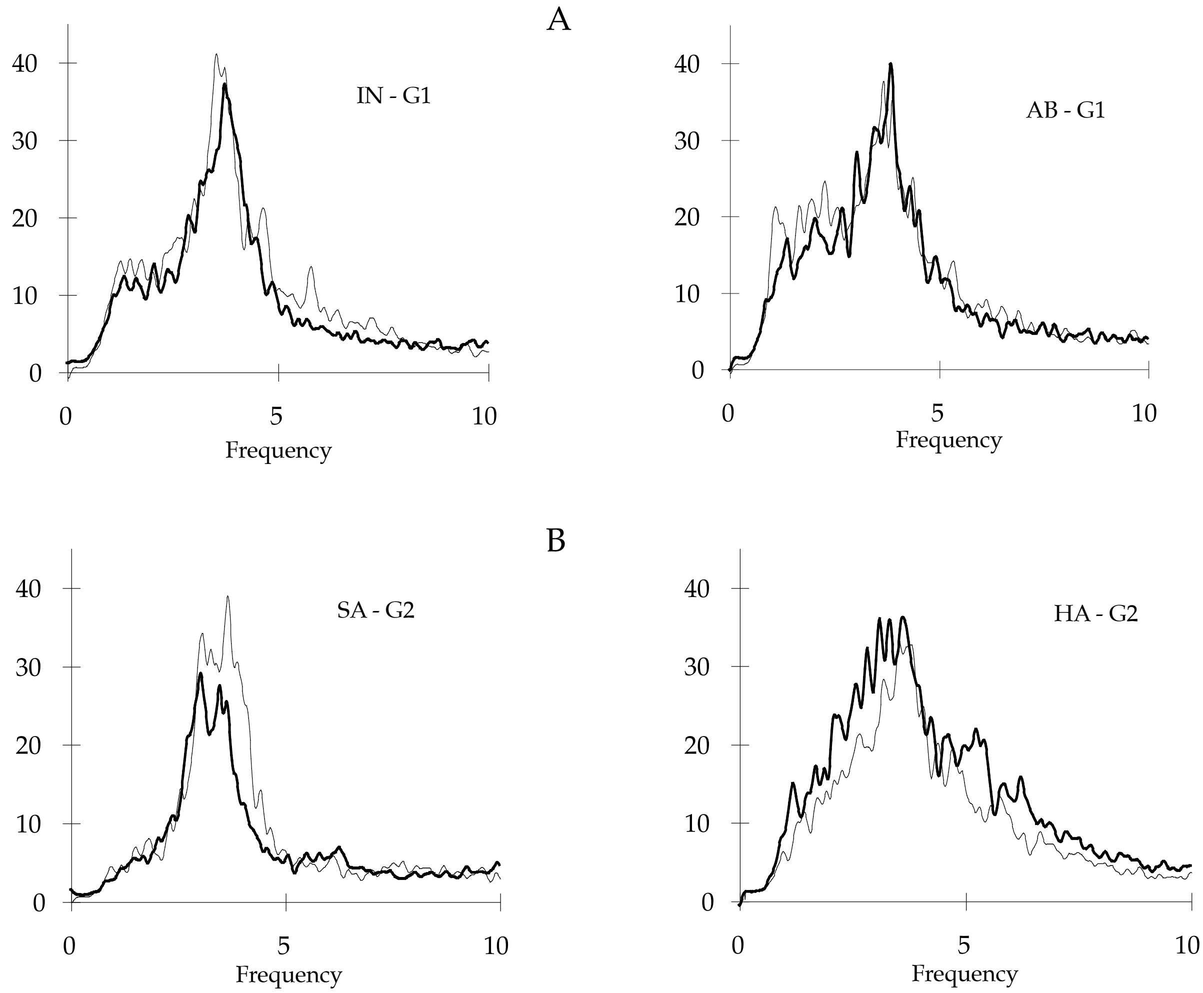

Figure 4.14. *Frequency distributions (power spectral density curves) for the large ellipsoidal preforms for craftsmen of group 1 (A) and group 2 (B) (average for 8 beads). Thin lines correspond to stone preforms, thick lines correspond to glass preforms.*

ing situation. On the other hand, for the craftsmen of group 1, since knapping a spherical roughout from glass is easier, the sequence results in a more harmonic behaviour, while in the case of large ellipsoidal preforms which are harder to knap, and the final preform being of good quality, the raw material does not affect the global process.

The elementary action

The analysis of the elementary action concerns the fluting sub-goal. As mentioned earlier, this choice was dictated by the difficulty in comparing actions in exactly the same condition — i.e. same state of the roughout. The first flutings — one for each crest — may be considered as a situation which is approximately the same for all the roughouts, since the crest has more or less the same length at this point of the knapping process, and the goal is to strike a long, thick flake along the crest.

The fluting operation is interesting for another reason as well. It is quite easy to identify failure or success while performing a fluting operation, as the movement performed is quite characteristic, and the flake produced is quite large.

A first difference between the two groups is the number of failures while performing this operation. On average, the number of fluting failures is higher for the craftsmen of group 2, for both stone and glass roughouts, and is about twice as high in group 2: 1.7 failures on average compared with 0.5 for large glass ellipsoidal preforms for craftsmen of group 2 and group 1 respectively, and 2.4 failures on average compared with 0.9 for large stone ellipsoidal preforms. Here again, major variability characterizes both groups, but is larger in group 2 than in group 1.

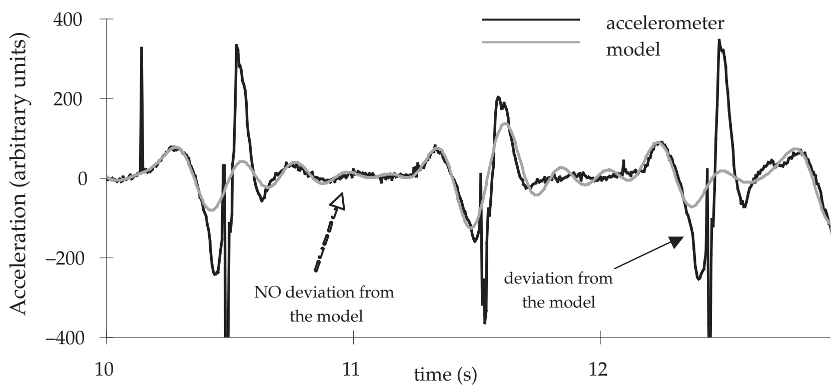

Figure 4.15. *Harmonic model. (The accelerometer curve is black and the model computation curve is grey.)*

Amplitude of acceleration: The values for the variation in the acceleration of the head of the hammer during the movement prior to the hammer strike on the roughout differentiate the two groups of participants in all conditions (see Fig. 4.15 & Table 4.3). It must be emphasized, however, that all the craftsmen are experts, in some ways.

Adaptation to the raw material: As far as the transfer to the new raw material is concerned, the acceleration is higher when fluting stone than when fluting glass (see Table 4.3 & Fig. 4.15). This is true in all cases. It means that all the craftsmen, regardless of their level of expertise, do make a distinction between the two raw materials: glass is not as hard as stone. For large ellipsoidal stone preforms, the average acceleration is 67.59 m/s^2 for group 1, compared with 51.41 m/s^2 for the glass preform; for the craftsmen of group 2 these values are respectively 63.10 m/s^2 for stone and 42.97 m/s^2 for glass. In addition, when looking at the variations between the craftsmen of the same group, it is interesting to note that there is less variation in the values of the acceleration displayed by the craftsmen of group 1 compared with those of group 2: that is, in group 1 the difference between the highest average value and the lowest is 19.6 m/s^2 (from 58.1 to 77.85 m/s^2) while it is 54.1 m/s^2 for group 2 (from 41.3 to 95.5 m/s^2). This phenomenon is present for glass as well, but to a lesser degree: 36.4 m/s^2 for group 1 and 43.4 m/s^2 for group 2.

Adaptation to the length of the crest[4]: In the case of large and small stone roughouts where the difference between the length of the crest is 3.5 cm (the length of the crest is 7 cm for large preforms and 3.5 cm for the small ones), the craftsmen from both group 1 and group 2 produce statistically higher acceleration when removing the longer crests (Table 4.3). In the case of glass, however, where the difference in length between the crests is only 2 cm (7 cm for the large ones and 5 cm for the small ones), all the craftsmen from group 1 show statistically significantly (p <0.001) greater acceleration for the longer crest lengths, while in group 2, four craftsmen show no difference at all, and two craftsmen show only small differences (p <0.05).

Table 4.3 gives the average values of acceleration for each of the craftsmen comparing the acceleration produced during fluting for large and small stone and glass preforms. These results express greater homogeneity in group 1 than in group 2. This highest homogeneity may be summarized along two main lines:

1. smaller inter-individual variability in group 1;
2. more stable difference in the values of acceleration displayed for large and small roughouts.

The low inter-individual variability in the craftsmen from group 1 suggests that a high level of expertise corresponds to a quite stable action solution from one individual to the next. A high level of mastery of action may allow for less latitude for inter-individual variations. In contrast, the individual solution of group 2 appears to be more diversified and results in a finished product of lower quality.

The coefficients of variation (standard deviation divided by mean) have been computed for acceleration in all situations for each craftsman of group 1 and group 2. Contrary to the commonly accepted idea that experts behave in a more consistent and nearly automatic manner, intra-individual variability, indexed by the coefficient of variation, is slightly greater for group 1 than for group 2.

A final aspect of the elementary action should be addressed here even though it has not been subjected to systematic quantification. As described earlier, the elementary action is bimanual, where each hand is specialized: for a right-hander, the roughout is held in the left hand, i.e. the postural hand, and the hammer in the right. The hand holding the stone can be more or less stable, that is more or less disturbed when the hammer hits the roughout. Based on the videos, we can say that globally, the postural hand of the craftsmen from group 2 is less stable than of those from group 1. At the moment of impact, the head of the hammer is either stopped, or its trajectory continues after the moment of the impact on the stone. The first strategy is usually displayed by the craftsmen of group 1, the second by the craftsmen of group 2. Here again, we can hypothesize that the craftsmen from group 1

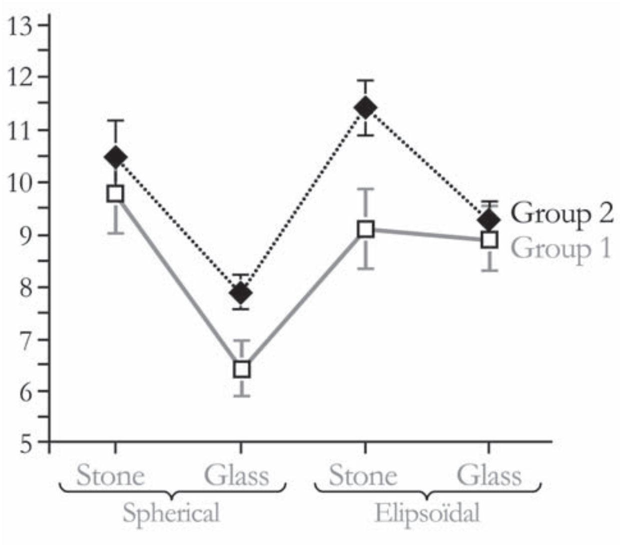

Figure 4.16. *Harmonic model: mean values of the deviation from accelerometer and harmonic model (in %) for each group and condition.*

Table 4.3. *Mean values of acceleration of the hammer for each craftsman of both groups (m/s²) (* = statistically significant at* p *<.05; ** = statistically significant at* p *<.01; ns = non-significant).*

		STONE		GLASS	
		LARGE	SMALL	LARGE	SMALL
GROUP 1	RA	58.2	34.8	27.5	24.4 *
	HU	75.4	44.5	63.9	44.9 **
	HA	77.8	67.4	47.8	40.4 **
	IN	66.4	49.3	57.8	46.1 **
	AB	68.4	52.6	57.1	52.6 **
	RN	61.4	42.4	53.7	45.4 **
GROUP 2	DE	95.5	74.5	69	65.6 ns
	SU	72.2	45.7	48.8	44.2 *
	SA	54.8	48.7	40.8	41 ns
	NA	41.4	35.5	25.6	23.8 ns
	AS	55.2	40.7	37.7	39.3 ns
	HK	59.2	47.1	40.9	33.3 *

better anticipate the disruption caused by the shock of striking the stone. In addition, they are able to control the hammer movement in such a way that the impact is almost totally absorbed by the stone, resulting in higher strike efficiency.

Discussion: What is expertise?

This experimental study was based on the hypothesis that, compared with less-expert craftsmen, expert craftsmen would be better able to transfer their knapping skill to a new situation. This should be true in particular with a new raw material, provided that the new raw material responds to the same mechanical principles as chalcedony, that is those associated with the conchoidal fracture. In addition, as a raw material, glass had the immense advantage of being homogeneous. Thus, as the aim of this experiment was to try to characterize the nature of expertise, a homogeneous raw material lets us discuss the differences in behaviour among craftsmen with respect to their production in terms of differences in skill. It was quite improbable that these differences would be due to the raw material as might be the case for stone, as stone is not a homogeneous raw material.

One of the innovative aspects was that this study was designed to enable simultaneous analysis of the action — the knapping process from roughout to preform — as well as the product of this process — the preform. In addition, three levels of action were investigated, based on recording methods adapted to the level of action referred to — i.e. video for the course of action, and accelerometer for the elementary action. In this discussion, we shall highlight the differences in the behaviour between the two groups of craftsmen who participated in the study, and relate them to the characteristics of the end-product, the preforms.

The characteristics of expert production and behaviour

The roughout produced by the craftsmen of both groups corroborate what everyone in Khambhat knows: during the experiment, the craftsmen producing high-quality beads (participants of group 1) for a living knapped more regular, spherical, better-shaped preforms with smooth contours. On the contrary, and as expected, the craftsmen producing low-quality beads for a living, produced less regular, less spherical, less well-shaped, and more bumpy preforms compared with the participants of group 1. The participants of both groups adapted very differently to the new raw material, i.e. glass. The craftsmen from group 1 were able to adapt quite well to the new raw material. Confirming our hypothesis, knapping glass produced a zooming effect on the difficulty of the task. This was particularly true for the craftsmen of group 2. When comparing the sphericity of the preforms produced by the craftsmen of group 2, the mean value obtained is much lower for glass than for stone. For the craftsmen of group 1, these values are very similar for stone and glass, reflecting near perfect adaptation to the new raw material. Similar facts can be reported from other characteristics of the preforms as well. The contour of the preforms produced by group 2 was much less smooth. In other words, the production of group 2 is more irregular. In the same way, bumps are larger for group 2, and the final shape of the preform is quite far from the ideal shape. In this group, the glass roughouts were barely transformed and it is easy to see the original parallelepipedic shape in the knapped preform.

Clearly, the difference in the production from both groups is substantial and can be attributed to differences in the competence of the craftsmen. We suggest here that an analysis of all three levels of action referred to in this study is necessary to understanding expertise.

Is the course of action a good indicator of planning capacity?

As discussed earlier, some theoretical approaches to action stress the role of representations that are considered to be at the origin of skilled behaviour. In line with this perspective, the course of action reflects the person's ability to plan.

The course of action proved to be quite similar in both groups except for the absence of the calibration operation for most of the craftsmen from group 2. Why did they omit this operation, even though it is important for good fluting? It could be that it was not worth spending time on a time-consuming operation for low-quality beads. Or could it be that the craftsmen did not know about this operation, or that they were not able to perform it? An experiment conducted more recently (see L. Biryukova *et al.* this volume) suggests that all the craftsmen know what calibration is, but it is not clear whether they have good knowledge of why it may be important to obtain a more perfect ellipsoidal preform. However, even when done by craftsmen from group 2, calibration turned out to be quite crude and did not meet its purpose, i.e. to prepare the shape of the crest to allow efficient fluting. As will be discussed in the section on elementary action, the hypothesis here is that the control of the elementary action of the craftsmen from group 2 is not sufficiently fine to produce very thin flakes. Consequently, since they do not really understand the purpose of calibration, they skip it.

The analysis of the course of action clearly suggests that all the craftsmen know about the method. Very few incoherent paths of sub-goals were noticed. However, the method used to knap a preform from a parallelepipedic roughout is quite simple, and it is not surprising that all the craftsmen were able to apply the method in a coherent path of sub-goals. More surprising is the very significant variability found among the craftsmen in both group 1 and group 2. Some of the craftsmen, in both groups displayed only one path of sub-goals, corresponding to one strategy. On the other hand, other craftsmen from group 1 as well as group 2, while knapping eight preforms of a similar shape, displayed up to five or seven different paths corresponding to one or even two strategies. This idiosyncratic behaviour is difficult to explain, but suggests that the quality of the end-product does not depend on the way the method is applied. This dramatic diversity in the application of the method suggests that there is no advance planning of the sequence of sub-goals to be carry out, otherwise why would some of the craftsmen follow a different path for almost every roughout? While the sequence of sub-goals is undoubtedly controlled, the knowledge of the method, i.e. the main steps, or sub-goals to reach the desired shape is necessarily associated with the knowledge of what constitutes the prerequisite for the next sub-goal to be performed. Along this line, what is referred to as planning is a 'resource' as Agre & Chapman (1990) put it. Along this line, the course of action is the expression of a continuous dynamic between the organism — the craftsman — and the environment. The question is then, what is this dynamic composed of?

The critical role of elementary action

An elementary action has been defined as the smallest unit of a functional action. It corresponds to a functional strike, i.e. the removal of one flake through the action of the hammer. In other words, the removal of one flake corresponds to the *actualization* of the technique. This study focused on the elementary action and not on the movement. The rationale of this choice was that it is necessary first to understand what functional aim the movement fulfils. Only then can the analysis of the movement of the striking arm make sense. Here, the functional goal — removing a flake — is achieved by the movement of the hammer. The trajectory, velocity and force displayed by the hammer index the performance of a stroke, and hence of the craftsmen's level of expertise.

The analysis of the hammer acceleration during fluting made obvious the necessary adaptation of the hammer movement to succeed in flaking. The smaller acceleration displayed by all the craftsmen when knapping the glass roughout, compared with stone, makes it clear that adapting to the characteristics of the task is one of the main requirements for successful flaking. In addition, the acceleration of the hammer must be tuned to the dimensions of the flake to be removed. The analysis of flutings of crests of different dimensions revealed that all the craftsmen are more or less able to adapt to the length of the crest. However, and this is one of the main results of our study, the craftsmen from group 1 demonstrate a finer tuning to the characteristics of the flake to be taken off than the craftsmen from group 2. When knapping glass roughouts, all the craftsmen from group 1 produced an acceleration of the hammer which was smaller when knapping a crest of 5 cm compared with one of 7 cm. The craftsmen from group 2 were not able to perform this fine tuning.

The results on the dynamics of the sequencing of elementary movements are interpreted as corroborating this interpretation. The frequency distributions displayed different features for the craftsmen of group 1 and group 2. The non-symmetrical distribution of group 1 was attributed to a different timing pattern for fluting and end preparation, the low frequency corresponding to fluting and axial removal, and the higher frequency reflecting end preparation. On the other hand, the symmetrical distribution displayed by the craftsmen of group 2 was interpreted as reflecting non-differentiated timing for the different operation. In addition, the major variation in the range of frequencies, either quite small or quite large, was interpreted as rigidity, or uncontrolled variability.

A common feature of these distributions, however, concerns the peak of frequency, which is approximately the same for all the distributions. This property is attributed to the natural physical properties of the hammer. Like a pendulum whose frequency depends on its mass and length we suggest that the frequency of the hammer might reflect a similar phenomenon. A recent experiment with craftsmen of different levels of expertise corroborates this hypothesis (Bril *et al.* 2001). In a similar experiment to the one reported in this chapter, the craftsmen were asked to work with a heavier hammer or one with a shorter handle. Depending on the characteristics of the hammer, the peaks of frequencies were different — higher with a shorter handle, lower with a heavier hammer. So, we can hypothesize that the value of the peak of frequency depends on the hammer's characteristics, while the profile of the distribution reflects the craftsman's adaptation to the specificity of the successive flakings corresponding to the different operations. A non-symmetrical profile in the low frequencies is interpreted as a voluntary modulation of the natural properties of the hammer, corresponding most probably to flutings and axial removals. On the other hand, a symmetrical profile around this peak value would reflect the absence of voluntary mastery of the natural properties of the hammer.

Here again, the adaptation revealed by the frequency profile is a salient feature of the craftsmen of group 1, and reflects the outstanding capacity of the craftsmen producing high-quality beads to adapt their striking action to the very precise characteristics of the flake to be removed depending on the operation performed.

The perception/action coupling

One characteristic of the group 1 elementary action is recurrent: the ability to very precisely adapt to the properties of the task at hand. The adaptation referred to here bears on the hardness of the stone, on the dimension of the flake to be removed, and on the tool, i.e. the properties of three elements constituting the system at hand. In other words, adaptation pertains to the level of the elementary action, i.e. to the technique.

In any case, adaptation to the specificity of the task cannot be achieved without the ability to perceive the necessary information that will allow the craftsman to tune the action in order to reach a very precise outcome. Adaptation and flexibility have often been addressed as the critical dimensions of expertise. The expert is one who, when confronted with the constraints of the task (the raw material, the hammer, the physical characteristics of the conchoidal fracture, the length of the roughout, the expected shape of the final product), is able to actualize the method through a constant dynamic fit between the state of the roughout and the next step, in other words, to remove the exact flake.

The common value of the peak of frequency for all the craftsmen has been interpreted as emerging from the linking of the three components — hammer, body, and raw material. We suggest that expertise consists not only in tuning as well as possible the properties of the system, but the expert is one who is able to *force* the system in one direction or another to adjust to the local features of the situation.

Such a perspective suggests that the core of expertise lies in the very precise control of the elementary action, i.e. on the bimanual activity that underlies the elementary action. Going one step further, we suggest that this fine control constitutes an (or even *the most*) important dimension of the possibility of carrying out the method. The ability to perceive the real meaning of what the sequences of operation relative to a method are about could well be limited by the ability to control the elementary action. Cognitivist theories have emphasized the role of planning the sequence of actions, the role of a mental representation of the desired goal to be reached. These theories focus on the prescription for action: they attribute a large portion of the behaviour to an intelligent executive device, regardless of the nature of the device. These theories focus very little on the execution phase of the action, which is often taken for granted. An analysis of the entire process of performing a complex goal-oriented action highlights the need to understand how the three levels of action interweave simultaneously.

We argue here that an adequate account of the knapper behaviour while knapping a roughout requires that we understand how the constraints of the system — task, raw material, organism, tool — work together. The necessary knowledge of the method to produce a roughout of a specific shape may be referred to as a 'mental representation' or a template. However, ascribing the observed course of actions to a kind of prescription defining a plan established in advance, makes it very difficult to explain the very important variations observed either within a group of craftsmen of approximately the same level of expertise, or perhaps more importantly within the behaviour of a given craftsman, whatever his level of expertise. We share the conviction that the most rewarding way of approaching an understanding of complex behaviour is to be found in a functional approach. This means focusing on the relationship between the environmental constraints and the behaviour produced. This approach does not deny the existence of a 'representation' regardless of the name given, but it does not consider a close causality between representation and the behaviour that may be observed. It emphasizes an understanding of the course of action based on an analysis of the dual complementarity between the organism and the environment.

Conclusion: a masterful technique for an efficient method?

The results of this experiment have highlighted the fact that a craftsman may have practised a method for years and still produce mediocre roughouts. This produces evidence that knowing the method, i.e. the operations needed to knap a preform of a specific shape, does not constitute the hallmark of expertise. It suggests that a prerequisite to expertise is to be found in the ability to finely tune the goal of the elementary action, that is to be able to produce a flake with the right characteristics at the right time in the sequence of flake removals. This may be fulfilled only through the movement of the hammer direction, amplitude, velocity, force (Biryukova *et al.* this volume) and the positioning of the stone. To produce the right values for these different parameters that define the production of a flake along the conchoidal fracture, the movement must be very well controlled. In other words, the knowledge of the method is of no use if the technique is not very finely controlled.

What we argue here is that a high level of expertise depends on the ability of the knapper to control the elementary movement. This leads to the hypothesis that a very fine tuning of the elementary movement determines the ability to plan the whole sequence of strikes. We simply need to consider someone who has a very good knowledge of the method but no experience in the elementary movement. We bet that s/he won't be able to produce anything at all. In other words, the ability to 'plan well' the sequence of sub-goals depends on the level of mastery of the elementary movement.

It will appear a truism to emphasize the fact that experts are better able to adapt their action, that is to utilize information on the state of the roughout in such a way as to adapt the next action to achieve a better functional fit than do less expert craftsmen.

The detection of information necessary to guide the entire knapping process depends on the level of expertise in the 'technique'. A high-level expert will be able to constrain mutuality relations between himself and his environment (i.e. the stone at different points in the knapping process) in such a way as to perceive the affordances (Gibson 1977; 1986; Stoffregen 2000), that is the properties of the system (stone/hammer/organism) that lead to the characteristics of the next flake, and consequently the next strike. In other words, the high-level expert knows better what to look for and how to turn the information perceived into action and movement: this capacity is directly associated to a high degree of control of the technique.

However, a basic question remains: what are the properties of the 'template' the knapper relies on to guide the sequence of flake removals. What has to be worked out is how the specific removal fits, and relates to the knapper's global goal.

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Notes

1. Description of the four different shapes to be knapped in the two raw materials:
   1. two ellipsoidal beads of different length (from roughout of 7 cm × 2 cm × 2 cm for both stone and glass; and 5 cm × 2 cm × 2 cm for glass and 3.5 cm × 2 cm × 2 cm for stone);
   2. one spherical bead from a cubic roughout of 2.5 cm per side for both stone and glass;
   3. one curved-prismatic-four-sided bead from roughout of 5 cm × 2 cm × 2 cm for glass and 3.5 cm × 2 cm × 2 cm for stone.

   The smaller size of carnelian roughout was unfortunately due to the hazard of field work. When we arrived in 1993, Khambhat was under curfew and there was a shortage of raw materials.

2. All the craftsmen participating in the study were paid the same amount of money, slightly more than what an expert earns in one day.
3. The ideal shape was calculated taking into account the preform produced. At first we had planned to compute the 'ideal' shape from the roughout. This did not take into account, however, the possibility of the raw material not being available. We then chose to determine the 'ideal' shape from the preforms produced.
4. See note 1.

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