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NUMBER 1

THE OLDOWAN:

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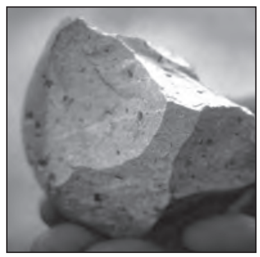

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Photographs of the Stone Age Institute. Aerial photograph courtesy of Bill Oliver.

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CHAPTER 11

Comparing the Neural Foundations of Oldowan and Acheulean Toolmaking:

A Pilot Study Using Positron Emission Tomography (PET)

By Dietrich Stout, Nicholas Toth, and Kathy Schick

Abstract

Functional brain imaging technologies provide human origins researchers with the unique opportunity to examine the actual neural substrates of evolutionarily significant behaviors. This pilot study extends previous brain imaging research on stone toolmaking (Stout *et al.*, 2000; Stout, this volume) by using Positron Emission Tomography (PET) to compare Mode II, Acheulean biface production with Mode I, Oldowan flake and core production. Results from this single-subject pilot study are not sufficient for statistical analysis, but do confirm the applicability of PET research methods to Mode II and later technologies as well as providing some indication of what may be expected from future research.

Introduction

Recent work using Positron Emission Tomography (PET) to examine the brain activation associated with Mode I, Oldowan-style toolmaking (Stout *et al.*, 2000; Stout, this volume) has begun to shed light on the psychological and evolutionary implications of the earliest stone tools. Applying these experimental methods to the study of more recent stone technologies will be an important next step for this research program. By identifying the actual neural foundations of the stone technologies associated with various periods of human evolution, functional brain imaging research will facilitate the psychological interpretation of archaeological evidence and potentially help to chart the evolutionary emergence of the human brain and intelligence.

As a step in this direction, the authors conducted a preliminary experiment in the use PET to examine Mode II, Acheulian-style biface manufacture. This experiment was intended primarily as a feasibility study, and confirmed that methods previously used to investigate Oldowan-style knapping (Stout, this volume) were also applicable to handaxe-making. Results obtained from this single-subject experiment are not sufficient for statistical analysis, but do provide a suggestion as to what may be expected from future research.

The emergence of Mode II technology, dated to at least 1.5 Ma (Isaac & Curtis, 1974; Asfaw *et al.*, 1992), has long been regarded as a milestone in hominin cognitive evolution. Compared with the simple cores and flakes of the preceding Oldowan, early Acheulean bifaces clearly reveal the appearance of more regularly patterned and technically demanding toolmaking activities. However, it is also important to appreciate the variation, both temporal and spatial, that exists within the broadly defined Acheulean Industrial Complex (Clark, 2001). Differences between early and later Acheulean artifacts are especially striking, and may reflect further important developments in hominin cognitive evolution (Wynn, 1989). It should thus be noted that the handaxe production undertaken for this pilot experiment is representative of later, rather than earlier, Acheulean technology.

The differences between earlier and later Acheulean handaxes reflect the emergence of more meticulous and skill-intensive knapping practices. Later Acheulean handaxes typically display more intense overall reduction, with a greater number of flake scars per unit of surface area and little or no preservation of original blank surfaces. Flake scars are generally shallower, being left by the thin, spreading flakes that are produced by striking close to edges that have been steepened through careful platform preparation. In some cases, soft hammers may have been used. Later Acheulean handaxes also tend to be thinner relative to breadth, with carefully thinned tips, straighter, less scalloped edges, and greater symmetry in both plan form and cross-section. Within assemblages, there is a tendency toward greater uniformity in handaxe size and shape in the later Acheulean.

Although some researchers have commented on the skill required to actually make refined later Acheulean handaxes (Callahan, 1979; Bradley & Sampson, 1986; Schick, 1994; Edwards, 2001; Clark, 2001; Stout, 2002), most psychological interpretations have focused on the degree to which imposed symmetry and "arbitrary form" are evident (or absent) in the finished artifacts (Wynn, 1979; Gowlett, 1984; Isaac, 1986; Wynn & Tierson, 1990; Noble & Davidson, 1996; McPherron, 2000; Noll, 2000). The presence of such imposed form is considered to provide evidence of relatively advanced spatial conceptualization, strategic planning and stylistic (cultural) awareness.

This orthodox, *representational* (Stout, this volume), approach defines the sophistication of prehistoric stone technologies in terms of their reliance upon internally constructed mental images, plans and concepts. Applied to PET research, this perspective calls our attention to those parts of the brain that are characteristically associated with representational and introspective activities, and especially to the classic "planning and problem solving" areas of the prefrontal cortex (e.g. Brodmann's Areas 9, 10, 45 and 46). Such regions are not significantly activated during Mode I stone knapping (Stout *et al.*, 2000; Stout, this volume), and their activation during Mode II biface production would provide support for the conventional view that Acheulean handaxes reveal "higher conceptual and cognitive abilities" than do Oldowan cores and flakes (Ambrose, 2001: 1750).

In order to enlarge upon this traditional perspective, Stout (this volume) proposes an additional, *perception-action* approach to understanding the brain activation associated with stone toolmaking. This approach emphasizes the importance of dynamic knapping skill, rather than static mental representation, in supporting stone toolmaking activities. Knapping skills are embodied in effective actions in the world and emerge from the purposeful coordination of outwardly directed perception and action (Stout, 2002). The resulting focus on external perception and action as opposed to internal representation draws our attention to different parts of the brain, including the visual and motor cortices of the occipital and frontal lobes and the sensory association cortex of the superior parietal lobe. These regions do appear to be recruited during Oldowan-style knapping (Stout *et al.*, 2000; Stout, this volume), but the greater technical demands of handaxe-making might be expected to produce relatively more intense and/or extensive activation. Of particular interest would be the level of activation observed in the premotor areas of the posterior frontal lobe (Brodmann's Area 6) and the polymodal association cortex of the superior parietal (Brodmann's Area 7), regions that provide essential neural substrates for the dynamic coupling of complex patterns of perception and action.

The Experiment

Brain imaging methods used in this pilot study very closely follow those previously employed to examine Mode I flake production, which are discussed in detail elsewhere (Stout, this volume). As in previous experiments, the slowly decaying tracer FDG (^{18}flouro-2-deoxyglucose) was used so that knapping could occur in a relatively naturalistic setting outside the scanner. A single subject (Nick Toth, an experimental stone knapper with over 25 years experience) was imaged during one trial for each of three task conditions. This constituted the maximum acceptable research-related radiation exposure for a one-year period. The three conditions were: (1) a control condition that consisted of striking two cobbles together without attempting to produce flakes, (2) Mode I flake production, and (3) Mode II handaxe production. All experimental activities were videotaped and all products were collected for analysis (Figure 1).

Activation data from each knapping condition was compared with the control condition in order to reveal any regions of increased neuronal activity. Where present, such increases reflect neural demands of stone knapping in excess of those associated with the simple bimanual control task (Stout, this volume). Unfortunately, small sample sizes (n=1) in the current pilot study do not allow the statistical significance of observed differences to be assessed (see below).

Oldowan Core and Flake Production

As in the Oldowan experiment reported by Stout (this volume), the subject in this pilot study was presented with an assortment of water-rounded cobbles of a variety of raw materials and asked to produce sharp, useable flakes through hard-hammer percussion. Both hammerstones and cores were selected from this assortment during the 45-minute duration of the experiment. Cores were reduced until they were exhausted, usually because the edge angles became so steep that further reduction was difficult. The resulting cores (in Mary Leakey's typological system) included nine choppers, four polyhedrons, two heavy-duty scrapers and one casual core (modified cobble). The flakes produced were also typical of the Oldowan, with thick striking platforms and cortex on the dorsal surfaces of most of the flakes.

Technical Acts

The videotape of the flake and core production was reviewed in order to quantify number and rate of technological acts employed. In Mode I knapping, technological action was limited to hard hammer direct percussion. Over the 45-minute period there were 1165 percussive blows, or roughly one blow every 2.3 seconds. With 16 cores produced, this equates to an average of 68.5 blows per core.

Late Acheulean Handaxe Manufacture

Acheulean handaxe production also took place during a 45-minute experimental period. As in the Oldowan condition, no clocks or timepieces were visible to the subject, who also made a deliberate attempt not to mentally "verbalize" the operation or count sequential technological acts (percussion blows, grinding). The materials used in this handaxe replication included the large obsidian flake blank for handaxe manufacture; a larger, denser sandstone spherical hammerstone for the roughing out of the biface; a smaller, less dense limestone disc-shaped hammerstone for striking platform preparation, shaping of the plan form, and abrasion of the striking platform; a soft hammer of elk antler to remove thinning flakes from the handaxe and for final shaping and straightening of sinuous edges; and a gazelle skin to protect the subject's leg, which supported the obsidian biface.

The blank used in this handaxe manufacture was a large obsidian flake that had been previously struck from a discoidal boulder-core with a very large hammerstone. The quarrying of such large flake blanks for handaxe and cleaver manufacture is a recurrent technological strategy seen in the Acheulean of much of Africa (see Toth, 2001) as well as sites in the Near East, Iberia, and the Indian subcontinent. The flake blank used in this experiment was a corner-struck, sub-rectangular thick flake with approximately 50% of continuous cortex on the dorsal face. The blank weighed 5,596 gm and measured 30 cm x 25 cm x 12 cm with a large, thick multifaceted striking platform measuring 22 cm x 11 cm. Both the proximal and distal ends of the flake were quite thick, with a thick striking platform and prominent hinged termination at the distal end.

Figure 1

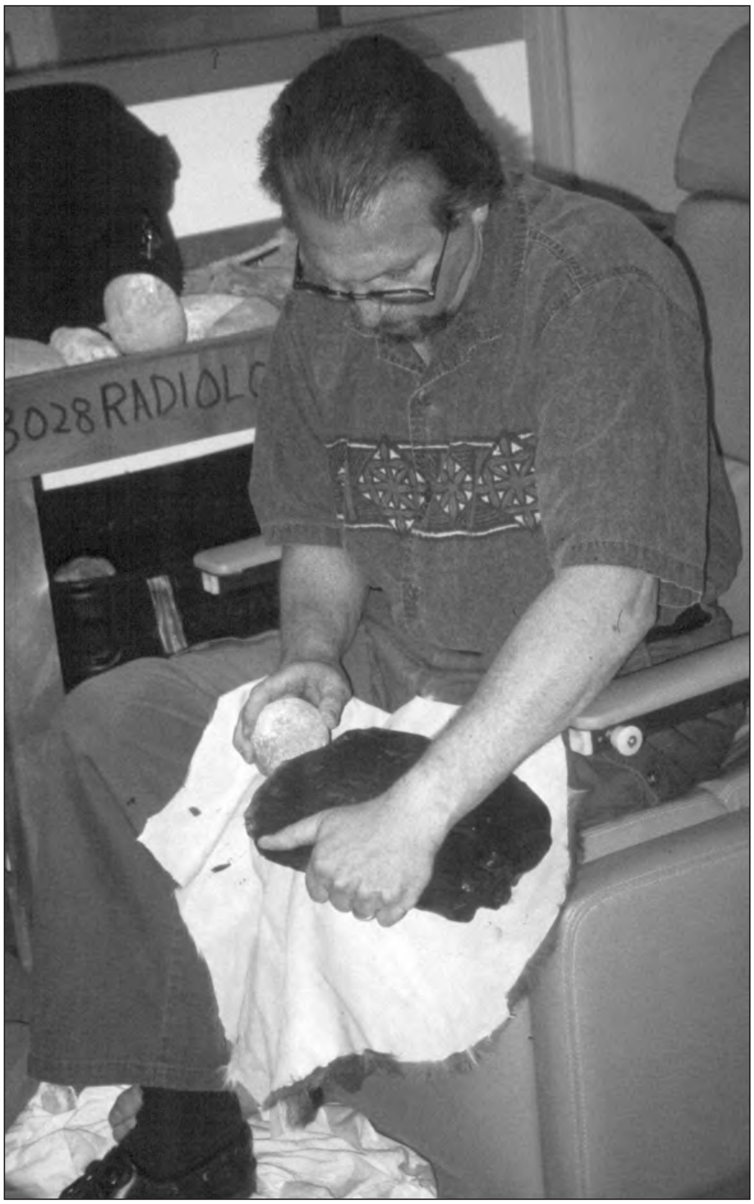
1. *Setting up the handaxe manufacture experiment: The slowly-decaying radioactive tracer (FDG) is being injected into the subject's foot, the video recorder is being set in place, and the subject is seated with the obsidian flake blank in his lap and the stone and antler hammers within easy reach on his right. (Photo by Kathy Schick).*

Although it is true that stone tool manufacture can be quite fluid rather than rigidly divided into sequential stages of reduction, nonetheless four major stages of manufacture were envisioned and could be identified in this experimental replication. These were:

1. Examination of the flake blank (3.5 minutes)
2. Roughing-out of the biface (8 minutes)
3. Primary bifacial thinning and shaping of the handaxe (24 minutes)
4. Secondary thinning and shaping of the handaxe (9.5 minutes)

Each of these stages of reduction will be discussed, with consideration of the mental operations and the technological acts that were employed.

Figure 2



2. The subject begins roughing-out the biface from the obsidian flake blank using a sandstone hammer. (Photo by Kathy Schick).

1. Examining the flake blank (3.5 minutes)

After the radioactive tracer was injected into the subject's foot and entered his bloodstream (Figure 1), the 45 minute experimental period began. The subject first inspected the flake blank, examining the overall morphology, looking for potential flaws or inclusions in the raw material, and testing the obsidian blank by tapping with the sandstone hammer to listen to its acoustic properties (a good obsidian flake will have a clear, glassy ring when tapped, while a flake with a serious flaw will often have a dull, muted sound).

2. Roughing-Out the Biface (8 minutes)

This first stage of lithic reduction was carried out with the larger sandstone hammer, and attempted to create a continuous, sharp edge around the perimeter of the biface and producing a continuous acute edge that was generally centered between the two faces of the biface (Figure 2). Reduction was conducted to make the blank more symmetrical and to generate a well-centered edge. Lighter hammerstone blows were used to remove overhangs and spurs from edges; more forceful hammerstone blows were used drive off larger, longer flakes in this first stage of reduction.

At first it was unclear exactly where the long axis of the biface would be, but as reduction continued, the long axis began to emerge in the rough-out: the right and left sides of the flake delineated the long axis, while the thicker proximal and distal ends of the blank became the sides of the biface. The proximal and distal ends of the blank were relatively thick due to presence of the original striking platform and bulb on the one hand and a prominent hinge release surface on the other. These surfaces provided the platforms for bifacial thinning. The thinner right side of the flake became the tip of the handaxe, and the somewhat thicker right side became the butt.

The flakes produced tended to be thick, with prominent bulbs of percussion and usually one or two scars on the thick striking platform; normally there were only a few bold scars on the dorsal surfaces of the flakes. Lithic analysts would generally classify these flakes as "hard-hammer percussion" flakes.

3. Primary Thinning and Shaping (24 minutes)

During this phase of reduction, the overall shape of the final handaxe could be envisioned in the still irregular, relatively asymmetric and thick biface. Large thinning flakes were removed from the biface with a smaller, less dense limestone hammer to decrease the overall thickness. Striking platforms were first carefully prepared by intensive, light flaking performed along the edge from which the thinning flake was to be removed but directed toward the opposite face. This edge preparation was done to steepen and strengthen the edge to receive the forceful blows of an antler soft hammer. Edges were also abraded with the limestone hammer, creating roughened areas that provided greater purchase for the antler hammer. During this intensive platform preparation it was possible to control the shape of the plan form of the handaxe, making it bilaterally symmetrical and beginning to shape the pointed tip end and the steeper, wider butt end.

The flakes produced in this process tended to be thin and slightly curved in side view, with a diffuse bulb of percussion, a thin or punctiform striking platform, a slight lipping on the ventral surface near the point of percussion, numerous scars (facetting) on the striking platform, a steep exterior platform angle, and occasional evidence of hammerstone abrasion on the platforms; often there were numerous shallow scars on the dorsal surfaces of the flakes as well. Lithic analysts would generally classify these flakes as "soft-hammer percussion flakes", although these flakes can also be produced with a hard hammer by employing careful platform preparation and marginal flaking near the edge of the biface.

4. Secondary Thinning and Shaping (9.5 minutes)

A new round of bifacial thinning and shaping occurred in the last 9.5 minutes of reduction. Platforms were prepared by robust light flaking and abrasion with the limestone hammer to produce regular, strong edges to support the robust blows from the antler soft hammer and remove invasive thinning flakes. During this flaking all of the original cortex, and almost the entire original blank surface, was removed, the pointed tip and steepened butt were carefully shaped, and any sinuous edges straightened. Much of the final flaking was carried out with light blows from the antler baton. The flakes produced tended to be morphologically similar to those produced in the primary thinning and shaping stage, but smaller in overall size.

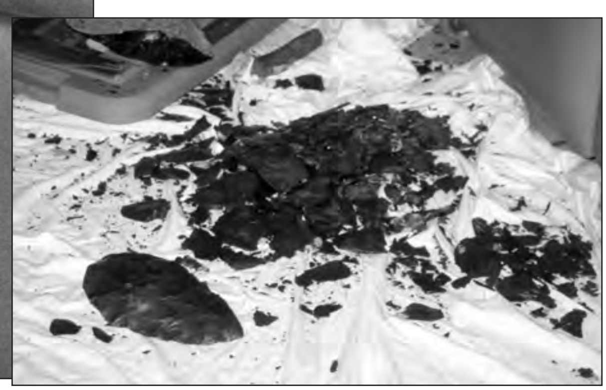
The Finished Piece

After 45 minutes, the final form of the biface was a large, elongate cordate handaxe characteristic of the late Acheulean (Figures 3 & 4). Retouch was extensive, shallow, and invasive, with all of the cortex (and all of

Figure 3

3. The finished product of the handaxe-making experiment: A large, elongate cordate handaxe. Handaxes with such a high degree of symmetry and extensive retouch, with removal of many invasive, shallow flakes, are characteristic of the later Acheulean. (Photo by Kathy Schick).

Figure 4



4. The finished handaxe along with the flakes and fragments produced in the 45 minutes of fashioning the tool. The antler soft hammer is in the top center. (Photo by Kathy Schick).

the original dorsal flake surface) having been removed from the dorsal face, and only one small area on the ventral face (3.4 by 2.4 cm) showing the original release surface. The final form of the handaxe had the following attributes:

Weight: 1,960 gm. (30.5% of the original flake blank weight)

Length: 25.0 cm (83.3% of the original blank length)

Breadth: 14.0 cm (56.0% of the original blank breadth)

Thickness: 5.6 cm (46.7% of the original blank thickness)

Flake scars (one cm or greater) on dorsal face: 48

Flake scars on ventral face: 58

Total flake scars: 106

Maximum dimension of largest flake scar: 9.8 cm

It should be noted that the final form of the large handaxe could still have been resharpened and thinned a number of times if there had been more time. Nonetheless, the 45 minutes of biface production was typical of the all of the technological operations and cognitive decisions that were required to make a late Acheulean handaxe.

Technical Acts

The videotape of the handaxe manufacture was reviewed a number of times in order to quantify number and rates of different technological acts employed to modify the stone and produce the handaxe. These technological acts did not include shifting from one knapping tool to another, turning the biface over from one face to another, or brushing off detached flakes from the animal skin, but rather only acts of physical force such as percussion and grinding on the obsidian artifact itself.

Figure 5

5. *The subject being scanned immediately after the 45-minute tool-making session. (Photo by Kathy Schick).*

Roughing-out stage:

Light (preparation) blows with larger sandstone hammer: 80

Strong blows with larger sandstone hammer: 57

Rate: One technological act every 3.5 seconds

Primary & secondary thinning and shaping

Striking platform preparation blows with smaller limestone hammer: 1640

Grinding striking platforms with limestone hammer: 270

Strong antler hammer thinning blows: 76

Light antler hammer shaping blows: 286

Rate: One technological act every 0.89 seconds

Interestingly, at the end of 45 minutes of intensive late Acheulean flaking, the subject felt more "mentally fatigued" than after 45 minutes of Oldowan flaking. The Acheulean flaking required much more concentration and attention to detail, more complex attention to three-dimensional space, and continuous imagining of the final handaxe shape inside the stone as reduction proceeded. The subject repeatedly would examine the underside of the biface (where flakes would be detached) before hammerstone or antler hammer blows were struck, and often platforms would be re-prepared as knapping proceeded.

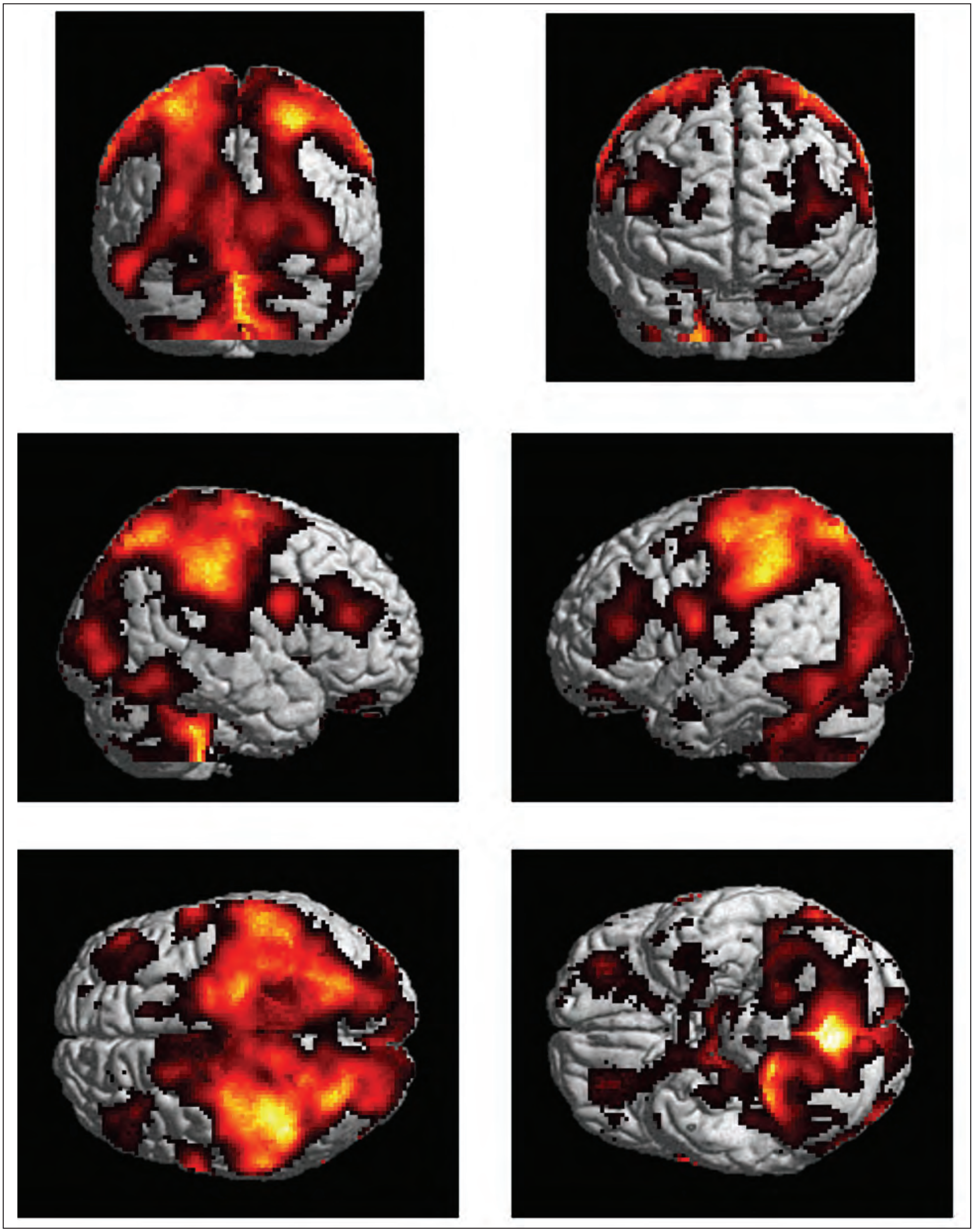
At the end of the knapping, the subject immediately went into the PET scanner and was immobile for the next 45 minutes of scanning (Figure 5).

PET RESULTS

The activation data collected during this experiment were analyzed using the *Statistical Parametric Mapping (SPM99)* software package developed by the Wellcome Department of Cognitive Neurology, Institute of Neurology, at the University College London. This software conducts statistical comparisons (t-tests) between the individual *voxels* (essentially three-dimensional pixels) in control and experimental data sets in order to generate an image showing significant differences. This process requires multiple scans in each condition in order to provide the data necessary for significance testing. However, in the pilot experiment presented here each condition is represented by only a single scan. Statistical analysis is thus impossible at this point.

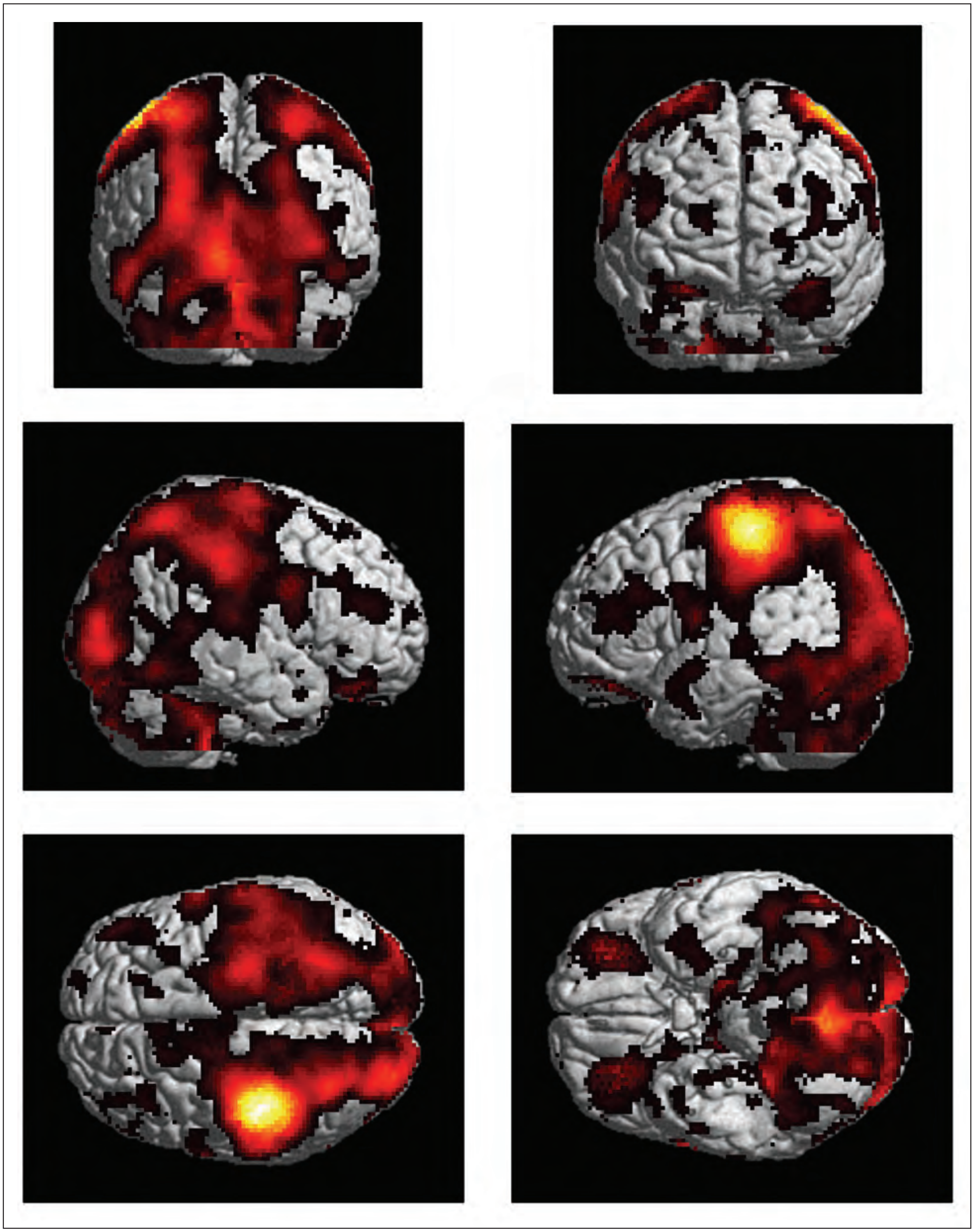
In order to obtain images for use in preliminary evaluation and hypothesis generation in this pilot project, data from each condition were entered three times, as if representing three separate trials. The resulting images reveal differences in activation between experimental and control conditions, but do not indicate the statistical significance of these differences. Any interpretations must therefore be regarded as highly provisional in nature. Nevertheless, it is encouraging that the regions of greatest difference between knapping (both Acheulean and Oldowan) and control conditions observed in this pilot experiment very closely approximate regions of significant activation observed in a more systematic six-subject study of Oldowan-style knapping (Stout, this volume). More specifically, these regions comprise an arc extending from the cerebellum through the occipital and parietal lobes and into the posterior frontal lobe (Figures 6 & 7).

Figure 6



6. *Brain activation during Acheulean handaxe production: Six views (posterior, anterior, right hemisphere, left hemisphere, superior, and inferior) of brain activation during Acheulean-style handaxe production. Activation is extensive and bilateral, occurring in a broad arc from the cerebellum through the occipital and parietal lobes and into the posterior frontal. Regions involved are those commonly associated with visuomotor action and spatial cognition.*

Figure 7



7. *Brain activation during Oldowan flake production: Six views (posterior, anterior, right hemisphere, left hemisphere, superior, and inferior) of brain activation during Oldowan-style flake production. Once again, the characteristic "stone knapping pattern" of activation in cerebellar, occipital, parietal and frontal regions is visible, however activation is less intense/extensive and more clearly lateralized when compared with Acheulean handaxe production (Figure 6). In particular, activation of the primary motor and somatosensory cortex surrounding the central sulcus appears to be much stronger in the left hemisphere (corresponding to the right hand) than in the right hemisphere (left hand).*

Discussion

The appearance of this characteristic "stone knapping pattern" in images contrived from a single-trial pilot study strongly suggests that FDG PET will be an effective means for investigating the brain activation associated with Acheulean-style biface production and later prehistoric technologies. It also provides some suggestion that differences in the neural foundations of Mode I and Mode II knapping will be more on the order of variations on a theme, with some areas activated in Mode I knapping being more intensely activated in Mode II knapping, rather than of drastic differences in overall organization. Unraveling these differences, and their import, will be a relatively subtle matter of identifying quantitative differences in activation intensity and extent.

For example, images produced from this pilot study seem to show a much more bilateral pattern of activity in Acheulean-style biface production (Figure 6) as compared with Mode I knapping (figure 7). Each activity produces activation in both hemispheres, but activation of the primary somatosensory and motor areas of the right hemisphere (corresponding to the left arm) appears to be less robust during Mode I knapping. Statistical comparison in multi-subject studies will be necessary in order to determine if this is actually the case. If so, it might possibly reflect greater demands on the left or "postural" hand in carefully positioning the core during handaxe production, as compared with more unilateral right-hand dominated percussion during Oldowan-style knapping.

Conclusion

This pilot study confirms the feasibility of using FDG PET to investigate the neural foundations of Acheulean-style handaxe production and of comparing these with the substrates of Mode I flake production. The results of the pilot study do not support detailed analysis or interpretation at this point, but do suggest that differences in activation between Mode I and Mode II knapping will relate more to quantitative differences in intensity and extent than to qualitative differences in pattern. Future applications of the methods developed here will test this and other hypotheses and begin to clarify the psychological and evolutionary implications of the major technological changes that accompanied human evolution.

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