UNIVERSITY OF SOUTHAMPTON
FACULTY OF LAW, ARTS & SOCIAL SCIENCES
SCHOOL OF HUMANITIES

In the knapper's hands: testing markers of laterality in hominin lithic production, with reference to the common substrate of language and handedness

Natalie Thaïs Uomini

Thesis submitted for the degree of
Doctor of Philosophy

June 2006

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

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IN THE KNAPPER'S HANDS: TESTING MARKERS OF LATERALITY IN HOMININ LITHIC PRODUCTION, WITH REFERENCE TO THE COMMON SUBSTRATE OF LANGUAGE AND HANDEDNESS

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Right-handedness is one of humankind's distinguishing features, but its origins are obscure. The archaeological record of non-*Homo sapiens sapiens* species provides evidence for bimanually coordinated hand-use patterns in the form of lateralised skeletons, use-wear on tools, and stone knapping. The underlying biomechanical assumptions of these were subjected to analytical validation using ethnographic parallels, biomechanics, and experimental data. The evidence shows robust handedness from Acheulean times onward, leaving a large gap in the dataset for more ancient hominin species. This dissertation explores in detail the handedness markers from lithic production, with a focus on the earliest hominin technology in order to bridge this gap. Knapping experiments were undertaken on three potential markers which could represent the earliest evidence for handedness: single-platform core rotation, large flake production, and tranchet flake production. A new methodology was created for tranchet flaking and was applied to a sample of 451 handaxes from the British Lower Palaeolithic site of Boxgrove, UK. A statistically significant bias toward left-struck tranchet negatives and flakes was found at Boxgrove. However, the experiments showed that knapping a *coup du tranchet* is not subject to biomechanical constraints relating to handedness. Similarly, the assumptions underlying the single-platform core rotation did not withstand experimental validation. The leftward tranchet preference at Boxgrove is interpreted as resulting from the well-established motor habits of skilled knappers. The possible connection between bimanually coordinated hand-use patterns and bi-hemispheric language is examined in a critical assessment of theories about the common substrate. A new model for the common substrate is proposed, based on the conceptual nature of the complementary roles of both sides, in which handedness and language are characterised by functional role differentiation.

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Acknowledgements

I wish to thank the scores of people in various countries who have contributed the advice, discussions, information, feedback, and encouragements that have made this dissertation possible. My Ph.D. research at CAHO (Centre for the Archaeology of Human Origins) was supported by a grant from the Department of Archaeology at the University of Southampton, UK. The knapping experiments were funded by grant number HAF 05/05 from the Lejre Historical-Archaeological Experimental Center, Denmark. I especially thank the LHAF Deputy and Head of Research Marianne Rasmussen, Helle, Hanne Belling, Signe and Matteo, Jen, and Dyveke for their valuable help during my visits to Lejre. The videos were digitised and analysed with VirtualDub 1.6.10, © Avery Lee, available from www.virtualdub.org.

I am indebted to Nick Ashton and Mark Roberts for permission to study the archaeological material, to Deborah Slatford and Georgia Bennett at Franks House, British Museum for their indispensable assistance in providing accesss to the Boxgrove material, and to Matt Pope and Francis Wenban-Smith for providing additional data. The information about knapping positions was gleaned from e-mail interviews which Bruce Bradley and John Lord willingly obliged.

For kind encouragements, publications, and inspiring conversations, I am most grateful to numerous people, especially Jan Apel, Louis-Jean Boë, Eric Boëda, Emiliano Bruner, Raymond Corbey, Tim Crow, Francesco D'Errico, Berit Eriksen, Kathleen Gibson, Naama Goren-Inbar, John Gowlett, Richard Ivry, Linda Marchant, Bill McGrew, Marie-Hélène Moncel, Jacques Pelegrin, Marco Peresani, Valentine Roux, Gordon Rugg, Richard Schultz, Jean-Luc Schwartz, James Steele, Dietrich Stout, Nathalie Vallée, James Varner, and Tom Wynn.

For extensive comments and suggestions on various drafts of the thesis, I owe appreciation to Margaret Clegg, Clive Gamble, Terry Hopkinson, John McNabb, and Sonia Zakrzewski. Grant funding from the Department allowed me to attend several conferences for which I am grateful. To Dimitra Papagianni, the CAHO lunchtime seminars, Maria Dias da Silva, and colleagues at Southampton I am grateful for valuable help in preparing presentations and manuscripts. My research has benefited greatly from many stimulating discussions at various conferences; for the opportunity to present my work I especially thank Laura Longo; Rob Hosfield; Mikkel Sørensen; Jim Hurford; Bernard Bichakjian; Wighart v. Koenigswald, Thomas Litt, Silvana Condemi & Friedemann Schrenk; Sophie de Beaune; Lambros Malafouris; and Bill McGrew.

I am also most thankful to all the hard-working folks at JSTOR, which has provided many valuable, old, and rare articles. The years I toiled in the PG3 office have been extremely cheerful and friendly thanks to Victoria, Farina, Tania-Morgan, Daniel, Tim, Mandy, Livia, Greg, and Hannah. Kirsty Hill, then at The Environment Centre in Southampton, kindly sourced the recycled paper from Evolve.

Additional thanks go to the additional friends who made Southampton liveable: Jorge, Argyro, Eamonn, Fotini, Fernando & Jenny (plus Ivo), John H., Kate & Maki, Vera & Lee, Li-Mei & Klaus-Peter, Fotini, Hannah, Lisa, Alan, Ilja, François, Virginia, Martin S., Richard H., Martin B., Annerose, James W., Simeon; Liz, Sandro, Franca, & Matteo; the Southampton University Caving Club; Richard P., Jani, Pawel & Active Arts; Natalie G. & the Southampton Sustainability Forum; Sue, Dave M., Zoe, Charlotte, & Trina from Wessex Archaeology; Bia & the Origens Capoeira people, and the Phoenix Film Club. For their long-distance support great appreciation is due to all my overseas family (my parents Robert & Catherine; Patrick, Rémi, Jaga, Mamie, Rolande, Stan & Suzi, Louise, Jonathan, Rachel) and friends (Karl, Elina, Shanee, Setsuko, Junyoun, Bernhard, Jed, Aurélie, Christophe, Franck, Mara-Julia, Andreas, Elisa, Mikolaj, and Amandine).

Finally, special thanks go to Mary Stubbington, the PG Administrator, for bravely dealing with all matters arising. Most importantly, I owe a special debt of gratitude to my Ph.D. supervisor James Steele for making this thesis possible, for many inspiring discussions and critical comments, for always having the solution, and for keeping me on track throughout.

Foreword: A note on the exclusion of references from invasive research

This dissertation does not refer to any studies that derive their results from invasive research, directly or indirectly (through citing). I believe that the continuation of such experiments is cruel and should not be allowed, whether on apes, primates, or other life forms. In fact, it is widely accepted that the findings of such research are not directly relevant to humans, especially in the neurosciences, because of the unique nature and structure of our brain (Greek & Greek 2003).

A close reading of some of the literature from these kinds of experiments gives examples of this treatment. The following quotes from Cisek *et al* (2003)[1] illustrate a typical experimental setting for a study on the cerebral substrates of hand motor learning. The animals that are bred or captured for laboratory experiments are housed in impoverished, stressful and unnatural conditions. Furthermore, when the animals fail the tasks they are often put into a deprivation chamber without human contact as punishment. They are forced to carry out thousands of trials of meaningless tasks in order to obtain food or drink, such as in Cisek *et al*'s (2003) experiments:

> "To receive a liquid reward, the monkey then had to hold the handle over the peripheral red LED for a further target-hold-time of 2 s."
> [...]
> "If the monkey made an error, either by moving the handle away from the central LED before the GO signal was given, by moving to the wrong location, or by not meeting the time constraints, the trial was not rewarded and was immediately repeated after a brief inter-trial interval. A block of trials was performed sequentially by the monkey using either the arm contralateral or the arm ipsilateral to the recording chamber, while the other arm was comfortably restrained in an arm rest at the animal's side using Velcro straps."

For mirror neuron studies they have to sit clamped into a chair with the top of their brain case open for single-neuron recording (which is never done on humans), as Cisek *et al* (2003) describe for their *in vivo* brain cell recording:

> "After training to a success rate of 70-90%, the monkeys [male *Macaca mulatta*] were surgically prepared for data collection. Using standard aseptic techniques and barbiturate anesthesia (35 mg/kg iv) (experiment 1) or gas inhalation anesthesia (experiment 2), a trephine hole was opened in the skull over the precentral gyrus. A Plexiglas recording chamber was fixed over the craniotomy

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[1] Cisek P., Crammond D.J. & Kalaska J.F. (2003). Neural activity in primary motor and dorsal premotor cortex in reaching tasks with the contralateral versus ipsilateral arm. *Journal of Neurophysiology* 89(2), Feb: 922-942.

> using vitallium screws and neurosurgical acrylic cement, along with a stainless steel head-fixation post."
> [...]
> "Daily recording sessions began after a postoperative recovery period of 10 days during which prophylactic antibiotics and analgesic drugs were administered."
> [...]
> "At the end of certain penetrations, microlesions (10 μA, 10-20 s) were made in the cortex at specific locations along the electrode track. At the end of each daily recording session, the cylinder was cleaned, flushed with sterile saline, and closed."

Finally, the subjects are killed as soon as the test is finished, so their brains can be sliced up and examined (Cisek *et al* 2003):

> "Data collection lasted 8-12 wk in each chamber. When the experiments were completed, the monkeys were deeply anesthetized and perfused with saline and then 10% Formalin solutions. The dura was removed, and dissecting pins were inserted in the brain at known coordinates to delimit the cortical region studied. Using the pins as cutting guides, the cortex was blocked and 30-μm frozen sections were cut, stained with cresyl violet, and examined by light microscopy to locate the microelectrode penetrations."

Protocols like these are standard among invasive research. As I strongly oppose such practices, all references deriving from invasive studies are excluded from this work. All of the data that are cited in this dissertation have been screened for their ethical justification given the above considerations. Alternative, non-invasive methods are favoured. For example, the vast literature on mirror neurons (e.g. Arbib 2005b), which is based largely on invasive methods, is bypassed in favour of *in vivo* imaging studies of healthy living humans, brain-damaged humans, developmental psychology, and the other human sciences.

Many independent charities and foundations fund non-invasive methods for studying the same processes. For more information about alternative, cruelty-free research, visit the British Union for the Abolition of Vivisection at http://www.buav.org/ and Animal Defenders International at http://www.ad-international.org/home/ .

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Chapter 1. Dichotomies and definitions

1.1. Introduction

This dissertation examines the evidence for handedness in Palaeolithic hominins[1] from the skilled production and manipulation of stone tools, and assesses whether the data are based on valid assumptions. In the field of prehistory, handedness is often neglected even when data are present. Yet an interest persists. The occasional remarks by 19th century archaeologists that certain stone tools fit better in the right hand, for instance, have given way to more rigorous experimental tests designed to recognise markers of hand-use from lithics. These are the focus of this dissertation, for they are often left untested. Specifically, do the assumptions underlying the methods for identifying handedness in the archaeological record stand up to scrutiny? The methodologies under scrutiny in this dissertation consist of published ones and a novel one created for this research. These are subjected to validation using three complementary approaches: experimentation, biomechanics, and ethnography.

The search for the origins of human uniqueness has too frequently disregarded laterality, the population-wide bias that makes a large proportion of us humans right-handed. Right-handedness is said to be a defining feature of our species but its origins are obscure. No other animal has such a lateralised manual motor system. In fact, our bias to the right side often makes left-handers become disadvantaged in traditional and modern societies (Winder *et al* 2002; Denny & O'Sullivan 2006). Even worse is the situation for ambidextrous people, who usually never even receive any mention in laterality research. Despite much debate about hand preference in non-human primates (apes and monkeys), little attention is paid to making any concrete reconstructions of past manual biases, such as modelling the hand-use patterns of the last common ancestor (LCA). Similarly, the multitudes of ongoing work on human handedness in adults and children usually ignore the data from archaeology and palaeoanthropology that reveal the hand preferences of our ancestors.

Despite this neglect, the archaeological evidence of handedness is relevant to much larger research questions. Language evolution, especially, is the subject of intense discussions in other fields (linguistics, neuroscience, anthropology, and computer science, to name a few). Recent language origins work tends to assume a connection between language and handedness. This idea is not new. Interest in language evolution has gained increasing vigour since the 1990s, although there is a much longer tradition of relating language origins to the origins of handedness. Several 19th and early 20th century publications must be recognised for their important theoretical contributions to the recognition and characterisation of a language-handedness link, which often triggered research interest.

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[1] In this dissertation, the following primate classification is used: Hominids = {Pan; Gorilla; Orangutan; Hominins = (extinct ancestors + *Homo*)}. See Appendix 1 for a schematic tree.

With the debates over language origins still current today, it is clear that archaeological research must play a crucial role in supplying hard data. The data for prehistoric hand preference have not previously been systematically reviewed and assessed in the context of their bearing on language origins. If archaeology can provide robust and reliable methods of identifying hand preference in past hominin populations, these can inform crucial issues in language emergence such as timing, pattern, phylogeny, and geography. The ultimate objective of this research is therefore to identify which methods and data are valid for determining handedness in extinct species, as potential diagnostic markers of language capability.

First (part 1.2) the uniqueness of human handedness is discussed. The comparative phylogeny approach requires that in order to discuss the evolution of a trait in the hominin lineage, it must be shown that this trait emerged after the divergence from the last common ancestor (LCA) such that it is unique to presently living humans. In other words, if handedness is claimed to have emerged in hominins, then it must not be found to exist in presently living hominids or other nonhuman primates. For this purpose the non-human primate hand preference data are reviewed. Then the concept of handedness is defined using Guiard's (1987) model of the Kinematic Chain combined with facts of motor learning. The distinction between techniques and methods, which is important in archaeology, is explained. In particular, the focus is on their relation to skilled bimanual tasks in which both upper limbs play complementary roles.

Secondly (part 1.3), the common substrate arguments are critically examined. The connection between handedness and language has often been argued to take the form of cerebral 'dominance' of one brain hemisphere over the other. However, in the case of handedness, the kinds of daily activities that prehistoric humans were engaged in probably did not rely on one upper limb exclusively. The use of the hands is more appropriately considered as a bimanually differentiated, coordinated effort of both sides of the body. Accordingly, it is necessary to find an analogous model of language that is relevant to extinct hominins. A bi-hemispheric model of language functions can provide a framework which can then be compared directly with the bilateral handedness model in order to construct an evolutionarily relevant characterisation of the common substrate. This forms the basis of the hypothesis presented in Chapter 5 for a new common substrate that unites the hemispheric division of labour in both language and handedness.

Finally (part 1.4), I shall address some key conceptual and definitional issues that must inform any analysis relevant to the emergence of language. I begin by presenting the semiotic definition of language. I then discuss how symbols have been treated by archaeologists, and how they are related to the concept of "modernity". The various different types of symbolism that are found in the literature actually fall into only two categories, of which arbitrary reference is the key one. A broad cognitive capacity which can be described as meta-cognition is a pre-requisite for referential symbolism. Beneath the broad umbrella of a conceptual referential symbolism sits 'language', set apart from questions of speech anatomy and speech origins. Language must be kept analytically distinct from speech, because these are two of the most commonly (but erroneously) conflated terms in the language evolution literature.

1.2. Handedness: a species-level bias

In the context of human evolution, the term 'handedness' refers to our species-wide tendency (in statistically significant proportions) to use the two hands in a consistent manner, not only individually but as a population. The commonly-accepted proportion of right-handers is between 70% and 90% in populations around the world (Annett 1985, 2002; Porac & Coren 1981). Handedness thus refers to a group-level bias in hand-use patterns. To contrast this with the lateral preferences of nonhuman apes, in which most individuals use their hands in a consistent way for a given action or set of actions but the group is roughly equally divided between right and left, the term 'hand preference' is used for the nonhuman pattern. Humans are unique in the animal kingdom in that they are strongly biased towards a specific pattern of hand-use favouring the right hand. Measures of right-handedness estimate an average prevalence of about 90 % in all living humans. In contrast, humans' closest living relatives, chimpanzees, do not show a population bias but rather some degrees of individual hand preference. This unique feature of modern humans implies that handedness emerged from selective pressures sometime after the divergence from the ape-human common ancestor.

Handedness has been used as a general term to refer to the consistent use of the right or left hand in various contexts. In fact, there are several types of handedness: at the individual level, at the task level, and at the population level. It is important to distinguish between these different manifestations of lateral bias, because current evidence maintains that only one of these, the population-level bias, is specific to humans.

Bias refers to a significantly more frequent usage of one hand over the other. In many non-human primate studies, there is considered to be a bias if one hand is used significantly more than half the time, namely if it occurs significantly more than the chance figure expected if there were no bias (50 %). Westergaard & Suomi (1996) distinguish hand preference (individual use of a preferred hand) and lateral bias (use of a preferred hand by an entire population). The latter can apply to a single behaviour or to all activities. A third type of bias, one which is task-specific, must be included. The terminology used by Marchant & McGrew (1996) incorporates this effect. They distinguish manual specialisation (one individual consistent for all tasks), task specialisation (all individuals consistent for a given task), and handedness (all individuals consistent for all tasks). Gaillard (1996) distinguishes three levels of laterality at the individual level: stability (of one hand within a task), consistency (of one hand across tasks), and homogeneity (of the laterality across the whole body). Combining all of the above distinctions, this paper uses a terminology that characterises lateral bias in hand-use on four levels:

1. an individual bias which depends on the task (task-specific hand preference)
2. an individual bias which is consistent across tasks (cross-task manual specialisation)
3. a population bias which depends on the task (population-level task specialisation)
4. a population bias which is consistent across tasks (population-level handedness)

The lack of a bias can be expressed at any of these levels. In these cases the distribution of right- and left-hand use is expected to be around 50 %. Individuals are termed ambipreferent for a given task if they use either hand randomly for that task. Stability refers to the commitment of one hand for a given task; hence, a task that is done by both hands equally is termed unstable.

1.2.1. Lateralisation and hand-use patterns in non-humans

Handedness appears to be specific to humans, in that only task-specific hand preference, manual specialisation, and task specialisation have been shown to exist in other species. In non-primates, any sort of lateral bias in behaviour is rare, although some other vertebrates show lateralised behaviour or anatomy (Chapelain 2004). Bumblebees have recently been shown to exhibit population biases in their direction of rotation around clusters of flowers. Individual bees consistently visit successive inflorescences in either a clockwise or anti-clockwise direction, and three out of four species studied showed a population-level preference for one direction or the other (Kells & Goulson 2001). This pattern of behaviour can be explained for individuals in terms of memory constraints and costs of motor activity, in that a direction chosen randomly at the start of the foraging bout will be maintained if it provides success, and it is most energetically efficient to continue rotating in the same direction on a flower cluster. But these arguments do not explain the observed species-wide biases and the fact that individual bees show consistent behaviour on different days. Kells & Goulson (2001) invoke the possibility of a "nonadaptive behavioural persistence", which has also been used to explain lateral biases seen in mice, capuchin monkeys, and humans. Nevertheless, the existence of a population-level bias in bumblebees would not pertain to human evolution, because it cannot be homologous to human handedness.

The evidence for handedness in apes and other primates suggests that they do not display a population-level bias, but that some individual chimpanzees show task-specific hand preference (Fletcher & Weghorst 2005). Some studies even fail to find any significant hand preference at the individual level across tasks (e.g. Mosquera *et al* 2007). Monkeys in general show no hand preferences except for complex tasks involving tool-use, but it is unclear what sort of bias exists among apes (McGrew & Marchant 1992). From a recent meta-analysis of studies, McGrew & Marchant (1997b) conclude that primates are individually lateralised but not at the population level, where preferences for the right or left hand are divided at 50 %.

Lateralisation in wild primates is common for certain tasks only. A study of wild langurs (Mittra *et al* 1997) found individual preferences for eating only, but the population was divided. There was a correlation between the hand used for picking and eating food, and the hand used to support oneself, because of the complementary nature of these two activities. Harrison & Byrne (2000) found that individual vervets were more strongly lateralised for more skilled tasks (termite feeding and detaching skin from fruit), but that there was little consistency across tasks (leaf shoot eating and sugarcane eating were performed with both hands by most individuals).

For the great apes the pattern is the same. Sugiyama *et al* (1993) found individual biases in wild chimpanzees for nut-cracking with stones, but not for picking or carrying food. They observed that many young individuals who were learning to crack nuts tried changing hands, but converged on the use of one hand when they became proficient. Because it takes young chimpanzees several years to master the hammer and anvil technique of nut-cracking, an innate hand preference might cause them to focus on learning the task with one hand (Sugiyama *et al* 1993). Boesch (1991) also reports consistent individual hand-use patterns for nut-cracking at Taï. Similarly, other studies of wild chimpanzees (McGrew & Marchant 1992; Lonsdorf 2005) showed that nearly all individuals are consistent in their hand preference for termite fishing, but the population is divided between left- and right-handers. Chimpanzees are strongly lateralised for bimanual processing of *Saba* fruit and lemons (Corp & Byrne 2004) and for cracking *Strychnos* fruits (McGrew *et al* 1999). However, observing chimpanzees across multiple tasks shows that individuals appear to be ambidextrous for most tasks and ambilateral (task-specialised) for a few tasks (McGrew & Marchant 2001). One study of orang-utans (Rogers & Kaplan 1996) found some individual hand preferences for holding and manipulating food, and a strong group-level bias for touching one's own face but no preference at all for touching other parts of the body; most of the individuals were ambidextrous.

As for a population-level bias for a given task (task specialisation) or an individual-level bias across tasks (manual specialisation), there is little evidence to support these. Byrne & Byrne (1991) report that individual mountain gorillas show a consistent hand preference across similar types of tasks: three edible leafy plants (nettle, galium, and thistle leaf) are manipulated with the opposite hand configuration to a plant with stems (celery). This may reflect a manual specialisation for leaf-processing compared to stem-processing. In captive baboons, there is a possible weak task specialisation for the hand slap, which is a communicative gesture (Meguerditchian & Vauclair 2006). Fifty-eight percent of the baboons studied showed a consistent right-hand use. However, as many as 26% of individuals were ambidextrous for this task. This indicates that individual preferences can be variable and that even if there is a population bias, it does not reach the 90% level of human populations. Papademetriou *et al* (2005) provide the most recent review of primate hand preferences. The only statistically-significant population-level bias they identified from 118 publications since 1987 suggested a left-hand preference for reaching in lemurs, rhesus monkeys, and Japanese macaques.

In summary, it is accepted that free-ranging primates as a rule can be individually lateralised but there is no population-level bias as in humans. The studies mentioned above appear to converge on one conclusion: the type of task seems to greatly influence the degree of lateralisation, both at the individual level and at the population level. McGrew & Marchant's (1997b) meta-analysis supports the dichotomy of Fagot & Vauclair (1991) in that simple, well-practised tasks are symmetrical. Asymmetry (i.e. lateralisation) is most strongly evident in complex, more highly skilled tasks (O'Malley & McGrew 2006). This is discussed below. First, the asymmetry can be better appreciated by analysing the constituent parts of bimanual gestures according to the special role of each hand.

1.2.2. Bimanual action

In order to characterise handedness in such a way that pertains to prehistoric activities, in particular to object manipulation, and more specifically to stone knapping and tool prehension, a model that accounts for both upper limbs is needed. The traditional definitions of handedness consider it as resulting from actions performed unimanually, and describe the right hand as 'dominant'. This is probably related to the traditional methods of measuring handedness in humans, by questionnaires or by noting the writing hand (Oldfield 1971; Bryden 1977). But this description is not suitable for the kinds of tasks that are relevant to archaeology or to nonhuman primates as reviewed above. For example, knapping stone involves complex coordinated movements in both hands, with some degree of precision, spatial positioning, and timing necessary for both the right and left upper limbs.

More specifically, the hand holding the stone core is responsible for orienting the striking platform using three dimensions. This serves to put the intended point of hammerstone contact into the knapper's visual field and into the path of the hammerstone trajectory. With respect to knapping gestures, Takeoka (1991:503-5) defines three axes of wrist movement which affect the position of the core, and thus the angle at which it receives the hammerstone blows.

The core hand is not restricted to spatial positioning, however. It often makes a brief upward movement in anticipation of the contact moment (Bril *et al* 2005), as noted by Stout (2003):

> "Along these lines, it is interesting to note that preliminary data from kinematic studies of Mode I knapping do indicate that knappers across a variety of skill levels often tend to raise the core to meet the descending percussive stroke (L. Harlacker, personal communication), bringing core and hammer together through coordinate bimanual movements."
> Stout (2003:140)

Also, stabilising the core is necessary to prevent it from falling when it is struck (Pelegrin 2005):

> "while the left hand orients the core within the three dimensions of space so as to control the direction and incidence of percussion delivered by the right arm, the left arm produces an antagonist muscular contraction exactly synchronic with impact".
> (Pelegrin 2005:25)

In contrast, the hammer-arm performs only ballistic movements during direct percussion, so no realtime feedback is available from the somatosensory, visual, or auditory modalities. This means the knapping gestures are acquired by both upper limbs' motor learning of the spatial and temporal accuracy required to meet the target point on the core. In a knapping event, the moment of contact between the hammer and core results from a bimanually differentiated coordination of the core hand / arm with the hammer hand / arm.

This kind of coordinated bimanual action, with well-specified roles for each upper limb, can be said to characterise prehistoric object manipulation. In fact, it is likely that very few of the daily activities of prehistoric people were accomplished with only one hand or arm, and certainly most of the supposed activities taking place would have required two-handed coordination (such as working wood and hide, threshing, crafting bone and shell ornaments, weaving baskets, painting, spinning, bow shooting, digging, and grinding grain, cf. Eshed *et al* 2004). Therefore a useful model will be one that accounts for the actions of both hands, rather than focussing only on a single 'dominant' hand.

The definition used here is adapted from Guiard's (1987) Kinematic Chain model of handedness as it applies to skilled lithic manufacture and use. In this model, one hand and/or arm performs movements which Guiard qualifies as high-frequency, being more spatially and temporally precise (i.e. being faster and having a narrower target), whereas the other hand is low-frequency, acting as a stabiliser or support, maintaining the spatial or temporal structure. To define the group-level handedness that is specific to humans, Guiard suggested that most humans tend to learn the low-frequency role with the left hand and the high-frequency component with the right hand.

The model is endorsed by Hinckley's (1996, Hinckley *et al* 1997) experiments, in that subjects maintained the stabilising gestures of the left hand and the manipulative gestures of the right hand even when the objects were held in the opposite hands. For example, in handwriting, the left hand stabilises the paper, actively moving it around, while the right hand manipulates the pen (Athènes *et al* 2004). One common Palaeolithic task which might appear to be unimanual (scraping hides) also requires this coordination of both hands: one hand to hold and orient the hide, the other hand to manipulate the scraping tool. The degree of bimanual coordination for hide-scraping is likely analogous to Athènes's model for handwriting with pen and paper.

In stone knapping, most right-handed people wield the hammerstone with the right hand and support the core with the left hand. Left-handers tend to use the opposite configuration (although occasional exceptions do exist, L. Hurcombe, pers. comm. 2005). The arguments for the nature and mechanism of the Common Substrate (see below) are based on the assumption that this tendency for humans to fixate on a consistent pattern of upper limb use reflects a laterality in the controller of the upper limbs (the brain). This can be related to the acquisition process of tasks which require some learning to master.

1.2.3. Motor skill

Another aspect of the present definition of handedness is motor skill, which results from motor learning. Learning is defined as a permanent neuronal reorganisation of motor cortex, which is due to Long-Term Potentiation (LTP) (Hebb 1949; Pinel 1997:393-396) and which facilitates the execution of the motor task (Magill 1993). Therefore skill depends on changes at the molecular level (e.g. Aumann 2002; Garry *et al* 2004; Pleger *et al* 2001; Sanes & Donoghue 2000; Thomas *et al* 2000; Weissman & Compton 2003; Wu *et al* 2004).

In so far as skill can be defined by changes in the brain, it follows that learning a manual activity involves such changes (Hammond 2002). In the context of prehistory, if we can assume that most subsistence and cultural activities were learned (as they are in chimpanzees and other animals), then it follows that archaeological artefacts are the result of skilled manufacture and/or use. An action such as knapping, therefore, which can be seen as highly dependent on motor learning for its elementary gestures, necessarily involves reorganising the neuronal connections in the motor and somatosensory areas. By inference, the differentiated roles of the two upper limbs in knapping cause different changes in each corresponding hemisphere. In application of these facts, Provins (1997b) invokes the learning of skilled motor actions as a possible mechanism for tool use and handedness. Because gestures are only learned by practising with the same organ (the transfer of motor skills from one learned hand to the other, unpractised hand is very weak), people tend to rehearse a skill with a consistent (bi)manual configuration.

Related to this is the fact that keeping a consistent hand-use pattern directly improves the efficiency and performance of the task (Todor & Doane 1977). This can be seen in the way chimpanzees learn to crack nuts at Taï forest: young learners try with both hands in turn, and eventually converge on the consistent use of one hand (Boesch 1993; Sugiyama *et al* 1993; Boesch *et al* 1994).

However, these facts only explain why an <u>individual</u> should become lateralised; the question of population-level handedness does not have such a simple answer. In fact, it is important to note that the division of hand labour occurs primarily in skilled manipulations (Provins 1997b; Hinckley *et al* 1997). This is supported not only by the standard measures of hand preference, in which lateralisation increases with task skillfulness (Healey *et al* 1986; Steenhuis & Bryden 1989) but also by human ethnography (Marchant *et al* 1995). Studying ethnographic video footage of the daily lives of people in three traditional cultures: the G/wi Bushmen from the Central Kalahari in Botswana, the Himba from northern Namibia, and the Yanomamö from the

Orinoco forest in south Venezuela, Marchant *et al* (1995) found strong right-handedness as expected (individually and at the group level) for using tools, especially where a precision grip was involved, but ambipreference and a random distribution of laterality for other manual actions such as clapping, kicking, poking, and waving at insects. In these cases, the non-tool-use hand actions were unlateralised both at the individual and the population level.

This finding directly challenges the accepted notion that humans are strongly lateralised for all activities; rather, there appear to be degrees of hand preference according to the type of task being tested (Healey *et al* 1986; Bishop 1989; Annett 1972; Fagard & Corroyer 2003). The ontogeny data find the earliest hints of coordination skills for bimanual role differentiation around 7 months of age (Michel 1998). Studies of wild apes also show that consistent patterns of hand-use at the individual level are strongest in skilled, bimanually coordinated manipulations (Byrne & Byrne 1991; Harrison & Byrne 2000; Byrne *et al* 2001; McGrew & Marchant 1992, 1997a, 1997b; Marchant & McGrew 1996). Regarding this last point, Corballis (1998:1148) proposes that individual hand preference simply cannot be seen in animals that do not carry out skilled manipulations. In other words, practising increasingly skilled actions may differentiate humans from other apes.

This skill can be defined in a more objective way, according to the various explicit or implicit definitions that can be found in the literature. Olausson (in press:1) defines skill as an "increased performance due to a learning process". Roux & Bril (2005:6) define mastery of a technical skill as depending on "the capacity of an organism to set up the constraints of the system according to the task demand, and to mobilize adaptively the degrees of freedom of the system". Callahan (1979) refers to a scale of 6 levels of achievement in stone knapping.

1.2.4. Difficulty

A starting point for characterising 'skilled actions' is task difficulty, also called complexity. The concept of 'difficulty' is hotly debated in archaeology, as is the word 'complexity' (e.g. MacNeilage *et al* 1987; Fagot & Vauclair 1991).

In an attempt to move towards a formal definition of the 'difficulty' concept, it is useful to begin with the basic premise that difficulty should increase with the time needed to learn a task. Provins (1997a) thoroughly discusses the particularities of motor learning, such that time and proficiency do not have a linear relationship for manual skill. However, to keep things simple, the general idea is that a more 'difficult' task takes longer to learn than an 'easier', 'simpler', or less 'complex' task (note that these terms are not yet defined). Here the term 'difficult' will be used in the context of lithic technology for actions and objects that require a learning period, where the time needed to learn the task is roughly proportional to the task complexity / difficulty. In this system, either one of the factors (learning time or task difficulty) can be used as a proxy for the other. Based on ethnographic craft-learning data, Hosfield (2004; in press) identifies 'craft difficulty' for living humans by the learning time and the number of production stages required to master a craft. A similar proposal is made by Sugiyama *et al* (1993), that the long-term learning required for bimanual nut-cracking at Bossou encourages lateralisation.

However, complexity is not exactly equal to learnability. Sterelny (2006) argues that skills vary in the amount of precision they require for the task to be accomplished. In other words, some gestures can be approximated, whereas other gestures require more precision. This scale of error margins for task function can be termed 'tolerance' (McGrew, pers. comm. 2006). Task tolerance refers to the margin of error that is acceptable in the execution of a gesture, where any excursion beyond this margin results in destruction of the object (if not destruction, then reduced optimality of results).

Tolerance can operate on two levels, spatial and temporal. For example, a gesture with wide spatial tolerance is the smashing of hazelnuts on an anvil using a large branch as a hammer: any roughly downward percussion gesture will result in contact between hammer and nut. An analogous gesture with narrow spatial tolerance is the knapping of flint blades with a hammerstone: the hammerstone must contact the striking platform within two millimetres of the core's edge in order to detach a blade. Michel (1998) defines manual skill as involving fine timing and sequential ordering of muscle contraction sequences; these could be analogous to the temporal tolerance of the motor and sequential components of skilled action.

Steenhuis & Bryden (1989) also argue for a distinction based on sequencing complexity, which requires executing a sequence of motor behaviours. Similarly, Boesch (1991:557) defines complex tasks as involving multiple movements. This would correspond to Byrne & Byrne's (1991) 'program level', in which familiar actions are put into novel sequences. Rugg (2004, 2007) characterises complexity on two levels, by the number of elements to be combined (fabricatory width) and the number of stages of production (fabricatory depth). Fagot & Vauclair (1991) propose dividing unimanual tasks into low-level (familiar) and high-level (complex) categories. They propose that routinised tasks are simple whereas novel manipulations require more visuo-spatial coordination, and they predict that lateral bias should not be expressed as strongly in routinised behaviour as in complex tasks. This is unsupported supported by Mittra *et al* (1997), in that the highly routinised activity of eating was found to be most lateralised in Hanuman langurs. McGrew at al (1999:85) suggest that skilled actions are related to precision. Related to this, Harrison & Byrne (2000:20) define organisational complexity as the sequential use of multiple and different actions requiring a degree of precision and two-handed coordination. Leconte & Fagard (2006) define skill as requiring an increased degree of task accuracy, also finding that it reinforces the use of the preferred hand.

These notions can be combined with the skill learning requirements in terms of technology. Considering that 'difficulty' can be characterised by a long learning period, then, one element in the uniqueness of stone knapping skill is the combination of extremely long learning times for the flaking gesture (<u>technique</u>) and for the sequence of tool production (<u>method</u>).

1.2.5. Technology

The distinction between method and technique must be stressed here, as it is frequently ignored in English-language archaeological publications. Technology is defined by Inizan *et al* (1995; 1999:13) as "a conceptual approach to prehistoric material culture, based on the reasoned study of techniques, including those of human physical actions". Here an inclusive definition of technology is used which refers to any kind of object manipulation that leaves traces on other objects or individuals. Technology is then divided into its two parts, method and technique:

METHOD: An orderly set of rational procedures devised for the purpose of achieving an end. The method followed to create a prehistoric tool is thus an orderly sequence of actions carried out according to one or more techniques, and guided by a rational plan.

TECHNIQUE: The physical modality according to which raw material is transformed. The practical manner of accomplishing a task, i.e. one of the procedures of the knapping craft (e.g. direct percussion, anvil percussion, use of hard or soft hammer or a punch, pressure-flaking, aspects of body position, etc.)

As proposed here, these two levels of analysis can be seen to correspond to the two levels of difficulty that characterise bimanual skill and tools themselves. A first attempt at defining difficulty for knapping stone can follow Ploux (1989, 1991). She divided know-how into three psycho-motor aspects: the conceptual scheme or planning, the realisation of the *chaîne opératoire* through operative ideational know-how, and the execution of gestures through physical motor know-how. The latter two elements (Apel 2001; Karlin & Julien 1994:159; Roux 1990; Roux *et al* 1995; Steele 1999) can be taken up to suggest that difficulty or complexity in lithic production arises from a need for (1) techniques (precise and accurate gestures) and (2) methods (long reduction sequences with many embedded levels of sub-goals (Pelegrin 2001-02; 2005)). In non-adult non-human technology, there seem to be limitations on the number of levels of sub-goal hierarchies that can be processed (Matsuzawa 1991,1996; Nettle 2003).

In fact, a similar distinction is made, with different terminology, by authors reviewed in Gibson (1991). These refer to 'techniques' as procedural knowledge and 'technology' as declarative knowledge. Techniques encompass sensorimotor skills and action sequences (which correspond to the techniques and methods mentioned here) and technology comprises awareness of social, environmental, and scientific principles. In a similar vein, Weaver *et al* (2001) consider the roles of both conceptual and motor aspects within all four types of Pleistocene 'intelligence'.

It can be proposed here that lithic production is characterised by a great degree of difficulty on these two levels: in the elementary gesture and in the sequence of fabrication. Furthermore, the uniquely human aspect of technology can be seen as arising from this combination, or duality of difficulty. The greater manipulative dexterity of great apes compared to other non-human primates partly accounts for their increased skills in feeding-tool manufacture and use (van Schaik *et al* 1999). Extending this, it can be suggested that in the manipulations of non-human apes, such an extreme degree of difficulty is found on only one or other of the levels, whereas the manipulations required for successful stone knapping necessarily involve extreme proficiency on both levels.

The minimum requirements of stone knapping, even for the oldest known industries over 2 million years old, include high precision with a narrow spatial and temporal tolerance (the knapping gesture) combined with elaborate sequences of sub-goals and error correction (the reduction sequences (Roche 2005; Delagnes & Roche 2005)). Biomechanical studies of fencing movements by people of different proficiency levels (Yiou & Do 2001) demonstrated that while experts and novices showed similar performances at the elementary gesture level, they differed widely in the combination of gestures: the experts benefited from an inhibition in the refractory period between successive movements, allowing them to execute smoother sequences. Therefore it appears that mastery of elementary gestures is not the only important factor in learning a skill; it is necessary to be able to combine these gestures into sequences as well (Roux 1990).

Handedness has been defined here as a lateralised human behaviour which is based on lateralised hand-use patterns. The next step is to explore what arguments have traditionally been put forward about its relationship to different dimensions of language. Next I present and critically review the various proposals that can be found in the literature. This includes publications from researchers in archaeology, human origins, linguistics, and neuroscience.

1.3. What is the Common Substrate?

This thesis addresses the experimental and analytical issues in the diagnosis of handedness from Lower and Middle Palaeolithic artefacts. The relevance of this must be understood in relation to a wider context, in which claims are made for common underlying mechanisms controlling behaviour in both the manipulative and the linguistic domains. This section explores published definitions of such a common substrate (CS) and how a link has traditionally been made between language and handedness. The CS is not the subject of primary research in this thesis: archaeologists do not have access to the wiring of the human brain, which is what is required to test hypotheses about such links. The CS arguments do, however, provide an intellectual framework which gives the archaeological questions asked in this thesis their relevance.

To illustrate debate about the CS, a few representative examples of the oft-written tacit assumption that this link is simple are given. Then some of the more explicit propositions are explored with respect to the three axes onto which they can be placed. These three dimensions of arguments about the common substrate are: the nature of the two linked entities (function vs. structure), the expression of their shared underlying features (language vs. speech), and the mechanism of the common substrate itself (hardware vs. software). The best candidates for more highly specified arguments are discussed at the end of this section.

In the literature, we can distinguish authors who make an implicit link between behavioural laterality (or handedness) and language from those who explicitly specify this link. Among the implicit and explicit connections, the underlying hypothesis is the same. This hypothesis can be schematised in a triangle of inference (Figure 1.2).

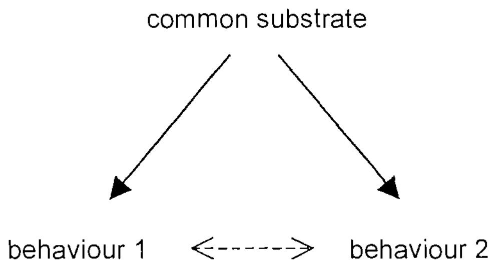

Figure 1.2. Schema for the triangle of inference that reveals how handedness and language are often linked in the literature.

According to the literature, which is reviewed below, behaviours 1 and 2 are handedness and language. The Common Substrate (CS) is unanimously accepted to be located in the brain (this includes the mind, for those who consider them to be two separate entities). The solid lines are drawn with arrows to reflect the supposed cause-effect relationships between the controller of each behaviour (the brain) and the behaviours themselves. Speculations abound as to what exactly the common substrate should be. The dotted arrow connection represents the association that is made between handedness and language. This connection is often fuzzy, as explained below. In fact, the dotted arrow can be considered equivalent to the common substrate: it is justified in the literature by the common substrate. The following review explores how the common substrate often lacks specification in the literature and concludes with some examples of well-specified common substrates.

Rogers (1993:5) rightly identifies the triangle of inference: "Anthropologists have drawn an association between the evolution of tool use and language ability. Neurobiologists have added the third side to the triangle, by including brain asymmetry as the basis for both behaviours." In other words, the reasoning can be declared in the statement that on the one hand, we observe that hand-use in humans is strongly lateralised, especially for complex manipulations. On the other hand, we know that language-related functions are lateralised in the human brain. Because there is a common factor of laterality in these two supposedly unique features, in addition to a common basis in the brain, a link is made between handedness and language.

This leads to the question: What exactly is laterality? Is it defined by function, or structure? In the literature, the characterisation of this connection varies in the degree of specification, implicit to explicit, and can be classified according to three axes. These are discussed below and consist of Nature, Expression, and Mechanism.

1.3.1. Examples of poorly-defined, implicit linking

The implicit level of specification for the Common Substrate usually takes the form of a simple correlation based on locations or functions. Two elements which have roots in the same place are said to be related to one another, but there is no justification and the argument is often embodied in one brief sentence. Classic examples are found in Levy & Nagylaki (1972:119), "Since the above data establish that a correlation exists between hemispheric dominance and handedness, the most reasonable inference is that both are under genetic control and that the genetic mechanisms controlling the two are in some way related", in Calvin (1982:120-21), "Certainly the tendency of both right-handedness and language to be represented in the left hemisphere is compatible with a common origin in a lateralized motor sequencer", and in Frost (1980:448), "The co-occurrence of these asymmetries in the hominids is perhaps too much to be a coincidence".

A slightly less implicit form of argument is found in bolder suggestions of a somewhat more specific ability which is common to both functions. For example, the sequential processing hypothesis proposes a common temporal aspect to language and handedness, while the adjacent motor areas hypothesis suggests that motor areas for speech and hands are connected due to their proximity in the brain. One can also postulate a common substrate of general cognitive abilities, symbolism, tools, or other unrelated activities. A link is made through any one of various abilities or activities, or combinations of them. This is the crucial point in exaptation hypotheses of language evolution.

The most explicit level of common substrate specification involves a thorough exploration of the nature of the common substrate; some of these are explored at the end of this chapter. First a few examples are provided to illustrate the commonly-encountered form of basic implicit correlation, to contrast with ensuing examples of more explicit arguments which can be seen as better-refined extensions of the same underlying hypothesis.

The implicit-link papers comprise most articles whose main focus is not the common substrate itself, but one of either Behaviour 1 or Behaviour 2, such as evidence for human or chimpanzee handedness, language lateralisation, or the emergence of symbolic activity. The connection is often made in the introductory sentences or the concluding paragraph as a brief justification for the study.

Despite the prevalence of such old-fashioned ideas, a few authors set a good example by simply making a careful statement to show their interest without committing to a particular viewpoint, such as Vauclair & Fagot (1993:203): "it is probably too early to draw a clear-cut pattern of relations between hand asymmetry and hemispheric specialization."

One historical aspect of the simple correlation is described by Harris (1993):

> "Cunningham (1902) was reluctant to conclude that the greater depression on the left Sylvian fissure in the human brain was associated with right-handedness or even with left-hemisphere localization of speech because the same condition was found in the ape, and he could not persuade himself that the ape possesses "any superior power in either arm."
> Harris (1993:33)

It seems that Cunningham was linking speech lateralisation and handedness via the (possibly) shared anatomical asymmetry of the left Sylvian fissure. Although the connection proposed by Cunningham was still quite implicit, it represents an early attempt to explicitly specify the nature of the common substrate.

Exactly one hundred years later, the specification of the common substrate is not any clearer: Hluštík *et al* (2002) connect left hemisphere language to left lateral premotor activation during a sequential finger-opposition task in that they both occur in right-handers, although they acknowledge the speculative nature of this link. Therefore this can be seen as a simple implicit correlation, despite their explicit suggestion of a common temporal processor. In summary, the Common Substrate has widely been alluded to since the 1860s, although it remains an implicit correlation for most authors. The next section considers some of the current proposals in more detail. These are structured according to three dimensions, or axes, that are introduced next.

1.3.1.1. Common Substrate: three axes of suggestions

The common substrate arguments described in the next three sections are presented with respect to three dimensions of the common substrate and its two linked behaviours (nature, expression, mechanism). These examples consist mostly of articles focussing on the common substrate, but they also include some whose main focus is elsewhere although they explicitly specify the common substrate. Whereas the first axis refers mainly to the nature of the two behaviours, the other two axes concern the common substrate itself.

1.3.1.1.1. Nature of the behaviours: function vs. structure

Structure and function are often confused in the literature. This is done by linking the *function* of Behaviour 1 (handedness) with the *structure* of Behaviour 2 (language). In this case the link becomes even more erroneous, since such a connection cannot be justified if Behaviours 1 and 2 are different in nature.

Functional laterality is expressed in many ways in humans: as language activation in certain parts of the brain, as the consistent use of one hand for a particular role in unimanual or bimanual actions, and as asymmetrical behaviour in general. Functional laterality is generally much more plastic than structural asymmetry, since each hemisphere can recover some or all (in adults or children, respectively) of the other's functions (Bach-Y-Rita 2003), and it is also much more influenced by the environment, both in development and in adult life.

On the contrary, structural laterality can be attributed in most part to genetics, and it is much less flexible. It is manifested in the asymmetrical petalia pattern of the great ape brain (Semendeferi & Damasio 2000), in differential growth of the two sides of the postcranial skeleton, and it can also be seen in basic patterns of neuronal connectivity, which seem to be specified genetically (although of course their full development depends on the right kind of environmental input, Provins 1997b). Of course, structure and function are not mutually exclusive, but rather they interact heavily during development and growth and even throughout an individual's lifetime. One example would be the differential growth of the arm bones, which is discussed in section 2.1.1 of Chapter 2, in which a slight right-hand bias existing at birth causes the person to use that hand more, in turn causing greater muscle development on that upper limb, in turn making it more economical to continue using the right hand. Another example is from neurology, where a genetic predisposition towards left-hemisphere language can be overruled and language functions be completely and perfectly shifted to the right hemisphere in case of left-brain damage in early childhood (e.g. Klawans 2000).

Many authors fail to discriminate between function and structure. In his primate laterality paper, Preilowski (1993:126) combines function and structure into a general model of asymmetry: "Laterality... describes a relatively permanent morphological or functional lateral asymmetry of the nervous system and behavioral asymmetries directly related to them." His definition is vague in that we do not know *which* functions are directly related to one another. Preilowski implies that asymmetry can be seen as a general aspect of human behaviour and physiology with no need to distinguish the structure from the function.

Although one can find many examples in the literature of merging structure and function, there are very few instances of the two being clearly differentiated. One is found in Greenfield's (1991) hypothesis for the purely functional common substrate of tool use and language, although she attempts to ground this common substrate in the structures of Broca's area. Aboitiz & García (1997) also keep a handle on function and structure, in their suggestion for purely neuroanatomical bases of cross-modal functions. These few articles should serve as examples to authors who are tempted to neglect the fact that structure and function are not equivalent regarding the nature of the common substrate and the two linked behaviours.

Because the focus in this dissertation is on the functional laterality of handedness, the hypothesis presented in section 5.4.4 of Chapter 5 is restricted to function. Without neglecting the role of structure in creating the said functions, the proposal focusses on evidence that can be obtained from behaviour. In other words, structure must be sought with imaging techniques or anatomical dismemberment, whereas function can be studied by observing behaviour. The archaeological record is considered to reveal behaviour (rather than structure, as gleaned from the skeletal fossil record); therefore it is most appropriate for the other elements in the triangle to stay focussed on behaviour (behaviour / function of language and handedness).

1.3.1.1.2. Expression of the CS: language vs. speech

It is found that common substrate arguments in the literature tend to support their hypothesis with various kinds of expression of the common substrate. Often the mingling of language and speech, as described in section 1.4.5 of this chapter, adds even more confusion to the argument since handedness becomes equated with either speech motor *output* or linguistic *input*. It must be stressed here that the connection between language comprehension and language production is a major theoretical and empirical problem in linguistics (Burling 2005 is a good example of their reconciliation); therefore one must clarify which manifestation of laterality and language is being used to argue for the common substrate. Language defined as speech is too simplistic in that it reduces language to simple motor output, and language defined as verbal comprehension is similarly limited to the processing of auditory input. Arguments for a common substrate usually focus on either one of these manifestations of Behaviour 1; rarely do they incorporate both language and speech.

Descriptions of the way in which the common substrate is expressed in either of the two behaviours it underlies typically fall into one of two categories, based on language and speech. This reflects the more general problem, described in the previous section, of a failure to properly distinguish speech from language. Falk's (1987) Field Effect theory, for example, invoked both verbal comprehension and production (language) and vocal communication (speech), although her (Falk 1980) hypothesis focussed only on vocal and manual output.

1.3.1.1.2.1. Expression: language

Although not specifically addressing handedness, Greenfield (1991) relates tool use to language, defining language for this purpose as grammar. In her view, tool use is expressed as a grammar-style embedding of objects. This is similar to Takeoka's (1991) hypothesis, in which there is a common ability for syntax underlying both language and the knapping methods of Levallois, including the Japanese variant Yûbetsu (*ibid.*:513). The sequencing notion also appears in Aboitiz & García's (1997) suggestion of a common language and tool-making sequencer located in parietal association cortex around Wernicke's area. The clear lack of suggestions in this particular category indicates that further work is badly needed.

1.3.1.1.2.2. Expression: speech

Zangwill (1960), for example, markedly focusses his research on speech, as evidenced by aphasia data. The motor organisation of the elementary gestural units underlying both speech and knapping are addressed by Steele *et al* (1995) to suggest a common "phonetics" of these activities. Bradshaw (2001) proposes more general motor programs for the common substrate. Calvin's (1982) throwing hypothesis comparably focusses on sequencing, but only for speech, in the oro-facial motor area. Kimura (1982; Lomas & Kimura 1976) appropriately restricts her attention to speech motor control; she defends the findings that apraxic impairment affects both oral and manual motor control, such as in making mouth movements and finger tapping. The plethora of studies in the speech subsection justifies excluding it from the present study; as was argued above, the main topic of interest is not speech on its own but language more generally.

1.3.1.1.3. Mechanism of the CS: hardware vs. software

The cerebral basis for the common substrate is seen either as a neuron-level connection or as an effect of general cognition. This mechanism is the key feature of the common substrate to disentangle from the literature, since its characterisation relies on a thorough description of the cerebral substrate for both Behaviours 1 and 2. After reviewing some aspects of Behaviours 1 and 2 in this section, further proposals are examined.

In terms of characterising the common substrate for language and handedness, published hypotheses concentrate on mechanisms either at a neural processing level or at a higher cognitive level. These are termed hardware and software. Hardware can be seen as the functioning of individual neurons and their patterns of interconnectedness, while software represents the cognition that results from these networks.

1.3.1.1.3.1. Mechanism: hardware

Early proposals for the common substrate were more creative than current ones. Blau (1977:999), in his discussion on schizophrenia, suggests the corpus callosum is responsible for "discreet yet interconnected functioning of the two hemispheres" in language, speech, and functional asymmetry. An even earlier proposal, made by Smith (1925), was that ocular dominance could be the common substrate for hand preference and cerebral asymmetry.

Steele *et al* (1995:249) typify the neural basis of the common substrate with their suggestion of the frontal lobe's role in motor learning, since it is this area which was, at the time, suggested to have expanded the most in human evolution. The basis for Falk's Field Effect (1980:75), for example, is a common substrate of motor pathways underlying both gestures and speech.

As an alternative common substrate to motor pathways, Calvin (1982) postulates a sequencer responsible for speech and handedness. He credits Kimura (Lomas & Kimura 1976) with the suggestion that rapid motor sequencing underlies language (i.e. speech) and hand gestures.

The proposal by Lomas & Kimura (1976; Kimura 1982) states specifically that the left hemisphere controls multiple oral and manual movements, especially in the prefrontal and parietal areas. The study of wrestlers by Nikolaenko *et al* (2001) suggested a common substrate consisting of anticipation of both motor habits and perception of verbal information.

Because most of the suggested common substrate mechanisms in the hardware subsection are based on structural studies, the function aspect is likely to be neglected. In addition, the wide range of these hypotheses lessens the necessity of developing a new proposal.

1.3.1.1.3.2. Mechanism: software

Bradshaw (2001) also embraces the idea of a temporal sequencer, although his argument can be seen as more to the software side:

> "It is as yet unresolved whether the evolution and lateralization of language and praxic functions were and are interdependent, and how unique we are in these respects."
>
> "Language and praxis would then be seen as two semi-independent, phylogenetically co-evolving (perhaps in a mutually catalytic fashion) faculties, both with major (but not exclusive) left-hemisphere mediation from the latter's involvement in sequencing and fine temporal order."
> Bradshaw (2001:184-5)

He suggests a pre-existing right-hemisphere spatial processing advantage, combined with a left-hemisphere temporal and auditory advantage, just as Aboitiz & García (1997) describe the right hemisphere as spatial and the left as sequential. The temporal sequencing role of the common substrate is also proposed by Hluštík *et al* (2002):

> "[...] perhaps lateralization for these two are *coincidental* [my italics]. This would be consistent with the notion that the left hemisphere is specialized for processing information incorporating complex temporal features such as speech."
> Hluštík *et al* (2002:60)

The hypothesis developed here applies to software more than hardware, in that the behavioural aspect is emphasised. Furthermore, the clear gap in the literature with software-based proposals calls for the development of new suggestions.

1.3.1.1.4. Summary of Common Substrate arguments on 3 axes

In terms of the degree of specification of the common substrate, publications range from routinely implicit to eloquently explicit. Among the less implicit ones, three axes were determined. The nature of the two linked behaviours is most often a combination of function and structure (Table 1.1).

function	function+structure	structure
Greenfield (1991)	Aboitiz & García (1997)	Steele *et al* (1995)

Table 1.1. Arguments for the CS nature: function vs. structure

The expression of the two linked behaviours, as seen in the language / speech distinction, is variable (Table 1.2).

speech	language
Bradshaw (2001)	Aboitiz & García (1997)
Calvin (1982)	Greenfield (1991)
Kimura (182)	Takeoka (1991)
Smith (1925)	
Steele *et al* (1995)	
Zangwill (1960)	

Table 1.2. Arguments for the CS expression: speech vs. language

With respect to the mechanism of the common substrate, most arguments fall into the hardware category (Table 1.3).

hardware	software
Blau (1977)	Aboitiz & García (1997)
Calvin (1982)	Bradshaw (2001)
Falk (1987)	Hluštik *et al* (2002)
Kimura (1982)	
Smith (1925)	
Steele *et al* (1995)	

Table 1.3. Arguments for the CS mechanism: hardware vs. software

While the common substrate and its two linked behaviours can be highly specified in many of these arguments, it is clear that authors are for the most part limited to their own discipline. The fact that few proposals focus on function or language points to the need for research to move in those directions. The mechanism of the common substrate, being most frequently biased to hardware, also could benefit from more detailed investigation into the cognitive aspects. Next are reviewed some proposals which approach these ideals.

1.3.2. Examples of explicit Common Substrates

The types of links mentioned above have also been extended beyond simple correlations or vague suggestions. Such highly-specified common substrate arguments represent more thorough explorations of explicit forms of the same hypotheses. They come from diverse fields and include recent information from genetics, apraxia, neuropsychology, neuroscience, and primatology. In addition, proposals about skill and segmentation are included because they offer additional potential for future directions.

1.3.2.1. Neuroscience

A bi-hemispheric viewpoint, by neuroscientists Aboitiz & García (1997), on the relationship of handedness to language is encapsulated in their concluding speculations:

> "it may be a consequence of previously established asymmetries for sequential left hemisphere vs. spatial right hemisphere skills. Perhaps the manufacturing of tools imposed a left-hemisphere tendency for sequential movements, to which the language system turned out to fit. Whatever the reason for language lateralization, we propose that it mainly consists of the specialization of two different types of temporoparietal–prefrontal projections: the left hemisphere emphasizes temporal and inferoparietal connections with the frontal lobe (sequential/linguistic processing), while the right emphasizes projections from posterior parietal areas involved in spatial vision."
> Aboitiz & García (1997:394)

While these authors support a tool-making hypothesis of language evolution, which seems to follow Falk's idea about speech and tools (1980, 1987), they propose that the transfer mechanism lies in a pre-existing sequential tendency which was exapted by the language system because of the sequential nature of syntax (*ibid.*:392). Their hypothesis is supported by the existence of increased connectivity in association cortex in humans compared to other apes. However, their idea is hindered by the assumption that language processing occurs only in the left hemisphere, in a sequential mode. Similarly, they restrict tool manufacture to the same side. Nonetheless, their suggestion remains compatible with the bi-hemispheric language model. All they need is to expand their common substrate to include the right hemisphere's involvement in both language and tool-making. In other words, the analytic left hemisphere can be responsible for the sequential processing aspect of both behaviours.

The role of the right hemisphere in the common substrate is advanced by LeDoux *et al* (1977:746) based on split-brain patients, in which the right hemisphere's "manipulo-spatial function is neither motor nor perceptual, *per se*, but rather is more appropriately viewed as the mechanism by which a spatial context is mapped onto the perceptual and motor activities of the hands". However, they still hold a left-hemisphere view of language, leading them to suggest that the left hemisphere lost its visuo-spatial abilities because language exapted their neural structures (*ibid.*). In addition, this view is based on hardware rather than software.

The different complementary roles of the hemispheres were probably most deeply explored by Hécaen during his lifetime of work on aphasias and apraxias. His book (Hécaen 1963; Hécaen & de Ajuriaguerra 1964) details the totality of symptoms based on lesions to various brain regions. Although he does not wish to decide whether handedness or language function was the cause of the other, he draws general conclusions about each hemisphere's role in the behaviour of language, gesture, and perception. In summary, for typical right-handers, lesions to the right hemisphere cause disorders of manipulating the corporeal and extra-corporeal space, and recognition of human features[2]. Lesions in the left hemisphere lead to disturbances in the formation of concepts and verbal formulation.

Hécaen's characterisations of the hemispheres fit nicely with the hypothesis proposed here. If the right hemisphere is a spatial processor, then a procedural, holistic mode is most relevant, and a more analytic or declarative mode relates to the left hemisphere's concept formation.

1.3.2.2. Conceptual links

Software suggestions are rarely found. Alter (1989), based on a study of drawing familiar objects, argues for a common substrate based on perceptuo-motor integration. A similar proposal is made by Vandervert (1999:224), who suggests that the left parietal lobe mediates a "joint visual-somatosensory action space reference frame" which encompasses actual movements in the same way as simply imagined ones, which may be communicated (via language). Like the above two, these two references are constrained by a view of left-hemisphere dominance. While they may contribute to the software role of the left hemisphere, they are silent about the right hemisphere.

Other proposals study laterality without specifying roles for each side. Arguing for a conceptual link based on the familiarity of object manipulation, Feyereisen (2005) proposes that conversational gestures that accompany speech are preferentially right-handed because such gestures involve mental activation of motor images, and people are used to manipulating objects with their right hand. Because only representational / iconic gestures exhibit this right-hand preference, Feyereisen argues that they are related to the linguistic task. This leads to an interesting prediction for the bimanual action model described above. If these gestures are

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[2] The right-hemisphere disorders are constructive apraxias, visuo-spatial disorders, dressing apraxias, unilateral hemiasomagnosias, metamorphopsias, feature agnosias, spatial agnosias, topographic memory problems, spatial dyscalculias. The left-hemisphere lesions cause motor/sensory amusias, ideational and ideomotor apraxias, conceptual disorders, bilateral digital agnosias and body-image agnosias, object and colour visual agnosias, alexias for figures and numbers, and non/verbal abstraction test problems. The anarithmias are the only type of disorder that can be caused by lesions to either hemisphere.

related to reality-based motor representations, then people should show the hand roles that they actually use when performing real object manipulations.

The links between the hand and language may be deeper than the psychology studies suggest, extending into neurology. One argument combining the hardware of motor control with linguistic symbolism is given by Leiner *et al* (1993). The prospect that increased neuronal connections between language areas and hand motor areas involves more than just neocortex suggests the cerebellum must not be neglected, as these authors assert. Traditionally seen as a driver of motor processes, this organ's role in non-motor learning is important. These authors suggest that the cerebellum's extreme structural expansion in humans drove functional expansion, as its incoming and outgoing connections were extended to wider parts of the neocortex. The newly evolved part of the cerebellum which is unique to humans, the dentate nucleus, projects mainly to frontal areas, and also to the premotor (Broca) area. Furthermore, humans have a special loop giving more control to the red nucleus (in the brainstem). Instead of the usual primate projections to the spinal cord, many projections go to the inferior olive, then to the dentate nucleus and back to the red nucleus, in parallel with inputs from the language areas. Although they do not specify whether they support exaptation of the neodentate by language or the inverse (the neodentate expanded to serve language), Leiner *et al* (1993:453) propose that this loop plays an important role in language evolution, because the neodentate is responsible for transmitting symbols (concepts) to the cerebral prefrontal cortex for storage. If this is true, then the connection from the neodentate to Broca's area must come from the right side, since the efferent fibres cross the midline (Glickstein 1993). This is homologous to the contralateral control of body limbs. Justus & Ivry (2001), for example, support the exaptation idea for the cerebellum, suggesting that the mechanisms for motor control were exapted by language, especially terms of temporal processing and implicit learning. Although they do not mention laterality, their suggestion includes both perception and action, and the software of language processing. There is more recent evidence that learning a new skill activates specific cerebellar regions (Johnson-Frey 2004:76), and this should be investigated further in terms of laterality within the cerebellum.

A proposal linking cognition with bilateral roles using conceptual-grammatical structure is the Topic/Comment hypothesis of Krifka (2005). T/C is defined as a possible precursor of subject/predicate structure in communication and thought. Krifka uses Guiard's (1987) model to characterise bimanual coordination in terms of T/C structure, such that the Topic is the first postural placement of the 'aboutness' topic or non-dominant hand, and the Comment is the subsequently added information, i.e. the manipulative action of the dominant hand. The topic identification is static (like the left hand) since it does not change the information state, whereas the comment is dynamic (like the right hand) since it does add information. Furthermore, he argues for an exaptation, where information manipulation builds on previous abilities for object manipulation. This is a good example of a common substrate proposal which fulfils all the criteria: it is conceptual, and is based on language and hand functions.

While Krifka (2005) makes use of MacNeilage's Frame/Contents theory, proposing the left hand for the frames and the right hand for the contents, this is not the original proposal of MacNeilage. In fact, this latter author explicitly rejects this division of labour (MacNeilage 1986); he maintains that both the Frame and Content are localised to the left hemisphere only. The right hemisphere, in his model, has an advantage for visuo-spatial skills, which emerged from unimanual predation. MacNeilage sees the F/C of speech as an exaptation of these manual skills, in which the left hemisphere controls bimanual coordination itself. However, he limits his theory strictly to vocal production, which excludes it from being of any use here. To be noted is that a frame/content terminology is also used by Guiard (1987) for a very different purpose, as described above in section 1.2.2: in bimanual manipulations, this author asserts that the left hand serves to create frames into which the right hand inserts contents.

1.3.2.3. Hierarchy and segmenting

A further category of common substrate suggestions relates to hierarchy and segmenting abilities. Greenfield's (1991, 1998) argument is based on a conceptual common neural substrate for hierarchical structuring, whether with objects (for tool use) or with grammar (for language). Although she does not address handedness, we can extend her suggestion to laterality. This leads to the proposal that any bias causing the brain to preferentially manipulate objects with a certain bimanual configuration (as in spatial or low-frequency for the left hand vs. temporal or high-frequency for the right hand) might influence, via the common substrate, a bias towards laterality in grammar (as in spatial for the right hemisphere and temporal for the left hemisphere).

The segmentation concept is also found in proposals outside the context of laterality (Sasahara *et al* 2006). For instance, Gibson (1991) proposes an underlying conceptual process of hierarchical mental construction for motor and cognitive abilities. This is similar to the idea of Greenfield (1991), probably because the concept was presented by both Greenfield and Gibson at the same conference (Gibson 1991). It also resembles the proposal by Wilkins & Wakefield (1995). In the segmentation idea, the motor, sensory, and conceptual constructs (tools, words, gestures, etc.) can be broken down into smaller component parts and recombined in embedded hierarchies. Gibson (2002:331) argues that "the fractionation of perceptions, actions, or ideas into fine component parts" underlies social intelligence, motor skills, language, and symbolism. Ambrose (2001) similarly suggests parallels between composite tools and language, based on hierarchy and compositionality.

The mechanism of the common substrate is seen to be this functional ability. Wilkins & Wakefield (1995) propose a scenario for the "first language acquirers" in evolution, which parallel the way deaf, non-linguistically-trained children develop their own manual languages, first from referential signs, then stylised pantomimes, then iconic symbols, which finally acquired ordering rules. The arguments from Greenfield, Wilkins & Wakefield and Gibson lack accounts of laterality, which is added here.

Tversky *et al* (2004) suggest a hierarchical and segmentation ability for manual manipulation. They propose that segmentation occurs when we perceive events in the world (i.e. action sequences), and that these salient changes correspond to changes in goals and intentions when we produce actions. Although they do not address handedness, their hypothesis offers a conceptual link between the perception and the production of events. A hierarchical characterisation of language is also favoured by Stout (2003) and Parker (2006).

Most importantly, Gibson (2002:331) invokes the combination of procedural motor / cultural learning and complex motor / language sequences as being most developed in humans. This harmonises with the main idea here, that two levels of skill are required for bilateral operations. These operations are the motor ones, as in skilled knapping, and the linguistic ones. If the learning of these two skill levels is distributed between the cerebral hemispheres, then the implicit, procedural learning can be attributed to the right (holistic) hemisphere and the explicit, sequence learning can be attributed to the left (analytic) hemisphere. In contrast, Johnson-Frey (2004) asserts a dominantly left-hemisphere basis for both kinds of skill in terms of tool use: the semantic knowledge and the motor skills. However, it could be that the experimental protocols used in most imaging studies require a clearly explicit reflection (i.e. attention) on knowledge and actions, which would bias processing to the left hemisphere. This is in fact one of Wray's arguments against the reliance on explicit language tests to localise language.

1.3.2.4. Summary of explicit common substrate proposals

As the summarising Table 1.4 shows, nearly every proposal is an exaptation account. The only one that refrains from suggesting exaptation is Hécaen & de Ajuriaguerra (1964) and Leiner *et al* (1993) who possibly conjure a scenario of mutual exaptation. In this literature, the common substrate of handedness and language tends to be constrained by a view of left-hemisphere dominance (LeDoux *et al* 1977, Alter 1989, MacNeilage *et al* 1987, Vandervert 1999, Aboitiz & García 1997). The papers that escape this constraint do not assign roles to each hemisphere, but are contented with describing global cognitive processes (Justus & Ivry 2001, Leiner *et al* 1993). The papers that do recognise the individual and complementary roles of the hemispheres do not make any suggestions for the common substrate (Fabbro 1992, Hécaen & de Ajuriaguerra 1964). Fabbro (1992) and Sieratzki & Woll (2002) are introduced in 5.4.

The five proposals which offer a common substrate based on segmenting and hierarchy (Greenfield 1991, Gibson 1991, Wilkins & Wakefield 1995, Ambrose 2001, Tversky *et al* 2004) are also the ones that do not mention laterality. Yet it can be useful to combine these concepts. The new common substrate, suggested in Chapter 5, attempts to integrate the laterality data with the concepts of hierarchy and segmentation for language and manual skill.

REFERENCE	PROPOSED CS	LEFT HEMISPHERE	RIGHT HEMISPHERE	DETAILS
LeDoux, Wilson & Gazzaniga (1977)	exaptation (entire left hemisphere)	language took over, pushing the skills to the right hemisphere	manipulo-spatial function, mapping spatial contexts onto perceptual & motor activities of hands	hardware; they reject analytic/holistic exaptation
Alter (1989)	exaptation?	perceptuo-motor integration, axial dominance	none	
MacNeilage (1986); MacNeilage, Studdert-Kennedy & Lindblom (1987)	exaptation (frame / contents for speech)	manipulation, bimanual coordination, frame & contents, right hand bias due to right-arm posture preference	visually-guided movement (reaching, grasping) for unimanual predation, left hand bias due to right-arm postural support	speech; he rejects the suggestion that Frame/Contents correspond to right/left
Justus & Ivry (2001)	exaptation (temporal processing & implicit learning)	no laterality		hardware: cerebellar mechanisms for motor control (perception & action)
Vandervert (1997, 1999)	exaptation (image-schemas become symbol systems & language)	joint visual-somatosensory action-space reference frame, including imaginary movements; space-time simulation structures that become image-schemas	none	
Leiner, Leiner & Dow (1993)	mutual exaptation? (cerebellum improves language processing, & neodentate was expanded for language)	no laterality		neodentate sends symbols to prefrontal cortex & sends motor commands to arms
Aboitiz & García (1997)	exaptation (sequential for language)	sequential skills, tool manufacture	spatial skills, spatial vision	software

REFERENCE	PROPOSED CS	LEFT HEMISPHERE	RIGHT HEMISPHERE	DETAILS
Fabbro (1992)	(no CS)	basal ganglia & thalamus, translation, switching languages, L1 + L2, right ear detecting syntactic/semantic errors in L2	prosody of L1, semantics, concepts, meaning, trained interpreting	software
Hécaen (1963); Hécaen & de Ajuriaguerra (1964)	parallel emergence	formation of concepts, verbal formulation	manipulation of corporeal & extra-corporeal space, recognition of human features	language, gesture, & perception
Sieratzki & Woll (2002); Woll & Sieratzki (2005)	exaptation	target-directed, speech, sequential	environmental monitoring, affective, spatial, holistic	based on emotional interactions
Greenfield (1991, 1998)	exaptation? (hierarchy)	no laterality		hierarchy for objects & grammar
Gibson (1991, 2002)	exaptation (hierarchy / segmenting)	no laterality		two kinds of skills: procedural & sequencing, for both hierarchy & segmenting (cf. Byrne & Byrne 1991, program & action levels)
Wilkins & Wakefield (1995)	exaptation (hierarchy)	no laterality		amodal representations based on hierarchy in the conceptual structure
Ambrose (2001)	coevolution (hierarchy)	no laterality		fine motor control, compositionality, hierarchical construction
Tversky, Zacks & Lee (2004)	exaptation? (segmenting)	no laterality		segmentation via perceived salient changes, executed in changing subgoals & intentions; action & perception

Table 1.4. Summary of Common Substrate proposals.

1.4. Language: referential symbolism and conceptual representation

The concepts outlined in the previous sections provide a very different framework for analysing language emergence to that which archaeologists have typically used in the recent literature. In contrast to the approach promoted in this thesis, which is based on manual praxis, laterality of hand skill, and bimanual coordination, these other approaches have focused on symbolism and on the archaeological recognition of arbitrary form. For the sake of completeness I shall review this body of work here, and its conceptual underpinnings; but I reiterate that the focus in this thesis is on handedness in tool production and use, underpinned conceptually by the Common Substrate models summarised and critically evaluated in the previous section.

1.4.1. Semiotics and arbitrariness

Before language can be discussed it requires a clear definition. To define language, it is useful to begin with a semiotic view (cf. Hawkes 1977) of linguistic symbolism and develop this towards a more generalised cognitive symbolic ability.

One of the oldest semiologists' definition of language is based on symbolism as an arbitrary connection, in the Peirceian sense of the relation between the Saussurean 'signified' and 'sign'. The signified refers to things in the world, whether concrete or abstract, and the sign being words in the language (de Saussure 1916). Peirce (1931-1958; 1991) called this relation 'reference' and defined three kinds of reference: iconic, indexical, and symbolic. They are ordered by increasing level of abstraction, implying a parallel with ontogenetic development (but see Capirci *et al* 2004 for evidence that human infants actually learn these in reverse order). In this system, iconic reference is a relation in which the sign and signified have enough resemblance that anyone can understand them intuitively; understanding the relation is not contingent on knowing the code system or customs of a particular group. Indexical reference is an indirect relation in which the sign is related to the signified, but manifested in a different modality, or else contiguous in time and/or space (Peirce 1931-1958). The symbolic level of reference attaches signs with objects that are unrelated in any way; this is the criterion of arbitrariness that is invoked in many accounts.

Wilkins & Wakefield (1995) make use of Geschwind's (1964) definition of language as an ability to make symbolic reference (associate a symbol with an object or action). Noble & Davidson (1996) also define human language as communication with symbols, after Sapir (1921:20). They clearly define a symbol as "anything that, by custom or convention, stands for something else. A symbol is a representative of another thing" (Noble & Davidson 1996:5).

This of course includes representations of another thing. These authors specifically require that the symbols not be "identical" to their signified objects; perhaps they mean not iconic.

In other words, signs like pointing "are discovered as objects that represent things other than themselves. Thus are symbols born." (Noble & Davidson 1996:7); this definition appears to match the one given above and the one from Peirce, in that sign and signified have an arbitrary relation (*ibid.*:59). These authors denote the specificity of symbols to be used referentially (*ibid.*:63); therefore the symbol system only works if it is conventionalised, in other words known and practised by every member of the group. A further requirement from Noble & Davidson is apparently that the symbols must be used intentionally; the authors have included this extra constraint in order to be able to exclude vervet alarm calls, which they see as devoid of intention (*ibid.*:5), despite much evidence to the contrary (Seyfarth & Cheney 2006). Their definition of modern-like symbolism entails intentional meaning transmission (Noble & Davidson 1996:140 and preceding chapter). This follows Mithen (1995:317), who includes attribution of meaning and intentional communication as prerequisites for visual symbolism. Corballis (2002) also uses conventionalisation as the criterion for symbolism, entailed in the shift from icon to symbol.

The arbitrary nature of symbols can be described as spatial displacement (from one object to another). 'Displacement' is a term from Hockett's (1960) design features of language, and this idea can be extended to displacement in time to include the ability to refer to objects which were previously seen. Goldenberg *et al* (2003) also mention this displacement in space and time, as does Salzen (1998:303): "words are symbols of objects and actions while vocalizations are only signs of internal states. The use of symbols means that behaviour can be performed in the absence of the natural releasing stimulus."

The arbitrary relation of sign to signified is also invoked by Cangelosi *et al* (2002), who define symbols as arbitrary physical tokens which refer to objects and events. These names are "assigned on the basis of their non-symbolic categorical representations" (*ibid.*:2). These categories are developed through sensory input over the person's lifetime (Harnad 2002). This ability to categorise is also included in Mithen's (1995:317) prerequisites for visual symbolism and in the definition of perceptual symbols as neural representations used by Barsalou (1999). Concrete support for the role of categorisation in symbolic ability comes from left-hemisphere brain damage (Goldenberg *et al* 2003:1571).

Chase (2001:196) defines symbols as the arbitrary relation. This author separates symbols qualitatively from icons and indexes because the latter two have some sort of natural relation to their signified; this can be perceived without knowledge of the group's code. Unfortunately, by Chase's definition, all cave art (paintings, engravings, etc.) must be excluded from symbolic representation because they are either iconic or indexical: the paint is an index of the image, and many images show clearly recognisable animal icons. Then one must redefine the term 'symbolic' as involving religion and ritual, in other words giving the symbol some sort of social significance (Chase & Dibble 1992:44). This corresponds to the 'social/cultural symbolism' discussed below. On the other hand, Firth (1973) grouped symbols with indexes, against icons, because they are both indirect relations that must be learned. It can be argued that even icons must be learned as relations (Rodríguez & Moro 1999), because their recognition is in fact dependent on the individual's sensory perception, which develops with categorisation (as argued above). The claim that icons can be intuitively identified for what they represent, without any social/cultural input, is not supported by data from human development and ethnography (Rodríguez & Moro 1999).

The relationship between symbolism and language is probably not exclusive. There is some evidence that each is a process which can operate independently of the other. For example, Vihman & DePaolis (2000:138-140) see language as a subset of symbolic culture. They assert that human infants only acquire symbolism around 14-18 months, as they begin to use language symbolically. In this case, it appears that the acquisition of symbolism enhances language.

One definition of 'symbol' used in linguistics, then, allows for language to be possible without a symbolic capacity, at least in ontogeny. Similarly, the opposite is true: symbolism can be possible without language. As Bradshaw & Rogers (1993:383) argue, the discovery or meta-awareness of symbolism can be facilitated by language, but symbolism can exist in perception and thought without an awareness of the arbitrary nature of the sign-signified relationship.

The proposition that language and symbolic capacity can exist independently of one another entails that symbolism is not a necessary precondition for language, nor vice versa. By extension, then, archaeological evidence for one does not entail the existence of the other. It is only the symbolic use of language that relates directly to human origins. Symbolism is thus defined as a cognitive capacity which is used by the language functions to create referential arbitrary relations. Therefore, the relevant information to seek is archaeological evidence for both symbolism and language in the same artefacts.

1.4.2. How archaeologists define symbols and modernity

The academic discussion about language evolution in the context of archaeology is intricately entwined with symbolism, a term which is constantly invoked in order to match archaeological finds with prehistoric cognition. Symbolism is a vaguely-defined cognitive capacity in most accounts of archaeological evidence for symbolic ability (Bouissac 2003), and yet it forms the basis of arguments for or against modern cognition, usually extending to language ability, in pre-modern humans. But there is no unanimous definition of 'symbolism'. Some authors take the term for granted, not even giving a reference for their use of the word. Symbolism is often conceived of as a way to make a link between the faculty of language and the archaeological artefacts and fossils.

Robb (1998) describes three frameworks used by archaeologists to study symbols: processualist, structuralist, and post-modern. An impetus for archaeology to search for concrete evidence of symbolic ability, an abstract thing in all of these three frameworks, was given by Marshack, starting in the 1980s (Bradshaw & Rogers 1993:309). He proffered the idea that the main innovation of modern humans was an ability to create abstract categories from visual input. Marshack (e.g. 1985, 1988, 1989) suggested this ability could be called referential, and that it encompassed both language and tool use. Even before any of these publications, Spuhler (1977) built a scenario based on a linear evolution of lithic technology and 'levels of abstraction' in the conceptual requirements for tool production.

In a direct application of semiotics to archaeology, Wynn (1995) seeks the three forms of reference (icon, index, symbol) with respect to handaxes to speculate that the handaxes themselves were neither icons nor indexes, and certainly not symbols. However, by accepting only concrete evidence, he fails to consider many options for icons and indexes in archaeology. For example, it is possible that some handaxes could have served as icons for a person's face: when held with the tip down, they resemble the outline of a human face. In the Boxgrove Q1B assemblage was found a striking example (Q1B #7927), in which two dots of lighter flint invoke eyes, the patch of cortex above it (on the butt) is reminiscent of hair, and the shaping of the middle surface can be seen to form the contour of a nose. Although this is a single occurrence, it shows that the possibility of iconicity in Lower Palaeolithic handaxes does exist. Without suggesting that all handaxes were designed to be icons of faces, it must be considered that some of these butchery tools could have been adopted into an iconic mode of representation.

Modernity and symbolism are normally accepted when there is evidence of <u>non-lithic</u> materials being modified intentionally: cave art, burials, ivory sculptures, use of ochre, and ostrich shells are examples. This strict requirement (originally developed to fit the *H. sapiens* revolution idea) has forced some authors to battle for the recognition of other, older objects as symbolic. As Henshilwood *et al* (2001:668) declare, the 70 kya bone tools and engraved ochre pieces from Blombos Cave, South Africa, "reflect symbolic behaviour, the meaning of which was shared through the use of modern syntactic language."

The purported 'symbolic explosion' is described by Mellars (1991:63-64; 72) with many flattering, ill-defined, unfounded adjectives (reproduced here in italics for emphasis): blade technology, *imposed* form on tools, *relatively complex* and *extensively shaped* bone, antler and ivory artefacts, regional diversification of tools, *systematic* hunting, *structured* settlements, *personal* ornaments such as beads and pendants, *clearly ceremonial* burials, and *sophisticated* and *highly complex* forms of representational art. Objective archaeological analysis does not provide any basis for these self-gratifying terms. The revolution, or symbolic explosion, idea was disposed of by Roebroeks *et al* (1988), who assert that patterns of lithic raw material transport show curation, and hence modern-like planning abilities, in the Middle Palaeolithic.

In other contexts, 'art' was defined as non-utilitarian activities (Bednarik 1997). It is likely that the focus on art to represent language arose through their common definition as symbol systems. Davidson (1999) defines art as a system of symbols, adding that symbols are embedded in the learned cultural values of society members. Davis (1986) defines art as the production of representational images. Lindly & Clark (1990:238) list their criteria for archaeological evidence of symbolism: "parietal or mobile art, ornaments, bone artifacts, or burials". All of these definitions are subjective, based on each author's agenda for demonstrating symbolism in archaeology.

Another example of biased definitions is found in Chase & Dibble (1987:265), who define symbolism as "the degree to which arbitrary categories and symbols structured behaviour". Their criteria are stylistic (i.e. non-functional) variation in lithics, intentional burials with associated grave goods, and an 'esthetic sense' (i.e. art). They structure their argument so that even single occurrences of any of these criteria are not sufficient unless they are dated to the Upper Palaeolithic; this makes their proposition inherently biased against any potential Middle Palaeolithic evidence for symbolism.

In a similar vein, Mithen's (1995:316, 318) criteria are: deliberate engravings, representational images, pierced objects, burials, and site structuring in the modern human sense, for whom "space is often used in a symbolically meaningful manner" (*ibid.*). This latter implies that Mithen is using a definition of symbolism which encompasses social/cultural behaviour, which is the point explored below. He maintains that any evidence of his criteria are insufficient to claim symbolic capacity according to his definition, because it must be proven that these artefacts or behaviours were made and used with symbolic meaning (*ibid.*:318). This requirement is clearly useless for archaeology because it precludes finding any proof of 'symbolic meaning' in the past. He allows the recognition of symbolic artefacts yet rejects them with the excuse that they were not perceived as symbolic. Since past perceptions are obviously beyond the reach of archaeology, Mithen's requirements can never be fulfilled.

In a more extreme perspective, Bednarik (1997) once pronounced that his criterion for 'symboling behaviour' was art, defined by a non-functional externalisation of human perception which is inaccessible to non-humans (*ibid.*:163). This very definition contains a reference to a uniquely human capacity, and therefore it can be considered as similarly biased. More recently (Bednarik 2000), this author has extended his symboling criteria to everything except lithic materials: sea travel, production and use of strings, hafted tools, bone tools, and resin are examples he invokes. This scheme effectively excludes pre-Acheulean lithics from being candidates for symboling. He now advocates an earlier origin of symbolism, and accepts for it any evidence of the simple perception of the sign-object relationship. One such example is manifested in the archaeological record by the presence of manuported objects like the 'staring' stone from Makapansgat or the Indian crystals. Bednarik (2000) states:

> "Finally, the use of such sophisticated objects as beads and pendants in the Lower Palaeolithic demonstrates, beyond reasonable doubt, that its hominids possessed well established semiotic systems of various types. In examining the origins of symbolism we would be well advised to abandon the traditional focus on the art of the Upper Palaeolithic of southwestern Europe. It played no decisive role in the advent of human symboling capacities, and it is probably not even relevant to the topic of symbolic origins. What is relevant to this topic are the products of symbolism that have survived from the earliest phase of human culture, the Lower Palaeolithic."
> Bednarik (2000:29-30)

Although the above statement agrees with the argument presented here, this dissertation suggests that the 'products of symbolism' (concrete evidence for symbolic behaviours) can be seen even earlier than this author proposes, and must be sought in the very first artefacts, which are currently known from 2.6 mya at Gona, Ethiopia (Semaw *et al* 2003).

The role of awareness has also been suggested in symbolism. Donald (1995:1092, 1095) invokes the invention of conscious representation as being the innovation which led to modern cognition. He suggests that the mimetic system became unique to our species when it came under greater conscious control, or "active reflection", because "a consciously repeated act is in effect *representing itself*, to both the actor and the audience" (*ibid.*:1096). If this is true, then it harmonises with the definition of language used here, as an arbitrary representation of a thing. In a similar focus on declarative memory, D'Errico *et al* (2003) name conscious symbolic storage as a prerequisite for modern culture and language, suggesting that the originality of humans was the creation of symbolic ideational cultures.

In a more helpful approach, Bouissac (2003) proffers five intrinsic and three extrinsic properties of lithic artefacts which should aid in the identification of non-functionality, and hence can be useful criteria for symbolism. The intrinsic properties are dimensions, density, complexity (in terms of unexpectedness content), complementarity (parts forming a whole), and pattern replication. The extrinsic properties are location, distribution, and context. Bouissac's suggestion is useful because it is the only one, besides Roebroeks *et al* (1988), which allows symbolism to be defined entirely around lithics. In fact, most approaches effectively exclude lithics from partaking in the definition of symbolism. Although Chase & Dibble (1987), mentioned above, do include non-functional variation in lithics in their criteria, it would not be a sufficient criterion for them even if they accepted non-Upper Palaeolithic data.

The concept of modern humans also arose in conjunction with the idea of symbolism (C. Gamble, pers. comm. 2004). The idea of modernity was probably launched by Mellars & Stringer (1989), who introduced the idea of a cognitive revolution (Hockett & Ascher 1964) corresponding to the apparent explosion of cave art in the Upper Palaeolithic. Perhaps palaeoanthropologists found it appealing to be able to associate fossils and artefacts with cognitive capacities in *Homo sapiens*. This made the link with the *Homo* genus particularly intuitive. As Wood & Collard (1999) articulate,

> "while it is attractive to link culture and language with 'the emergence of the genus *Homo* and the arrival of *Homo habilis*' and the attainment of a 'new level of organization' (Tobias 1991:844), we caution that there is little hard evidence to support such a scenario."
> Wood & Collard (1999:14)

However, the concept of modernity is still pervasive in the thoughts of many researchers (e.g. Balter 2002).

The concept of modernity developed as it was applied in parallel to fossils and behaviour (as extrapolated from artefacts). The review by McBrearty & Brooks (2000) discusses all the criteria that have been used. Symbolic capacity was connected with artefacts through the argument that only 'modern' behaviour could be performed by anatomically 'modern' humans. Lindly & Clark (1990), however, reject this connecting of anatomically modern humans to symbolic activity. (Unfortunately their argument slides to the other extreme of suggesting that symbolism was not present before the Upper Palaeolithic, regardless of species.) It is intuitive to associate cave paintings and bone musical instruments with symbolic activity because they resemble the artefacts made by living humans, which are imbued with significance. It is also easy to associate these kinds of 'artistic' remains with human uniqueness because no other animals produce such objects (Belfer-Cohen & Goren-Inbar 1994). One example of such an unfounded preconception is found in Mithen (1995:315): "the ability to create, manipulate, and interpret visual symbols is a universal feature of the human mind".

In such references, the notion that humans are 'special' in some way is promoted by claims of uniquely human capacities such as creativity, reasoning, problem-solving, planning ability, and language. None of these terms has much meaning, but they appeal to our sense of superiority and therefore we find it hard to reject the idea that we are qualitatively different from all other species (Wood & Collard 1999:15). By extension, then, the possibility of language is taken to fall into the same category. For example, Henshilwood *et al* (2001:668) state that "material culture suggestive of symbolic behaviour is the only archaeological evidence of the use of modern syntactic language (Aiello 1998)." For this reason, and because they are the only tangible objects depicting such customs, these artefacts[3] are taken to represent linguistic behaviour, and so populations which have no associated sites of such objects are presumed to be non-symbolic and therefore non-linguistic. Such a linking mechanism is a circular argument. It is expressed clearly by D'Errico *et al* (2003):

> "we can utilize the behavioral corollary of language abilities and, in particular, its expression in material culture, to create a properly structured model on which to

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[3] For Henshilwood *et al* (2001:668), these 'symbolic' objects which show 'advanced behaviour' are: bifacial lanceolate points made of silcrete, quartzite and quartz, circular- and end-lithic scrapers, 'pencil' and 'crayon' forms of shaped ochre, engraving of geometric designs on ochre, catching large fish, shellfish and a 'wide range' of fauna, polishing and engraving of bone tools, and bone tools in general.

> base their origin. It is widely accepted that a direct link exists between the highly symbolic nature of modern language (i.e. its capacity to refer to past, present and future-actual or imaginary-events) and the creation, maintenance, and transmission of the material expression of symbols within a given human culture." D'Errico *et al* (2003:6)

In searching for something that defines our genus, researchers have been forced to devise elaborate definitions of symbolism which invariably exclude lithics, since lithics are not specific to *Homo sapiens.* Symbolism *sensu lato* should not be restricted to modern human behaviours. Symbolism is defined here as a strictly referential behaviour, which for our genus can include language, in contrast to ritual significance and cultural symbolism, which are behaviours specific to humans.

1.4.3. Two aspects of symbolism: social / cultural vs. referential / linguistic

The strictly referential nature of symbolism is used as a definition by most connectionist models of language, for example in associating images with arbitrary labels, but they also acknowledge the internal representation of symbols as the perception of meaning (e.g. Plunkett *et al* 1992). In contrast, many archaeologists, as described above, include religious meaning in their definition of symbolism.

Taking the precise definition even further, Facchini (1999) defines symbolism in terms of three manifestations: functional, social, and spiritual. Functional symbolism is the attribution of meaning to an object (a sign), and Facchini contends that, in any given individual, any object (sound, gesture, tool) can become such a sign. Symbolism becomes social when the group uses a consistent sign-signified relationship with a consistent meaning (this resembles the criterion of conventionalisation, discussed above). The third kind of symbolism is spiritual in that it is completely divorced from function, such as religion, art, and ethics (*ibid.*:518). This author groups the latter two as social or cultural, since they entail aspects of group living, whereas the first only takes place within an isolated mind.

In this way, Facchini's (1999) functional symbolism corresponds to linguistic or referential symbolism; we can contrast this with the culturally-imbued symbolism that takes on 'meanings' and is used (learned, perceived, and produced) socially. A shift from functional to social symbolism is what happens when an individual, whether adult or infant, human or chimp, is becoming enculturated: starting from its own symbolic relations, it eventually learns the group's code.

Chase (2001) suggests that two kinds of 'symbolism' are discussed in the literature on human evolution: referential symbolism (which comprises language) and symbolic culture (the extension of symbolism to culture). The former is evidenced by speech and brain structures in palaeoanthropology, the latter being represented by artefacts (where style, ritual, status marking, religion are necessary elements of symbolic culture).

Gibson (2002) also writes about symbolism, distinguishing customs from symbolic culture. She argues that animals possess customs, whereas symbolic cultures are specific to humans. She defines social customs as socially learned and transmitted behavioural patterns, while symbolic cultures are defined as symbolic systems of values or beliefs governing behavioural practices. Gibson argues that a quantitative difference with the other apes is that humans have greater procedural learning abilities and more "complex" sentences and tools (being made of parts each individually constructed); this resembles the idea of difficulty discussed above in section 1.2.4.

Chase's definitions of symbolism are both contained within Gibson's "symbolic cultures" term, and Gibson's definition of social customs are not included in Chase's symbolism. Because Chase places language in a category separate from symbolic culture, his definition of referential symbolism contrasts with Gibson's social customs. The present research is concerned only with strictly referential symbolism in the semiological sense. In a similar vein, Noble & Davidson (2001) consider language to be a form of referential communication. The social and cultural aspects of symbol standardisation and transmission are not useful for reasoning about the individual linguistic capacity for symbolism which emerges in one's brain. Following Sperber (1975), symbolic ability is accepted to exist beyond just language, being a more general cognitive feature of our conceptual representations.

In sum, the narrow definition of symbolism, based on language, is divided into two aspects: cultural symbolism, which entails the attribution of meaning, and semiological symbolism, which is based on Peirce's (1931-1958) three types of reference (icon-index-symbol) and depends on a neural capacity for categorisation and concept formation (as argued by Sperber 1975). The cultural aspect of linguistic symbol use must be isolated in order to attain the underlying nature of symbolic language. Greenberg (1959:72), for example, suggested that 'symbolic behaviour' should be reserved for humans whereas other apes are only capable of 'sign behaviour'. Some chimpanzee language projects can shed light on the probable limits of nonhuman symbolic ability (Limber 1977; Gardner & Gardner 1992).

The 'duality of continuity' in symbolism refers to one possible solution for the Paradox of Continuity, discussed below. On the one hand, there appears to be a qualitative gap between *H. sapiens* and all other species of hominid. In fact, this gap can be explained by the lack of one kind of symbolism in these other apes, that of ritual meaning attribution. On the other hand, continuity can be found in the semiological symbolic capacity. The other species of apes appear capable of referential symbolism, although they might have less processing power for it (Nettle 2003), and they do not apply it to language. In sum, the opposing impressions of quantitative continuity vs. qualitative leaps can be reconciled by differentiating the two kinds of symbolism that all hominids use.

1.4.4. The Continuity Paradox

One of the problems that plagues language origins researchers is the 'Paradox of Continuity'. Bickerton (1981:216-217) explains it as "there must have been evolutionary continuity in the development of language, yet there cannot have been evolutionary continuity in the development of language." In sum, it refers to the conflict between evolutionary continuity suggesting that language evolved from a prior system, and the present form of language which appears qualitatively different to other mammalian communication systems. This paradox was discussed at length by Greenberg (1959:75), who defined it as "it would seem that [...] language does involve a new skill of which other animals are incapable. Yet, this skill can still be understood as a stage that depends on the sign skills occurring in pre-language behavior." The paradox was reframed by Renfrew (1996) in terms of the emergence of *Homo sapiens sapiens*, by postulating a difference between genetic causes and behavioural effects. Spuhler (1977) also touches upon it, regarding the reluctance to accept a continuous evolution of mind and language despite established continuity in biological evolution.

The Paradox of Continuity can in fact be explained by the presence or absence of one aspect of symbolism, that of ritual significance. This 'cultural symbolism' can be defined as the attribution of religious or ritual meaning to things. There is no known analogue to cultural or religious symbolism in other animals. Because it is a behaviour which emerges from our meta-cognitive abilities, it causes the appearance of a qualitative 'gap' (Greenberg 1959:75) between us and our primate cousins. In contrast, with respect to strictly referential symbolism, we can place ourselves on a quantitative scale of cognition next to other apes. This is possible because chimpanzees and bonobos can master the three Peircean levels of reference in the right contexts. The difference with humans, then, may be as minor as a degree of processing power in the brain, with other apes seemingly limited in being able to embed more than a certain number of levels of hierarchically nested components (Nettle 2003). In conclusion, by distinguishing two kinds of symbolism (cultural and referential), it is possible to account for the apparent duality of continuity known as the Continuity Paradox.

1.4.5. Speech and language: their definitions and relationships

It is imperative to make the distinction between speech and language because this is one of the basic concepts of linguistics. Spuhler (1977) and Wilkins & Wakefield (1995) rightly identify the main problem in many published language evolution hypotheses: a lack of clear distinction between speech and language. Non-linguistic literature on language evolution often confuses the two, sometimes using evidence of one to argue for the other, even though they are not equivalent. As argued here, speech is just one vocal expression of language. Language can be expressed in many ways by humans, one of which is the vocal-auditory medium called speech. Terms often found in human origins literature like 'vocal language' and 'complex speech' are ill-defined although they sometimes hint at the distinction. This section explains what roles are played by language and speech in terms of co-evolution. In as much as speech is only a physical mechanism used by and for language, it is a subset of the topic of interest in this work (language). Similarly set aside are other possible forms of 'speech' that may have emerged, such as a gestural medium, or more probably, a combination of vocal and manual utterances (Corballis 2002).

In this section, speech and language are defined and their relationship is clarified. Although there is by no means agreement among linguists, language can be described as a general cognitive faculty in which people arbitrarily connect things to mental concepts. The term arbitrary is used here in the standard cognitive-linguistic way, in the sense that this connection has no natural affordance (Hockett 1960; Jackendoff 2002). Because it cannot be understood intuitively, it must be learned through participation in the social environment (this can apply either to infants or to adult immigrants). Speech can be seen as one subset of these arbitrary things; the other things can include gestures from other parts of the body, images and markings, and stone tools.

Tools can be described for this purpose as objects which are produced by people; they are usually composite, either in the sense that they are made by combining several elements or they are made by combining several gestures. A longer discussion of this notion is given in section 1.2.4 above; combining elements refers to the levels of 'complexity' entailed in, for example, a hafted spearhead (e.g. Rugg 2004; Haidle 2006), whereas combining gestures refers to the sequence of gestures entailed in, for example, stripping twigs for termite fishing. For instance, Matsuzawa (1996) combines grammar and nut-cracking. In this sense, the definition of 'tool' thus applies to all hominin industries, known and unknown. In a simplified definition of 'tool', then, it is simply an object which is produced by humans, along with images, stone implements, and vocal sounds. The common factors underlying all of these objects are found on two levels: the set of motor actions and the sequences of execution that result in the objects. These two levels have counterparts in the two levels of difficulty discussed above, which can be interpreted in terms of <u>methods</u> and <u>techniques</u>. In particular, this is the basis for the gestural origins theory of language evolution (Hewes 1973).

1.4.5.1. Typical examples of language / speech confusions

First are presented some typical speech / language confusions seen in the literature. One problem which follows from this kind of unintentional merging is what such authors then argue to be the object of natural selection. Hypotheses that fall under the label of 'language evolution' range from one extreme -- selection for vocal tract shape (e.g. Tobias 1998) to the other extreme -- selection for 'complex' oratorical skills (e.g. Burling 1986).

One example of excessive merging is seen in the special issue of Cambridge Archaeological Journal entitled "The origins of speech" (1998), which comprises essays on Indo-European language origins, speech, and symbolism. Most of the authors in this issue, whether linguists or archaeologists, seem to use evidence for speech and language interchangeably as evidence for one another.

One could mention Aitchison's 1996 book title, *The seeds of speech: language origin and evolution* as an example of confusing language and speech. In fact, Aitchison (1996) and Dunbar (1996) both describe language as a means of communication, in contrast to Bickerton (1996), who argues for a concept- or thought-based function of language. Bickerton being a linguist, this is not surprising, since one definition of language used in the field of linguistics is very much based on the formation of concepts and categories (Langacker 1990; see 1.4.6).

Another definition of language as primarily a means of communication is used by Burling (1986). He focusses entirely on the later process of language change, leaving aside the question of how it emerged in the first place. Even so, however, his definition of language is the spoken expression of social manipulation. Throughout his article he implicitly refers to 'language' as a vocal means of manipulating other people in order to raise one's social status, either consciously or unconsciously. Technically this should fall into the category of speech, but Burling escapes this criticism by centering his argument around the complexity of linguistic skill, which he describes as stemming from social intelligence. The main effect of having the complex linguistic skills that Burling proposes is leadership, which emerges from an ability to influence other people: "It is in defining ourselves in relation to others, in conducting interpersonal negotiations, in competing, in manipulating, in scheming to get our own way, that the most subtle aspects of language become important." (Burling 1986:8). This suggestion is also found in Buckley & Steele (2002) and it emphasises the interactions between language and speech; *contra* Liberman & Whalen (2000) below, their relationship is better described as bi-directional.

Schepartz (1993) embraces an even wider definition of language, almost to the point of defining 'modernity' itself: she uses brain structure, vocal tract morphology, spatial behaviour, and symbolism (art) as evidence for 'language'. This overly broad definition of language is possibly reminiscent of the 'modern humans' notion discussed above.

1.4.5.2. Good examples of the language / speech distinction

Buckley & Steele (2002) invoke various anatomical markers of speech as possible archaeological evidence for language. However, this is not a merging of definitions, but an inclusive view of language: they also include motor skill, arbitrariness, and symbolism in their definition of language. Therefore their use of speech can be considered an inclusive element in their proposal. In their view, speech is just one part of a system which evolved.

In their use of the Frame/Content theory (MacNeilage 1998) of language, MacNeilage & Davis (2000) use a strictly speech-centred definition of syllabic structure, and they only extend their argument to language evolution in the narrow sense of word formation. As expected from linguists, the speech / language distinction is kept clear in their argument.

In an even more expert linguistic perspective, Liberman & Whalen (2000) describe the two conflicting views existing in the literature of the relationship between language and speech, views called horizontal and vertical based on their role in evolution. The horizontal view considers that the processes of speech perception and production were exapted from other behaviours to language. The vertical view argues that speech is a specialised system which evolved for linguistic communication. Although the authors clearly support the latter view, contending that speech evolved only to subserve language, there is no unanimous agreement on such a linear, unidirectional evolutionary process. Co-evolution and mutual reinforcement seem more plausible and parsimonious (cf. Buckley & Steele 2002).

In a more complete definition of speech, elements from both views can be combined: speech is simply a vocal medium for expressing, using, and/or perceiving language. Whether speech evolved specifically for language or not is irrelevant for the present study. Speech can be considered as equivalent to hand gestures, body language, and all other kinds of communicative acts. The Liberman & Whalen (2000) suggestion that motor acts are the common underlying unit of speech perception and production is pertinent to the present study, since speech can be reduced to its elemental components of vocal gestures just as knapping stone can be reduced to its elemental components of upper limb gestures. Because speech involves physical processes, it is considered to be one physical manifestation of language. In other words, speech is a tool for using language.

Speech must not be confused with language when discussing evolution. Authors from all fields frequently fail to distinguish the two, either through neglect or a desire to cross-justify data from both fields of study. Here speech is considered to be a subset of language, and evidence for the evolution of speech is not sufficient to infer language evolution. In this sense, the archaeological evidence for language should exist independently of fossil evidence for speech.

1.4.6. Language as a cognitive behaviour

Language, in contrast to the specificity of speech, can be seen as a more widely-available cognitive ability based on referential symbolism, but one that, in living humans, structures our perception of all things in the world. The mechanism for this structuring is categorisation (Langacker 1987-1991, 1990; Martin 1998). Other animals do indeed categorise; it is the very foundation of visual perception and object recognition in all species that have eyes, although primates have particularly well-developed vision areas in the brain (for example, the strong facial recognition ability of primates is probably connected with our highly social nature). Categorisation in humans has been overtaken by concept formation; these concepts are in turn given names. This is the basis of linguistic reference. This mode of cognition can be termed linguistic, simply because of the pervasiveness of names for things (concepts and categories, cf. Langacker 1990) in non-language cognition.

Here it must be stressed that such referential activity must not be restricted to the vocal-auditory channel (i.e. speech). If language is a general cognitive function, then its referential ability can also be exploited for body language and all other means of communication, manipulation, and emotive perception which are the hallmarks of primate social systems[4]. This idea is compatible with the Wilkins & Wakefield (1995) hypothesis that an underlying amodal conceptual structure is responsible for the referential nature of language.

The underlying broad conceptual structure is thus responsible for the referential nature of language. In this sense, symbolism is equivalent to linguistic reference. This concords with Russell's (1996) definition of symbolism as an ability to maintain in working memory a representation that is out of sight. Sperber (1975) defines symbolism as depending on conceptual representations. These conceptual representations can be considered as the result of the categorisation process, as outlined above. If objects in the world are defined as including all senses, such as gesture, image, smells (cf. Sperber 1975:118), and sound (e.g. speech), then it is possible that 'language' is the attribution of these concepts to things and events (speech sounds, hand signs, paintings of bisons, stone tools, emotions, etc.).

This idea follows White (1940), in that

> "A symbol is a thing the value or meaning of which is bestowed upon it by those who use it. I say 'thing' because a symbol may have any kind of physical form; it may have the form of a material object, a color, a sound, an odor, a motion of an object, a taste."
> White (1940:453)

[4] The large issue of theory of mind will not be discussed here, except to say that it is not considered relevant to referential symbolism because it is not an especially unique feature of human cognition.

Symbolism then becomes the meanings which connect the two entities: 'internal' concepts and 'external' objects. This is not the use of 'meaning' *sensu lato* as religious or ritual significance as argued by some authors, but rather 'meaning' *sensu stricto* as an arbitrary mapping of an object to a concept. Thus, 'language' is dependent on the conceptual representations of things and events (speech sounds, hand signs, paintings of bisons, stone tools, etc.).

The terms discussed above can be schematised in a hierarchical diagram which clarifies their relationships (Figure 1.1).

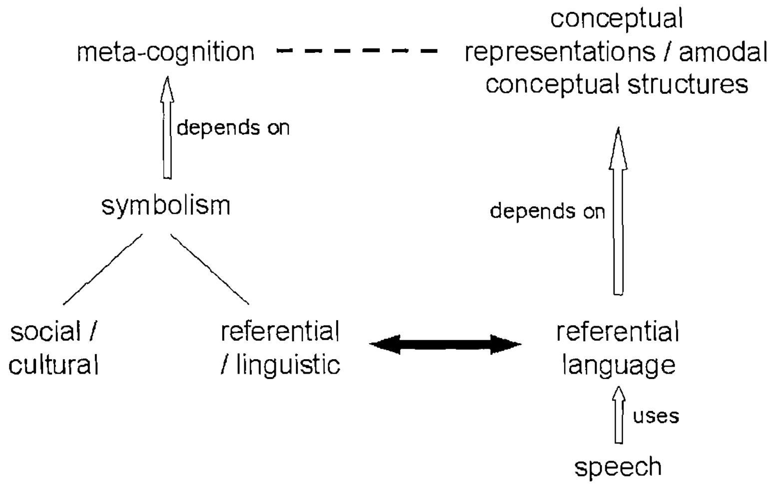

Figure 1.1. Diagram of relationships between terms discussed.

1.5. Summary of Chapter 1

As this chapter has argued, language origins research awaits vital input from prehistoric archaeology. The most interesting and controversial questions, namely about the time frame of language emergence and the hominin species that used language, can only be answered with hard evidence. The most pressing problem is the validity of methodologies for determining handedness from prehistoric artefacts. This is investigated in detail the next three chapters.

The triangle of inference that is so often invoked by language origins researchers can be described as the linking of two behaviours, handedness and language, via a common substrate. An exploration of the common substrate revealed that, to make it fit in the context of Palaeolithic archaeology and human origins, it will require a definition that is based on asymmetrical language function and invokes a mechanism of software.

Handedness was defined as a species-wide tendency, in statistically significant proportions, for humans to assign specific and complementary roles to both hands when carrying out skilled bimanual tasks. These are activities which involve differential coordination of both upper limbs and require a long learning period to acquire. For prehistoric activities, their difficulty is found on two levels, the techniques (elementary gestures) and methods (sequences of actions). A bimanual model of handedness, when restricted to skilled tasks, can account for the data from primatology, ethnography, and humans in experimental laboratory settings.

Chapter 2 reviews the archaeological evidence for bimanually-coordinated role differentiation in stone knapping and lithic use-wear patterns. Maintaining the definition of handedness as involving both hands to equal degrees, each for a specific role, this dissertation will use the familiar terminology of 'right-handed' and 'left-handed' to denote the hand that holds the hammer (in the case of knapping) or the tool (in the case of tool-use).

Chapter 2. Evidence for laterality in palaeohominins

2.1. Background

2.1.1. Introduction

The bimanual model of handedness that was defined in Chapter 1 draws on the Kinematic Chain model of Guiard (1987). It indicates a specific class of data to be sought from the archaeology: evidence for the complementarity of hand functions, when acting together upon single objects. Such evidence is seen directly in the products of tool manufacture and tool use, because these objects were created and manipulated directly by hominin hands (Nowell 2001:1). The prediction for archaeology is that handedness should leave traces, through repeated use of single objects by single people or several people, and in the isolated manufacturing events that took place when stones were knapped. In terms of the bimanual model, the traces to look for are the evidence of a left-hand bias for low-frequency or stabilising movements and a right-hand bias for high-frequency or manipulative movements. As outlined in Chapter 1, the well-known terminology 'right-handed' and 'left-handed' will refer to this pattern.

Indicators of handedness in extinct hominins can be found in several different fields, being either indirect (primatology; ethnology) or direct (osteology; archaeology). Here the main focus is on data that relates to stone knapping and use, with an emphasis on the time span of non-*Homo sapiens* hominin species. Although the focus is on stone here, it does not imply that only stone should be considered; knapped bone in particular is widespread in prehistory. Lithics are the most universal, constant, widespread, and abundant artefacts of prehistoric human behaviour (Nowell 2001:1). Nonetheless, the skeletal data must also be considered because they provide direct evidence for handedness.

2.1.2. Skeletal evidence

There are suggestions that humans are the only primates to show a right-biased asymmetry in arm bones. For instance, Schultz (1937) measured paired humeri and radii in skeletons from 130 gorillas, 82 chimpanzees, 8 orangutans, 21 gibbons, and 722 humans; although he found more chimpanzees with longer left limbs, the human skeletons were about twice as asymmetrical and biased to larger right arms. A more recent study examined skeletons from wild-caught chimpanzees: a 66% left-biased asymmetry was found in the sample of 58 chimpanzee humeri, based on length and cross-sectional area (Sarringhaus *et al* 2005b).

However, the same study also found a weak right-biased asymmetry in the paired metacarpals of 45 individuals. These mixed results suggest that the biomechanics of chimpanzees during locomotion and arm-loading postural support are still poorly understood compared to humans (Sarringhaus *et al* 2005b), while reinforcing previous indications that the human pattern of upper limb asymmetry is unique among great apes.

The relationship of upper limb asymmetries to handedness has been known since 1845 (Smith 1925). Because the skeleton grows and adapts itself according to the way it is used (i.e. the mechanical pressures it experiences from muscles and tendons) in a person's lifetime, the differential loading of paired hands, arms, and shoulders necessarily causes asymmetrical adaptations in the skeleton. It must be noted that the effect of asymmetrical muscle strength and mechanical loading on bone mineral formation is localised to the specific site of muscle-bone interaction; the skeleton's response is directly related to the actions of the muscles. The bone's response to loading can include increases in bone strength through increased bone mineral content, density, and/or cross-sectional area (as in the playing arm of tennis players, Haapasalo *et al* 1994), increases in mechanical efficiency by shape change (such as the scapula and clavicle allowing a greater range of motion in the gleno-humeral joint on the side of the preferred hand, Bonci *et al* 1986), and resistance to avulsion by increasing the surface area of the attachment sites of muscles and ligaments on the bone's surface (Carter 1987). One example of this is found in a recent archaeological individual from Rota, in the Mariana Islands, whose right scapula has a bevelled joint extension facet, possibly due to habitual slingstone throwing (Heathcote 1995).

Right-arm dominance exists in all *Homo sapiens sapiens* populations studied to date. Steele (2000) and Weaver *et al* (2001) have reviewed the fossil evidence for handedness in the fossil record. Measurements of modern anatomical collections for humans yield overall figures of 79% longer right arms, 18% longer left arms, and 3% equal lengths (Schultz 1937). The sample contained 232 U.S. skeletons of European ancestry, 233 U.S. of African ancestry, 122 Alaskan Inuits, 118 North American Indians, and a few Chinese and Aboriginal Australians. These figures are repeated at the Medieval cemetery site of Wharram Percy, UK, where Steele & Mays (1995) found 81% right-handers, 16% left-handers, and 3% with no sign of asymmetry. A study of 416 skeletons from the Roman site of Poundbury, UK found longer right arms in 210 individuals and longer left arms in 65 people (Thould & Thould 1983). In three German Neolithic farming sites in the Middle Elbe-Saale region, Reichel *et al* (1990) found a right-handed pattern in 70% of individuals, 15% left-handedness, and 15% 'ambidextrous' individuals. Constandse-Westermann & Newell (1989) found, in a study of foraging peoples from the Mesolithic of Northern Europe, 43 individuals with longer right arms and 14 with longer left arms.

In contrast, very few studies of arm bone asymmetry have been reported for non-*Homo sapiens* fossil hominins. This is often due to the poor preservation of paired upper limbs, or to a total lack of postcranial material for some species. Species that are defined solely on cranial characters are *Sahelanthropus tchadensis, Kenyanthropus platyops*, and *Australopithecus (Homo) rudolfensis*. Others have only unpaired arm bones, such as *Orrorin tugenensis*, *A. garhi*, *Homo floresiensis*, and *A. anamensis*. *A. afarensis* is best represented by Lucy, whose fragmentary paired humeri and ulnae (Senut 1981) have not been studied for laterality. The oldest hominin fossil with data is the Nariokotome Boy's (WT-15000, *Homo ergaster*) right-sided skeletal bias seen in the greater development of the clavicular area of attachment of the right deltoid muscle and greater length of the right ulna, consistent with right-handedness (Walker and Leakey, 1993).

Nonetheless, some well-preserved Neanderthals specimens do provide important information. The data from Neanderthals showing greater humeral robusticity in the right arm have been suggested to result from hunting with thrusting spears (Schmitt *et al* 2003). The Neanderthal individual buried at Le Régourdou shows several markers for right-handedness, notably as greater diaphyseal diameters in the clavicle, humerus, medio-lateral ulna, and radius, in addition to greater radial neck diameter, proximal clavicular curvature, radial interosseus crest development, and ulnar radial facet height (Vandermeersch & Trinkaus 1995).

Trinkaus *et al* (1994) quantified the asymmetries in the paired humeri of eight individuals: La Chapelle 1, La Ferrassie 1, Neandertal 1, La Quina 5, Spy 2, Shanidar 1, Tabun 1, and Kebara 2. The measurements taken in these individuals were humeral length, distal articular breadth, and the cortical and medullary areas both at 35% and 50% of the length from the distal end of the humerus. All but Shanidar 1 are right-biased; this can be attributed to this individual's pathological right arm and associated disuse atrophy on the left arm (*ibid.*). The arms of Neandertal 1 also show pathologies, in the form of left-arm lesions which may have partly contributed to the strong rightward asymmetry in this pair of humeri. A possible left-arm trauma can be attributed to a third fossil, La Quina 5, despite the absence of visible lesions. The remaining five individuals are considered as having nonpathological asymmetries, indicating they were subjected throughout their lifetimes to differential loading patterns which favoured the right arm (Trinkaus *et al* 1994).

With a variety of data from different sources, the evidence for right-handedness in Neanderthals is firm and unanimous. The presence of skeletal asymmetry features in Neanderthal fossils deriving from stratigraphic deposits of varying ages suggests that right-handed lifestyles were a long-standing behavioural pattern in this species. The artefact data reviewed below make the case even stronger.

The high proportion of right-handers in the skeletal data throughout prehistory implies an overall figure of 80-90% right-handedness. Although the Neanderthal evidence for handedness is the most reliable and abundant of all non-*Homo sapiens* species, it is far from complete. The wide time spans and geographical ranges, the paucity of sites with associated fossils and artefacts, and the lack of detail in the existing data prohibits calculating the percentage of right-handers in a given population. More studies are needed, in the form of comprehensive analyses which combine several different categories of evidence. The next section (2.2) presents the artefact data which can complement the data from primates, living humans, and fossils that were reviewed above.

2.2. Indicators of handedness in lithic production and use

This section focusses on the archaeology of all Lower to Middle Palaeolithic hominins that were either directly associated with, or potentially responsible for, the artefacts discussed in this chapter. These are *Homo heidelbergensis, H. sapiens neanderthalensis, H. antecessor, H. erectus, H. ergaster, Australopithecus rudolfensis, A. habilis*[5], and *Paranthropus boisei*. These include the East African hominin species that are thought to have existed contemporaneously with the artefacts at Koobi Fora and Kariandusi, discussed below.

The approach begins with Semenov's pioneering methods in reconstructing the kinematics of tool use from a combination of use-wear, experimentation, ethnographic observations, and biomechanics. Because the mechanical action of body joints is constrained by physiology, it is useful to incorporate this knowledge into the reconstruction of gestures from artefacts. One main assumption of knapping biomechanics is that the two halves of the body are more or less mirror images of each other. This means that the traces left by the gestures of right and left sides of the body can be identified from either side of a line of symmetry. In short, the knowledge of biomechanics should help guide our predictions, justify our assumptions, and explain our observations.

In the following paragraphs, published evidence for handedness in lithic production and use is reviewed and the results are evaluated in terms of biomechanical assumptions, experimental validation, and ethnographic parallels. In addition, the issue of levels of measurement and independence of data points remains central throughout. There are two kinds of data for handedness in the archaeological record: data can reveal the hand preference of an individual, or they can testify to a sum of hand preferences over time or within a group. Also, data can pertain to either artefacts or people. Certain categories of data give better information on one level or the other (i.e. group or individual), and these are clarified as they apply in each part of the text. The summary Figure 2.7 shows a timeline for the hominins in question and the artefacts in question.

[5] *Homo habilis* was reassigned to the Australopithecines in the new species classification of Wood & Collard (1999) and Steele (1999).

The publications in this chapter are divided into two sections: production and use. Within each, the data are grouped by material (i.e. the nature of the artefacts). In the Production section (2.2.1), data can apply to either methods or techniques, in other words be based on either knapping sequences or knapping gestures; this relates to the presentation of skilled bimanual action set out in Chapter 1. The Production section covers Methods with reduction sequences and Techniques with knapping gestures. In the Use section (2.2.2), all data are obtained with the same general concept of linking gestures to traces: that grips constrain the direction of tool movement, and therefore that tool movement direction indicates grips. This reasoning is slightly circular, and therefore only consider the proposals that are validated with either an experimental reference base or with ethnographic / observational parallels. Since most use-wear studies on handedness are justified by experimental reference creation (Mathieu 2002), there are few known ethnographic parallels, despite the frequent usage of ethnology for other aspects of traceology research involving grips and hands. The Use section covers data based on unimanual use and on the more realistic bimanual coordinated action.

2.2.1. PRODUCTION

2.2.1.1. Method-based

The publications reviewed in the method-based section are Toth (1985), Bradley & Sampson (1986), and White (1998). These three methodologies all rely on flaking sequences for their interpretation of handedness.

Archaeologists have written about evidence for handedness in their artefacts since the 1800s (e.g. Brinton 1896, Cushing 1892, de Mortillet 1883, Wilson 1885). Many of these early references were mentions within larger publications, often as interesting sidelines. Working in the 20th century, one important Russian archaeologist applied the modern methods of scanning electron micrography (S.E.M.) and experimentation to seriously study handedness in lithic technology. S.A. Semenov had a keen interest in handedness; he mentioned it several times in his 1964 volume, for example when describing the bone retouchers from Kiik-Koba and Teshik Tash: "...in working, the right hand of the Neandertaler played the predominant part, for he held the retoucher in the right hand and the flint being worked in the left" (Semenov 1964:173).

However, it appears that Semenov's observations about handedness in his assemblages went largely unnoticed in European and American archaeology until Toth's (1985) publication. It is considered to be one of the seminal studies in the archaeology of prehistoric handedness. Indeed, the Toth paper launched international interest in the topic of determining handedness from lithic remains, using experimentation combined with assemblage analysis. Ever since its publication, this brief article has been widely cited as the main, often the only, evidence for right-handedness in prehistoric populations. It has fostered a host of publications on the same subject, both experimental and theoretical; there have been several replication attempts by independent researchers around the world and several new methods invented. However, the paper has experienced what Boë & Iranzo (1994) term the "erroneous diffusion of scientific ideas". This is particularly dangerous because a number of major faults in Toth's study come to be overlooked when the article is cited. One of the most problematic effects is that authors interpret his findings (a ratio of 56:44 right-oriented *flakes*) as meaning there were 56:44 right-handed *hominins*. This type of error is well-known and often emerges through citing articles from secondary sources (Sarringhaus *et al* 2005a).

2.2.1.1.1. single-platform cores

The influential study by Toth (1985) proposed that right-handedness can be seen in the archaeological record by reconstructing the preferential direction of core rotation during single-platform flaking. The direction of rotation of the core was inferred from the presence of cortex on the right or left side of the dorsal surface of a flake[6]. These single-platform cores were produced by removing all the flakes from the same platform. On a round cobble, this reduces the number of possible flaking locations to two: to the left of the previous removal, or to the right of it. A right-biased flake has cortex on the right, and vice versa. Toth's methodology for interpreting handedness was based on proportions of L:R flakes; in other words, each individual flake carried no information, and it was the analysis of multiple flakes that yielded data. Specifically, he claimed that a right-handed knapper would produce a higher proportion of right-biased flakes. This methodology means it would be impossible to identify an individual's flakes, and therefore only the group level of analysis would be possible. But the fact that one individual can produce many flakes raises the issue of independence of data points (McGrew, pers.comm. 2003), especially since the Koobi Fora flakes are each counted as one data point. This is a common problem in archaeology, where individual knappers can only rarely be identified.

According to Toth (1985), during his own experimental Core Scraper replications he consistently rotates the core clockwise in his left hand, thus knapping each flake to the right of the previous one. He argued that this decision is dictated by "the musculo-skeletal structure of the left hand and arm, in which the superior power of the supinators and flexors produce a preferential rotation in this direction for a stronger and more controlled turning motion (O. Lovejoy, pers. comm.)" (Toth 1985:611). Even if such a biomechanical preference did exist, it would be irrelevant for single-platform flaking unless it could be proven that there is a need for a strong or controlled turning motion in the core hand. The Core Scraper video experiments in section 3.3.2.1 of Chapter 3 will test this assumption. It is more likely that the core (left) hand needs to hold the core in place to receive the hammerstone blow and the turning only occurs in between blows. But the core rotation in between blows does not affect the quality of flakes. In fact, for most types of knapping, the order of flake detachment is mostly contingent on the shape of the core or flint nodule (Patterson & Sollberger 1986; Pobiner 1999). The fact that the Karari cores were flaked from a single platform certainly could have allowed good serial flaking. This was demonstrated by Ludwig & Harris (1994), who are the only authors to confirm that right-handers rotated the core clockwise and left-handers counterclockwise when making Karari scrapers. Therefore we must be cautious when applying Toth's method to industries

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[6] Toth's study only applied to a specific reduction strategy (Reduction Mode 20; Toth 1982), a subset of the Oldowan called the Karari industry from the locality of Koobi Fora (Kenya). There is only one site at Koobi Fora that contains these Karari Scrapers or Core Scrapers, which is FxJj 18GL, site dated to ~1.5 mya. The 1985 publication includes data from other industries that were not tested.

whose reduction strategies were not restricted to single-platform serial flaking. With other kinds of flake production, the figures seem to approach 50:50 as the sample sizes increase (Noble & Davidson 1996:170; Pobiner 1999; Uomini 2001). So it may be true that Toth has an idiosyncratic preference to flake single-platform cores in a strictly unidirectional, rightward order, but this cannot be attributed to any biomechanical constraints, nor can such an assumption be extended to other lithic industries.

2.2.1.1.2. Caddington

In a study of Acheulean handaxes from Caddington, UK, Bradley & Sampson (1986) replicated the reduction sequences for bifaces and Levallois production using a right-handed knapper. They classified the flakes with respect to cortex retention and the presence and location of relict margins. Comparing the experimental collection with the archaeological sample from Caddington, the authors find that the experimental sample is more strongly correlated with right-handed production. They interpret their results as revealing a weaker bias towards right-handedness in Caddington than in the experimental knapping.

The same problems of individual invisibility as at Koobi Fora apply here. If the site was created by a single knapper, it would mean that this individual was sometimes knapping with the left hand. If several individuals knapped at Caddington, then perhaps there were one or more left-handers creating more left-biased flakes to add to the ones produced by the right-handers. The fact that the right-handed experimenter made more than 1/3 left-biased flakes indicates that a group of right-handers would still produce many left-biased flakes, and therefore applying these authors' Handedness Index depends on having large numbers of flakes. Bradley & Sampson's classification according to relict margin location also makes their methodology open to the same criticisms about reduction sequences as the Toth method, as discussed above.

2.2.1.1.3. twisted ovates

Reduction strategies can interact with the manner of holding the core in direct percussion. White (1998) experimentally identified four possible bimanual configurations for manufacturing twisted ovates, two for each handedness pattern. These bifaces exist in British sites dated to between late OIS 11 and early OIS 10 (362 kya and 334 kya), and in France they are found at sites with dates from OIS 12 to OIS 8 (478 kya to 242 kya).

According to experiments done by White (1998), twisted ovates are made with a particular method, usually at the finishing stage: first, one quarter of the edge is flaked unifacially. Then the handaxe is inverted about the long axis and one quarter of the opposite face is flaked. These two sets of unifacial removals, on opposing faces, are now joined at one tip of the handaxe. Next, the piece is rotated (clockwise or counterclockwise) 180 degrees and one more quarter flaked unifacially. Finally, the piece is inverted about the long axis again and the opposite quarter is flaked, bringing the last two sets of removals to join at the other end of the handaxe. The result is a handaxe with an edge alternating 4 times between the two faces. This makes the profile look 'twisted' in the same way, no matter how it is held. These are shown in Figures 2.1 and 2.2.

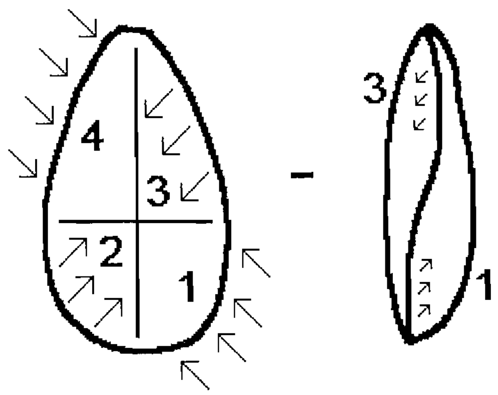


Figure 2.1. Diagram of Z-shaped twisted ovate profile. After White (1998).

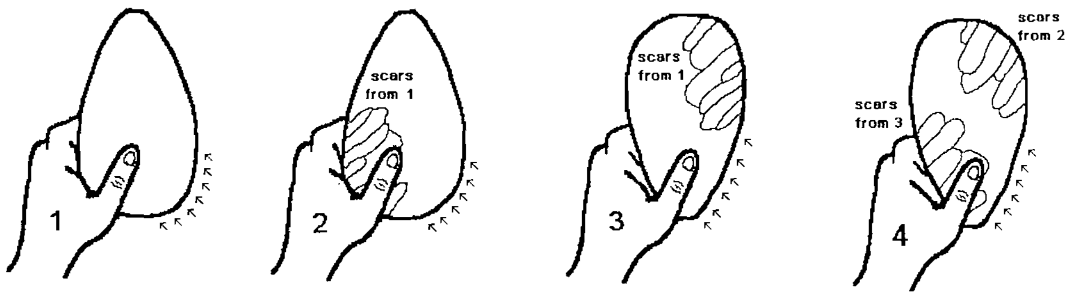


Figure 2.2. Diagram of proposed knapping sequence for twisted ovates. After White (1998).

In this reduction method, for all four edges that are knapped unifacially, it is the handaxe which is rotated so that the hammer hand always knaps in the same 'active zone' of the core hand (White 1998:99). The interpretation of handedness comes from the fact that nearly all twisted ovates have a Z-shaped profile rather than an S-profile. This means that the Z-twist knappers had two possibilities for the knapping zone (or quarter of the handaxe face): either the area near the wrist for a right-hander, or the area near the fingers for a left-hander. (A right-hander using the fingers area, or a left-hander using the wrist area, would produce an S-twist.) If it is the case that one biface represents one knapper, then the proportions of right-handed twisted ovates should reflect population handedness. The use of the fingers quarter can only be justified if the prehistoric knappers were mostly left-handed, and so this possibility can be excluded, leaving only the right-handed option if the reduction strategy is correct. The same logical argument is also used by Cornford (1986) (below) to statistically eliminate the possibility of preponderant left-handers. Winton (2004) presents a case where the twisted profile is achieved by flattening the tip while keeping a thick butt, which suggests that twisted ovates should be analysed individually. White's (1998) method is experimentally valid but remains to be confirmed through detailed technological analyses of lithic assemblages.

2.2.1.2. Technique-based

The publications reviewed in the technique-based section are Newcomer & Sieveking (1980), Wenban-Smith (1997), Rugg & Mullane (2001), Takeoka (1991), and Cornford (1986).

2.2.1.2.1. knapping scatters

Although there are very few high-resolution sites with *in situ* knapping scatters (e.g. blades at Pincevent, Bodu *et al* 1990; Bromme blades at Trollesgave, Fischer 1990; Neolithic axes at Oresund, Högberg 1999), they are valuable because they can reveal handedness in an individual. Of course, this assumes that one scatter is produced by one knapper. This is not always the case, as learners' debitage can be embedded within a more expert knapper's reduction sequence, even on a single tool (Pigeot 1990).

It has been shown experimentally that a knapper sitting on a seat produces a central concentration of debris which is skewed to the side of the knapping hand (Johansen 1996). When sitting directly on the ground, with the core-side leg folded and the hammer-side leg straight out, a clear triangular scatter appears in which the scatter is skewed to the core-side and ends abruptly against the hammer-side leg. Newcomer & Sieveking (1980) replicated 16 Neolithic axe roughouts at the site of Grime's Graves, UK. Although this study refers to a Neolithic industry, it is included here because it provides the only left-handed experimental reference data in the literature on knapping scatters. The left-hander, Newcomer, sitting on the ground with his right knee bent and left leg out, produced a right-skewed scatter ending abruptly where the legs were. It must be noted that there is another action which can produce a concentrated scatter: the use of a piece of hide or cloth for leg and crotch protection (Karlin

& Newcomer 1982:163). The pieces which fall on the material collect into a distinct heap when they are dumped onto the ground, for example when emptying the debris or when the person stands up. It is important to note that the dumped heap looks identical whether the knapping is done sitting on the ground, on a seat, or squatting (Newcomer & Sieveking 1980). Specifically,

> "the manner in which the roughout was held during flaking did not seem to have much effect on the size and shape of flake scatters. When the [sheepskin] thigh pad is used, it catches the flakes as they are struck and the flakes then tend to drop in a circular heap below. Without the pad, which is difficult to use when standing or seated on the floor, the flakes are either caught in the fingers and then dropped, or allowed to shoot off freely; in either case the roughly circular shape of the scatter is recognisable."
> (Newcomer & Sieveking 1980:350)

An experimental reference scatter was also produced by Wenban-Smith (1997), a right-hander, who sat on the ground with the left leg folded and right leg out (the inverse of Newcomer) and produced a left-skewed scatter bounded by the legs. An identical (consistent with a right-hander) pattern was found at Boxgrove (Roberts & Parfitt 1999), the UK site dated to 400 kya which also yielded remains of *Homo heidelbergensis*, and which forms part of the case study in Chapter 4.

2.2.1.2.2. skewed cone of percussion

An experimental study on flake production was done by Rugg & Mullane (2001), who studied the skew of the Hertzian cone of percussion. These authors hypothesised that

> "the angle at which the cone of percussion occurs relative to the striking platform is usually around 90 degrees, but can vary ... Because the human arm has pivot points at the shoulder, elbow and wrist, it is plausible that some blows would lead to cones of percussion that were angled to the right or left relative to the striking platform."
> (Rugg & Mullane 2001:252)

Because the Hertzian cone indicates directionality, its skew should reflect the exact trajectory of the hammerstone.

With respect to knapping gestures, Takeoka (1991) defines two kinds of movement which affect the position of the flake blank (or core), and thus the angle at which it receives the hammerstone blows. One is wrist abduction / adduction, the other is forearm pronation / supination. When knapping, the axis of wrist movement (if the palm is placed flat on a table, this would be a side-to-side motion of the hand) affects the direction of fracture force propagation within the core; this is the effect that the Cone of Percussion hypothesis (described below) exploits, although they argue for an entirely hammerstone-based cause

(Rugg & Mullane 2001). Forearm rotation affects the working angle (angle between the platform and hammerstone trajectory); a more pronated wrist results in an obtuse angle (because the platform is tilted towards the body) while a more supinated wrist results in an acute angle (platform tilted away from the body). A third factor, wrist flexion/extension, affects the horizontal position of the striking platform, bringing it closer to the knapper's eyes (Takeoka 1991:503-505).

Rugg & Mullane (2001) experimentally validated their recognition criteria, with 4 left-handed knappers and 4 right-handers: in a blind test three people were able to assign 75 % of the flakes to the correct handedness. The fact that right-handers produced right-skewed cones and left-handers produced left-skewed ones indicates that the tendency to skew the blow comes from either slight, unintended supination of wrist or unintended flexion at the elbow of the knapping arm. If we assume that the basic knapping gesture for hard-hammer direct percussion consists of partially pronating the wrist and simultaneously adducting the forearm, then any deviation to orient the blow towards one's body is caused by extra supination and/or flexion. Although this study is based on such biomechanical assumptions, these remain to be fully validated and applied systematically to archaeological collections. When this methodology was applied to British Lower Palaeolithic flakes from Swanscombe and Purfleet, equal proportions of L and R were found, but was only possible on a small subset of the flakes, and the measuring method was very difficult to implement objectively (Uomini 2001). In addition, it is not known whether the bimanual configuration used when knapping has an effect on the hammerstone trajectory; this is explored in section 3.3.2.2 of Chapter 3.

2.2.1.2.3. lateralised resharpening and Tranchet flakes

Cornford (1986) describes evidence of handedness from asymmetrically retouched tools. This asymmetry can be due to lateralised use, making it necessary to retouch the more worn side of the tool, or simply from constraints in knapping when holding the piece. This latter assumption is the basis of Cornford's (1986) argument about flakes resulting from a *coup de tranchet*. The site of La Cotte de St. Brelade (Jersey) has a long stratigraphy spanning the last two interglacials (from 240 kya to 122 kya). These scrapers possess a burin plan, which is termed a longitudinally struck flake (LSF), along the working edge which "creates a new edge of the greatest possible length and sharpness on the parent tool" (*ibid.*:337). Cornford argues that the hand used is constrained by the holding position when knapping because the knappers preferred to remove LSFs from the same edge as the gripped edge (*ibid.*:344, 350); Cornford's replication experiments showed that an experimental knapper was unable to make LSFs on another edge (p.345). Secton 4.5.1 in Chapter 4 explores the validity of this methodology.

The interpretation of the knapper's handedness is based on an underlying assumption about biomechanical constraints on holding positions when knapping the long and transverse sharpening flakes. Cornford (1986) noted that most of the LSFs at the site were removed from the same corner of the tool, regardless of the tool's orientation. This is illustrated in Figure 2.3. Cornford's replication experiment showed that a right-handed knapper was unable to make LSFs when striking on the opposite edge, meaning that the removal location chosen by the La Cotte knappers was the preferred one for a right-handed knapper. Out of 1302 unbroken LSFs, 79% were removed from the right distal end of the dorsal or ventral surface and from the left proximal end of the dorsal surface. However, by far the most frequent removal location was the distal right end of the dorsal surface (leftmost image in Figure 2.3), accounting for just over 50% of the assemblage. All of these removal locations are achieved with the same holding position. The proportion of 79% is taken as representing a right-handed preference among the population of Neanderthal knappers at the site (*ibid.*).

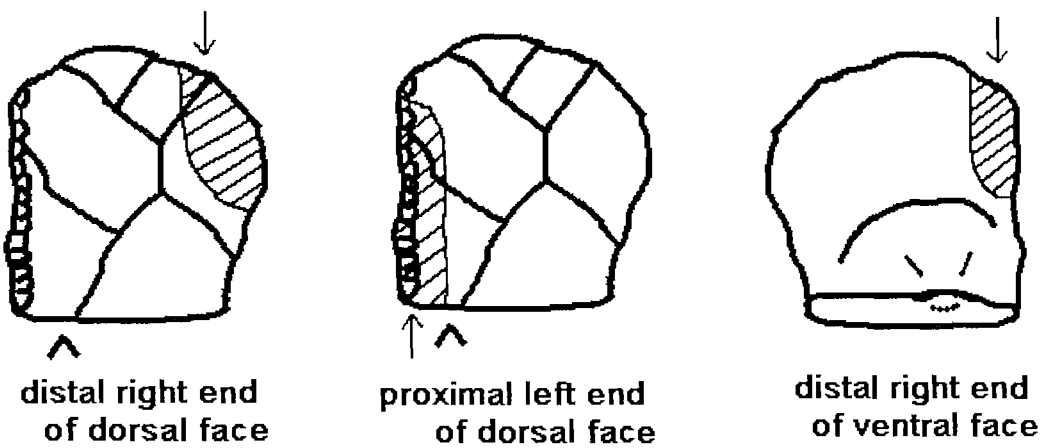


Figure 2.3. Preferred removal locations for Long Sharpening Flakes, shown on a schematic scraper. Striped area shows future negative (flake scar) of LSF to be removed in the direction of the arrow.

Cornford (1986) proposes a slightly different argument for transverse sharpening flakes (TSFs). The biomechanical constraints for TSFs are different from LSFs. These can be struck with a blow that is either perpendicular to the edge of the tool, or oblique to it. A perpendicular blow results in the TSF showing its point of percussion located at the centre of the butt. An oblique blow results in a point of percussion located at one end of the TSF's butt. This shift can be achieved by changing the relative positions of the tool edge and the striking arm (Figure 2.4). Combined with the holding constraint that the struck edge must be opposite to the gripped edge, this leads to Cornford's interpretation that a point of percussion located at the right end of the butt represents a right-hander's knapping, and vice versa. Out of 288 TSFs, about 53% were struck with an oblique right-handed angle, 32% with a perpendicular angle, and 15% with an oblique left-handed angle (*ibid.*).

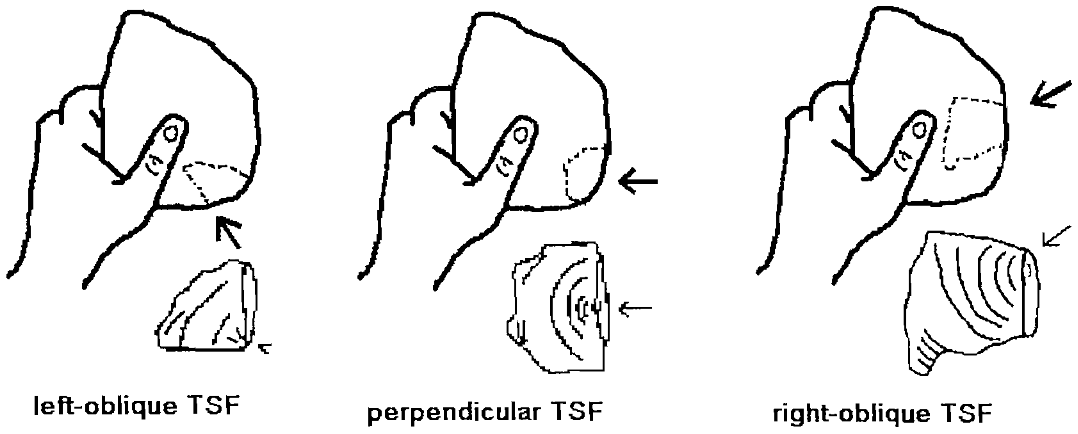


Figure 2.4. Possible hand configurations for knapping Transverse Sharpening Flakes, and resulting TSFs, shown on a schematic parent tool. Dotted line shows future TSF located on the underside of the parent tool. After Cornford (1986).

Regarding the group level, in this assemblage the number of individuals is unknown, so the same caution about multiple flake analyses applies as for the Koobi Fora and Caddington flakes; in other words, we must not extrapolate numbers of people from the numbers of flakes at any given site.

As is detailed in section 4.3 of Chapter 4, a new methodology similar to Cornford's was applied to the tranchet flakes and handaxes from High Lodge and Boxgrove. For the analysis of these two sites, a simple count of right- and left-sided tranchet flakes and negatives led to a computation of their ratio in the assemblage. In this research no attempts to estimate the ratios of right- and left-handed knappers are made, but a future calculation could be envisaged, based on the appropriate kinds of experiments, that would take into account the number of flakes produced by each knapper and the time span within the assemblage in order to estimate numbers of individuals.

The Boxgrove assemblage consists of artefacts from sites with different degrees of temporal and spatial resolution (Pope 2002). Given that many of the handaxes share features suggestive of individual knapping styles (M. Roberts, pers. comm. 2005, and personal observation 2005), it is likely that some of the Boxgrove knappers made more than one handaxe. However, there has not yet been a formal study to estimate the number of knappers at Boxgrove. In addition, we do not know what kind of cultural constraints or mental templates existed which might have imposed asymmetrical flaking (J. Pelegrin, pers. comm. 2003), or how biface use determined which edge needed resharpening. Therefore it is impossible at this point to make any statement about the number of right- and left-handed knappers at these sites.

2.2.2. USE

Because lithic tools can be used by more than one person in their life history, their traceological record contains a sum of usage over time. Therefore they cannot give information about individual hand use, but only show which hand the majority of users preferred, obscuring the traces from minorities. The S.E.M. approach is widespread now in functional analysis, but unfortunately nobody is applying it to study handedness. Yet it contains enough detailed information that the precise trajectories of hand gestures can be reconstructed (Fritz *et al* 1993; Bello & Soligo 2005).

2.2.2.1. Unimanual

These publications are those that assumed the wear-traces were produced by the action of one hand, in other words that a given tool could only be held in one hand (which is probably true for any given instant, C. Rodríguez, pers. comm. 2006). They are Frame (1986), Keeley (1977), Phillipson (1997), Posnansky (1959), de Mortillet (1883), and Black *et al* (1933).

2.2.2.1.1. La Cotte use-wear

The La Cotte artefacts were examined for microscopic use-wear traces to determine handedness by another technique. Frame (1986, in the Cornford volume) inspected the striation orientation and bands of polish from working wood, hide, or other materials on *tranchet* sharpening flakes. Of 18 right-asymmetrical sharpening flakes, 4 had oblique rightward marks, 1 left, and the remainder either perpendicular, parallel, or multidirectional. Of 4 left-asymmetrical flakes, 2 had traces of moving leftward, 1 perpendicular, and 1 multidirectional. Frame reasons that these marks, in relation to the working edge indicating the direction of tool use, showed they were preferentially used by right-handers. This conclusion only holds if we assume that one flake was used only by one person, or that each flake was only used in one direction.

2.2.2.1.2. Clacton

Keeley (1977) describes a biface from Clacton, UK (Lower Palaeolithic) with microscopic use-wear showing it was used with a vertical rotating motion, such as boring holes, in a clockwise direction. Keeley's argument implies that greater torque forces are exerted during wrist supination (clockwise for a right-hander) than pronation. The mode of prehension is not specified, but a tool being vertically rotated can be held either with the elbow up and palm facing outward (screwdriver grip), or with the elbow down and palm inward (stabbing grip). This presupposes that whatever the grip on the tool, people grind in a direction outward from the centre. In a screwdriver grip, the wrist must produce mainly supinating forces, while grinding with a stabbing grip, the wrist produces mainly extensor forces. Both of these could reflect a preference to supinating/extension rather than pronation/flexion (which would be the forces required if the grinding motion went inward). Cahen *et al* (1979) confirm this constraint:

> "Although a back-and-forth turning of the borer is efficient when the borer is hand-held, the outward turn of the wrist is more powerful. Experimental observations have shown that the return stroke in the weaker, inward direction is usually accompanied by a slackening of the vertical pressure."
> (Cahen *et al* 1979:668)

In other words, boring is usually done with a back-and-forth motion, but the outward stroke produces the bulk of the striations. In addition, microwear polish and edge damage indicate the principal direction of turning: "Generally speaking, microwear polish forms on the aspect of edge ridges and projections facing toward the principal direction of turning, while utilization damage is created most heavily (sometimes only) on the aspect facing away" (Cahen *et al* 1979:681).

Unfortunately, because Keeley's report only concerns one Clactonian biface, nothing can be said about group-level handedness, unless it can be established that all the members of the group used just that single biface.

2.2.2.1.3. Kariandusi

Phillipson (1997) made reconstructions of biface grip types, taking into account different kinds of butchering gestures such as vertical chopping, scraping, cutting, digging, and scooping. Her experiments revealed biomechanical efficiency in biface use; constraints of use involve the efficient exertion of force and resistance of finger and hand muscles, for example:

> "A line of force from the working edge through the central mass of the tool to the base of the palm of the hand, for example, permits steady pressure to be applied

> while the fingers are partially freed to rotate the tool in subtle scooping, twisting or scraping motions. A grasp in which the handaxe is compressed between the tips of the fingers and the palm of the hand is needed to prevent loss of control when it is used for heavy cutting or sawing in a direction parallel to the utilized edge. The shock of chopping or digging motions is best absorbed by the front of the palm of the hand or the base of the fingers, although a posture with the fingers well spread and the force falling somewhat further forward is also effective." (Phillipson 1997:174)

Drawing on these experiments, Phillipson scrutinised 54 handaxes and cleavers recovered by a 1931 L.S.B. Leakey excavation in Kenya, with a stratigraphy dated to about 1 mya. Starting from the premise that the trailing face, not the leading face, of a used edge, would show greater signs of use, Phillipson reconstructed possible grip types for each piece. Of 54 tools, 6 (11%) could be assigned to probable left-hand use, 45 to the right-hand, and 3 were indeterminate. The high proportion of right-handed bifaces in this assemblage suggests a minority of left-handers among the population of tool users, without assuming that one tool belonged to one person. The sum of all use-wear traces is simply taken to represent the sum of all people's tool usage.

2.2.2.1.4. subjective assessment: fit in the hand

A number of early archaeologists involved in excavations have observed that certain tools fit better in the right or left hand. Nowadays archaeologists refrain from making such comments because they are seen as unscientific, but in the last century they were acceptable. For example, Gabriel de Mortillet (1883) found that most "hand-stones" of "very early tribes" found in the Somme gravels were made for right-hand use. Other right-hand supporting declarations were also made by Black *et al* (1933) about the Zhoukoudian artefacts in China (dated to 800-600 kya), and by Rust (1973/4) and Montagu (1976).

Such subjective observations were based on an intuitive supposition of how to hold the tool, because the grips, purposes, and manners of tool use were not known. Nonetheless, it is interesting that separate researchers have made similar judgements of material from vastly distant sites both in time and space. These early assertions are therefore worth including in this review and may be worth revisiting in the future, especially now that the methods of gripping and using tools are becoming better-known. Semenov's (1964) volume is a good example of the level of detail that can be obtained in a study of use-wear in order to specify the precise kinds of hand configuration that were used to grip tools during their use. Also, recent papers (Takeoka 1991; Phillipson 1997; Posnansky 1959) do take grip position into account, showing that it is possible to include such observations in serious research. Furthermore, two handaxes in the Boxgrove Q1B tranchet-biface assemblage were encountered that restrict usage to one hand, assuming a grip in which the biface tip is the active part: one handaxe has a depression in one face for the right thumb (Q1B #2768), and the other handaxe has edge features that make it impossible to wield with the left hand (Q1B #3507) However, the symmetry of most handaxes means that they can be held equally comfortably in either hand, which would therefore tell us nothing about hand preference, even if we knew the manner of gripping them.

They are reminiscent of Phillipson's (1997) observations that an asymmetrical weight distribution on the tool can facilitate use:

> "a hand-hold was provided by a retained area of the original cortex or a flake striking platform on an otherwise bifacially worked specimen. In most instances this more rounded area was associated with an asymmetric bulge on one or both faces of the handaxe which fit comfortably into the concavity of the user's grasp and greatly facilitated the controlled manipulation of the tool."
> Phillipson (1997:174)

This latter statement by Phillipson in the 1990s, like Posnansky's (1959) below, is an excellent example of how to reconcile the 19th-century subjective observations mentioned above with the rigorous scientific approach preferred today. A similar observation on the use-constraining effects of asymmetrical weight distribution in the artefact was made by Posnansky (1959), in studying a collection of Early to Middle Acheulean handaxes from the Trent Valley, UK and 118 handaxes from the Furze Platt site, UK. He states "it is found that the displacement of the weight away from the cutting edge, which a non-central median ridge implies, increases the efficiency for cutting" (Posnansky 1959:42). Like Phillipson, Posnansky tested the handaxes for ease of use in either hand, assuming a cutting function. Specifically, "the most efficient method of cutting is one in which the butt of the tool is held in the palm of the hand with the fingers splayed around the blunter of the two edges and the flat face of the tool faces the inner cut face" (Posnansky 1959:43). Of 40 complete tools in the Turton collection, 35% were found to better accommodate the right hand, 12.5% the left hand, and 52.5% either hand. Two independent observers were reported to have found similar proportions, assigning respective proportions to the same handaxes of 37.5%-15%-47.5% and 22.5%-10%-67.5%.

2.2.2.2. Bimanual

Only two sets of authors have considered the coordinated action of both hands. These are Semenov (1964) and Bermúdez de Castro *et al* (1988). To complement these, data from Fox & Frayer (1997) and Roberts & Parfitt (1999) are included.

2.2.2.2.1. Semenov's data: scrapers

Semenov (1964) combined biomechanics with experimentation to identify right-handed wear on Upper Palaeolithic hand-held end-scrapers. These data are mentioned here despite their recent age, because the outstanding cross-disciplinary work of Semenov provided the model for the approach used in this dissertation. In his volume on use-wear, Semenov describes the mechanism for asymmetrical scraper wear. The scrapers were used on hide, without handles, simply held in the hand (Figure 2.5). Because the tool is held with its axis at an angle of 75-80 degrees to the skin surface (Gunn 1975 finds an optimal working angle of 70° for burins), by implication, there is a constraint on simultaneous abduction of the upper arm and pronation of the wrist/forearm, when orienting the tool-using hand perpendicular to the surface being worked. This implies that force is more efficiently exerted when the arm is less abducted and the forearm less pronated. Semenov counted that about 80 % of end-scrapers are worn on the right side (assuming the tools were used moving frontally with the ventral face forward). His data include Russian (Kostenki 1, Timonovka, Mezin, Suponevo, Sakajia) combined with other Upper Palaeolithic sites. Once again, the high proportion of right-handed use indicates a right-handed bias, either synchronically or diachronically, but the data give no information about individuals and groups.

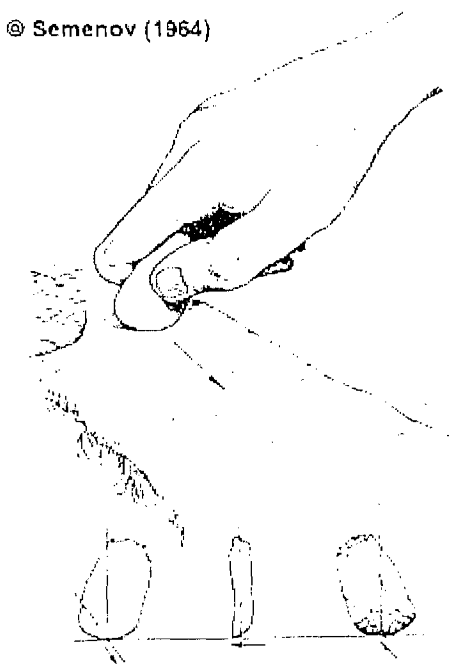


Figure 2.5. Reconstructed working angle for scrapers. From Semenov (1964:88).

2.2.2.2.2. Semenov's retouchers

Further evidence comes from the use of bone retouchers (Semenov 1964:173). The artefacts come from Middle Palaeolithic (Kiik-Koba and Teshik-Tash) to Upper Palaeolithic (Kostenki 1) sites in Russia, dated to 37-34 kya. Semenov indicates dents on the convex side of bone retouchers which met at an angle of 75-85 degrees to the long axis, suggesting these retouchers were used by right-handers. Figure 2.6 illustrates this bimanual configuration. Because the traces occur clearly oriented in one direction, we can infer that each tool was only used by one person or by several people using the same orientation.

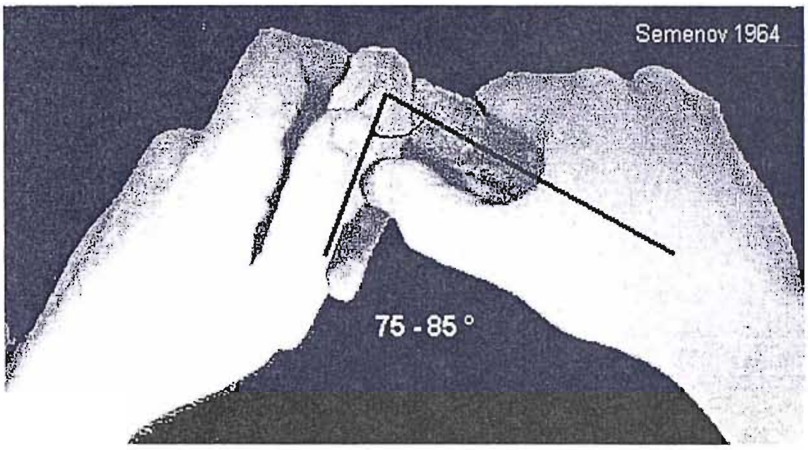


Figure 2.6. Holding position for retouching flint with bone. After Semenov (1964:177).

2.2.2.2.3. dental use-wear

The traces left on the body are one direct way to determine handedness in individuals. Of the many behaviours that can produce lateralised traces, cut-marks on teeth are caused directly by artefacts. The characteristic striations found on Neanderthal and *Homo heidelbergensis* people's teeth can be attributed to stone artefacts and, presuming they were self-inflicted, they bear directly on the hand usage of the individual over his/her lifetime. A valuable reference for this bimanual behaviour is ethnographic observations. Semenov subscribed to the hypothesis that Neanderthals ate meat by holding it between their teeth and cutting off pieces with a knife, because he had personally observed this practice in Russia (Semenov 1964):

> "Generally pastoral or hunting people (like the nomads of Mongolia, Tibet, Abysinnia and other countries) eat such meat with a knife in one hand. Meat is normally cut into strips, and baked or cured in this form. Then each person takes a piece and, holding one end in his teeth, cuts it free with a quick movement of the knife at his mouth, repeating the operation until the whole strip has been consumed. The cutting is done upwards from below. We have seen this done among Nenetz reindeer herdsmen in the Kanin peninsula in 1928."
> (Semenov 1964:104)

This practice exists in many parts of the world, and it appears that the common pattern among living people is to hold the meat with the left hand and the knife in the right hand. This division is mentioned in all of the references that specify hand roles. The following eight quotes are drawn from the e-HRAF archive (Human Relations Area Files at Yale University). Their geographical distribution is shown in Figure 2.7.

1. Koryak, Kamchatka (Jochelson 1908:575)

> The women serve cooked meat in the inner tent. After it has been cut into pieces, it is placed on boards, wooden platters, or troughs. The Koryak take hold of a chunk of meat with the left hand, and, holding it with their teeth, cut off a mouthful with a knife held in the right, cutting from below upward. All Siberian natives eat meat in the same manner.

2. Copper Inuit, Canada (Pryde 1972:142)

> Dinner, then, consisted of a barely warm piece of meat. If it was seal flippers, they still had the hair on them. Each diner had his own knife, usually just a pocket knife, and rather than cutting meat on the plate, would take the whole piece of meat into his mouth, grip it with his teeth and cut off a bite.

3. Kalahari, S. Africa (Fourie 1928:100)

> ...some of the meat for the men is also cooked. As soon as the latter is ready for eating the gei-khoib removes a piece from the pot and "tastes" (tsā-tsā) it. This is done by holding it between the teeth and fingers and cutting off and eating a morsel or two.

4. Amhara, Ethiopia (Messing 1985:63)

> Iron knives are used at dinner time only at a feast of brindo, raw beef. In former times, and even today, men can be seen cutting off a morsel just in front of the teeth. But women rarely do so, and the meat is usually pre-cut.

5. Somali (Burton 1856:98)

> ...in the left hand they held the meat to their teeth, and cut off the slice in possession with long daggers perilously close, were their noses longer and their mouths less obtrusive.

6. Blackfoot, USA (Lancaster 1966:276)

> The Chief and Agnes Morning Gun ate the moose meat in the old Indian fashion, holding a piece in the hand, clamping the teeth over a portion of it, and cutting the portion off close before the lips with a sharp knife. Joe, who has no teeth but is very handsome for all that, ate very fastidiously with a knife and fork.

7. Navajo, USA (Bailey 1942:210-11)

> Eating: Eating is done daintily and slowly. Small pieces of meat are cut from the larger one with a knife. Sometimes the meat is grasped with the teeth and the left hand and cut off close to the mouth with a knife, cutting toward the face. Sometimes the piece desired is held in the fingers and severed from the main portion with the knife moving away from the body.

8. Bakairí, Brazil (Steinen 1894:608)

> There was, of course, no longer anything to be seen of stone axes and cutting fish teeth; axes and knives were present in abundance. But all kinds of things from the old days were still to be observed. For instance, the Bororó, when they ate, cut off pieces of meat in front of their mouths with bamboo splinters.

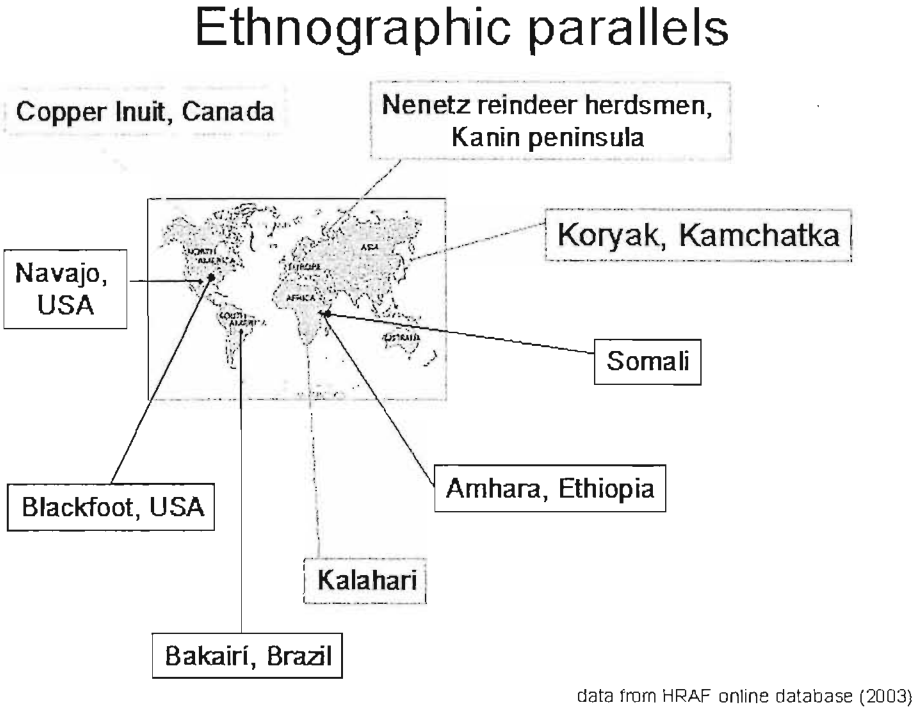


Figure 2.7. Documented ethnographic examples of cutting meat held in between the teeth.

Three archaeological studies have examined the marks left on hominins' anterior dentition, with the assumption that they were caused by this practice of cutting meat with stone flakes. If one dislikes the idea of using the teeth as tools (e.g. Bax & Ungar 1999), there is also the interesting possibility that these marks were made by chipping flint with the teeth, an action which has been observed in 1963 by Hester (1973:23) in Plains Indians (Comanche, Apache, and Omaha, USA): "...sharpening old flint arrowheads by biting with their teeth against the edge, thus breaking off small particles" and Australian Aborigines (Hester 1973), and also in Papua New Guinea: "A worker produces a sharp edge on a bamboo knife by using his teeth to detach a splinter from the side of the knife" (Pospisil 1963:279). This practice can be identified archaeologically in the form of obsidian microflakes present in human coprolites (Hester 1973), although no experimental references were found to test this connection.

Bermúdez de Castro *et al* (1988) experimentally replicated such striations in order to determine the best way to move the hands. A prognathic mouth-guard with fake enamel Neanderthal teeth was worn by a right-hander. The experimental procedure involved holding a piece of meat between the front teeth and cutting off bite-sized pieces with flint flakes. The experimenter made striation patterns consistent with a right-handed downward motion from left to right (when viewed from the front), as in Figure 2.8. The authors state that "in the experimental study, the action that would produce striations consistent with a right-handed operator cutting leftwards was uncomfortable and felt less efficient" (*ibid.*:410). This implies that it would be equally uncomfortable and inefficient for a left-hander to cut rightwards. The inefficiency of the right-handed leftward motion implies a constraint on simultaneous pronation at the wrist and extension of the forearm. A right-hander cutting from below (as described by Semenov) would produce the same pattern moving upwards from right to left, consistent with a right-hander cutting rightward from above, so it is not necessary to distinguish between an upward and downward cutting motion.

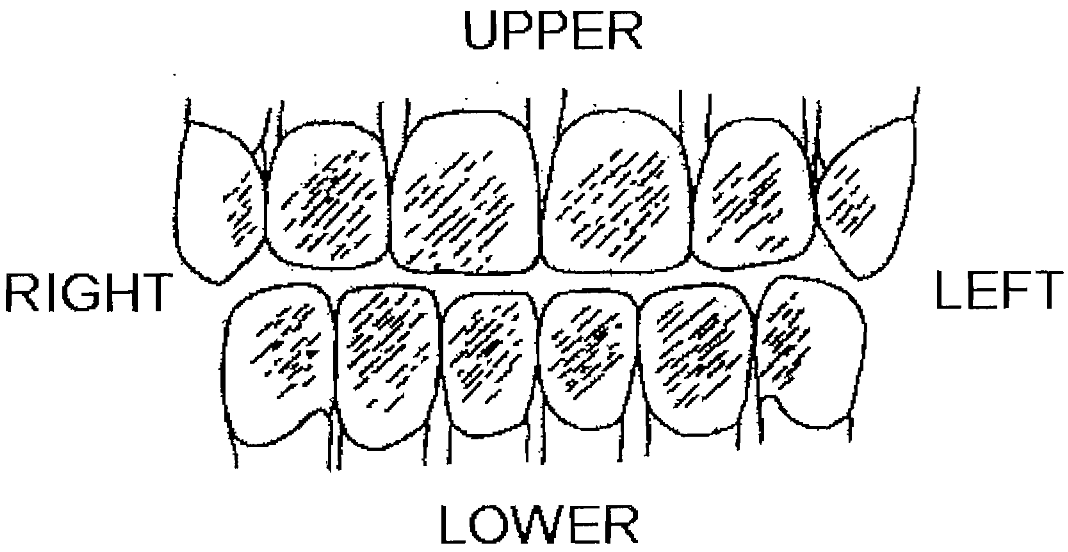


Figure 2.8. Diagram of right-handed striations. From Bermúdez de Castro *et al* (1988).

The striations occur on *Homo heidelbergensis* individuals from the Sima de los Huesos site, Atapuerca, Spain (19 teeth, assigned to four individuals and 10 unassigned teeth), two teeth from the La Quina 5 Neanderthal (France), one isolated tooth from Cova Negra (Spain), several anterior teeth from five individuals at Hortus (France), and single isolated teeth from Saint Brais (Switzerland), Angles-sur-l'Anglin (France), and two teeth from the buried Shanidar 2 Neanderthal (Iraq). All but two of these fossil samples show striations oriented downward to the right. Angles has horizontal marks. The teeth from Hortus VIII have inversely oriented striations, suggesting this individual was a left-hander (Bermúdez de Castro *et al* 1988). Fox & Frayer (1997) found that among the teeth of 13 Krapina Neanderthals, six of the individuals have rightward striations, with one showing the opposite pattern. The remaining six individuals showed no predominant pattern. Further evidence comes from the two *H. heidelbergensis* anterior lower teeth from Boxgrove, UK which were adjacent on the mandible. These also show the right-handed pattern (Pitts & Roberts 1997:265; drawings, photographs and S.E.M. images can be found in Roberts & Parfitt 1999).

In total, these three studies total only 2 left-handed hominins for 19 right-handers. The number of individuals of unknown or indeterminate handedness is 7 in these studies, but might assume that the proportion of right to left (10.5 %) is roughly similar in the indeterminate samples as in the known population.

2.3. Summary of the hard evidence

The review of literature in this chapter favours the approach of Semenov, who was the first and most important scientist to show the potential of combining experiments, use-wear, and ethnography to study handedness. The history of publications about prehistoric handedness stretches back to the 19th century, yet very little interest is found among present-day archaeologists. Nonetheless, there is a vast amount of untapped information in S.E.M., experiments on knapping and use-wear, and from courageous experimenters who try things like flaking with their teeth.

To summarise the published fossil and archaeological data for handedness in the Lower Palaeolithic (Figure 2.9), the evidence from individuals (consisting of the dental striations, and knapping scatters) clearly shows higher proportions of right-handers than left-handers. Specifically, the bimanual role differentiation that is expected for right-handers according to Guiard's (1987) Kinematic Chain model is supported by the data. Namely, the left hand tends to act in a supporting role while the right hand manipulates objects. These apply to both the bimanual-use and unimanual-use categories, where the right hand is preferred for one-handed actions, as exemplified by the strong right-arm bias in the skeletal material.

The data from tools and flakes, and the small number of left-biased skeletons, also reveal that left-handed lithic production and use are at most a minority. It is unclear whether these represent actual proportions of people, or simply that right-handed hominins were the ones who knapped, or if the left-handers knapped right-handed (e.g. L. Hurcombe, pers. comm. 2004). More contemporaneous sites from other parts of the world are urgently needed for comparison. Also needed are data from earlier sites and from other species of hominins in order to study changes in proportions over time.

- In all cases, there are no archaeological data that indicate a preponderance of left-handed production or use.

As mentioned throughout this chapter, the interpretations of handedness in these studies are based on assumptions of biomechanical constraints. The experiments in Chapter 3 aimed to validate some of these assumptions using actualistic research. In particular, three of the most relevant potential markers of handedness in the Lower Palaeolithic were tested: the skewed cone of percussion method, single-platform core rotation, and tranchet flake production.

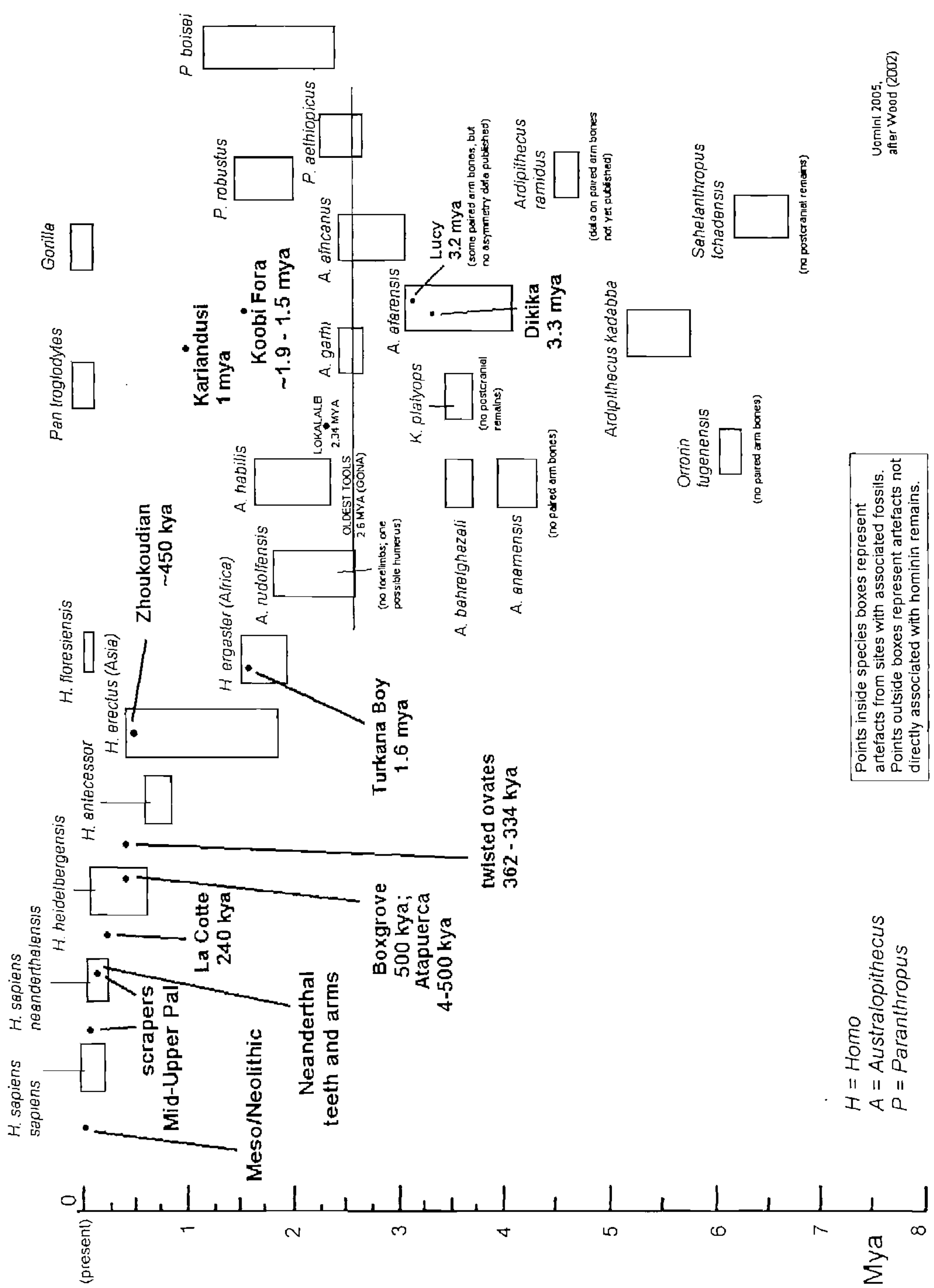


Figure 2.9. Summary of hominin timeline with hard evidence.

Chapter 3. Experimental validation of laterality recognition criteria in lithic production

3.1. Introduction

This chapter aims to confirm experimentally some of the recognition criteria proposed for right- and left-handed knappers in the Lower Palaeolithic that were reviewed in Chapter 2. Detailed video, lithic, and interview analyses explore the factors that may bear on hand choice, as seen in the bimanual configurations used during direct percussion. Three hypothesised markers of handedness in lithic production, isolated from the previous chapter, were tested with knapping experiments. First, Toth's (1985) flake scar method was tested because its validation would endorse the earliest evidence for right-handedness in the archaeological record. Second, the Cone of Percussion method of Rugg & Mullane (2001) was tested because it represents a method that can potentially be applied to Pliocene stone flakes. Finally, the methodology of Cornford (1986) using flakes and flake scars from resharpening was selected because it is applied to a sample of British handaxes (Chapter 4). The experiments were conducted in parallel with the artefact analyses, in between two bouts of lithic data collection. This makes the experimental validation of the Cornford methodology particularly relevant to the new artefact methodology described in the next chapter.

3.1.1. Background

Modern-day stone knappers (experimental, not ethnographic) in the Western world have generally learned to knap on their own, with another knapper, or in a group setting. In the course of their lifetime, as they gain increasing knapping experience, they tend to develop their own preferences. These preferences can be defined as idiosyncracies (Gunn 1975) which do not affect the overall shape or function of the finished products in a one-to-one manner. In other words, in theory their choice should not restrict the knapper to producing a certain kind of object, and the finished products should not show evidence of these choices. Expressed simply, idiosyncracies reveal the many ways of achieving the same goal. However, on a finer level of analysis, the knapper's 'idial style' can appear (Gunn 1975).

These idiosyncracies can be observed in any (or a combination) of the following: the tools they own and use, the raw materials they like to knap, the types of objects they produce, the techniques and methods they use to produce them, the kind of protection they use, the way they sit or stand, and the position of the arms and hands relative to the legs. A compilation of some proposed possibilities for these variables is presented in Table 3.1, based on my personal experience.

The markers of handedness that were reviewed in the previous chapter are based on biomechanical assumptions that all revolve around the trajectory of the knapping arm. This trajectory is in turn determined by the knapper's bimanual configuration for flaking. By implication, the effects of handedness on knapping products are directly related to the knapping configurations and postures used.

The last variable in Table 3.1 (bimanual configurations), in terms of direct hard-hammer percussion, is the focus of the present study, as it is hypothesised that there is a very wide range of variation postures which has never been studied in detail. Ethnographic studies by Hewes (1957), Desrosiers (1997) and Stout (2002) have begun to chart the existing variation in sitting and knapping postures. Callahan (pers. comm. 2005) has been compiling a list of knapping techniques, and Olausson (1998) has studied the uniqueness of knapping gestures in relation to ability levels. The early work by Gunn (1975) showed that individuals can be distinguished from flake scar patterns. Ploux (1989, 1991) devised a system for identifying individual knappers. The bimanual nature of lithic production is of particular interest for the model discussed in this dissertation, since knapping requires a pattern of complementary role differentiation.

A thorough examination of the bimanual knapping configuration is in order, since several of the other variables listed in Table 3.1 do in fact show effects of handedness, as reviewed in the previous chapter. Debitage scatters are for example highly handedness-specific (Desrosiers 1997). It is also established that the tools used for knapping leave clear, specific attributes on the flakes produced (Pelegrin 1986). The three markers chosen for the experiments are especially important in the search for data that can indicate handedness in the earliest stone knappers, with a particular focus on lithic production. It is important to study flakes in particular because they are the most abundant and widespread data source for prehistoric lithic production. Furthermore, stone flakes are often found in isolation archaeologically; in these situations they give little information about production methods, so the only recourse is to techniques, of which hand-use is one. If a methodology can be developed to extract handedness information from isolated flakes found outside their production or and/or use context, it will be valuable for the majority of the archaeological record.

Although many of the potential handedness features on flakes reviewed in Chapter 2 have been identified based on replication experiments, only one of these experimental studies was applied archaeologically (Toth 1985). Furthermore, the Toth method is the only one to have been followed up; these have found conflicting support for the assumption underlying the Toth method. For example, two independent follow-up studies (Patterson & Sollberger 1986; Pobiner 1999) found that the order of single-platform removals was dictated by the shape of the core, while only one study (Ludwig & Harris 1994) was able to replicate the core rotation pattern in which people rotated the core with the wrist turning inward (clockwise for right-handers and anticlockwise for left-handers). The Core Rotation experiment was designed to explore this issue in detail by filming the single-platform knapping sequences to see whether people do indeed rotate the core in a single clockwise direction. In addition, the dorsal cortex pattern on the flakes was compared with the predicted values based on the core rotation direction. These could then be contrasted with the Toth (1985) predictions.

The Cone of Percussion experiment was designed to supplement the original Rugg & Mullane (2001) experiment by adding the use of video to check for skew in the arm trajectories. These authors' hypothesis was that the knapping arm is slightly biased to one side because the knapping gesture tends to be directed toward oneself. The video study was intended to examine the knapping gesture and verify to what extent the toward-self direction was universal.

Finally, the hypothesis underlying the new methodology that is applied to the archaeological case study (Chapter 4) was tested. The assumption is that knapping a *coup du tranchet* on a biface requires a specific hand configuration that is constrained by handedness. The Tranchet experiment was designed to explore these constraints by recording the hand configurations that are used when knapping tranchet flakes. It was expected that this would lead to a characterisation of tranchet knapping similar to that of sharpening flakes by Cornford (1986).

Variable	Possible variations (presence / absence of any or all)
Tools owned and used	Hammerstones – differing in hardness, shape, weight, and raw material Soft hammers – antler, bone, wood Punches – antler, bone, copper Pressure flakers – antler, copper, Ishi sticks
Raw materials worked	Stone – flint, quartzite, obsidian, basalt, etc. Bone Petrified wood Ivory Beer bottle glass
Types of objects produced	Flakes Handaxes Scrapers Levallois products Blades Microliths Arrowheads Artistic objects (e.g. Maya excentrics; jewellery, etc.) etc.
Techniques of production	Direct percussion Inverse direct percussion (Callahan's "block-on-block") Anvil (bipolar, e.g. Isernia) Indirect percussion (with a punch, either of antler or bone) Inverse indirect percussion (e.g. Roux's Cambay knappers) Pressure flaking setups – against the stomach, against the ground, with levers... Throwing (e.g. Kanzi)
Methods of production	Alternate flaking Single-platform flaking Levallois Stages of roughing out, preforming, and thinning Resharpening (e.g. tranchet) etc.
Protection	Goggles and/or glasses Gloves Thigh pad Palm pad Piece of material for crotch and/or leg protection – hide, cloth Shoes Ground protection to keep ground clean and/or collect debitage – plastic tarp, cloth, hide
Body support (cf. Desrosiers; Stout)	Standing Sitting – on ground, on a stool / chair / log Crouching (e.g. Stout's Langda knappers) Kneeling – on one or both knees
Bimanual configuration (cf. Callahan)	Core in unsupported hand (freehand) Core in hand with elbow supported by leg Core against thigh – on outside / inside of ipsilateral / contralateral leg (4 possible combinations, + 2 on top of thigh) ----------------------------(other configurations, not bimanually differentiated) Core held between feet Core on ground or on wooden anvil (e.g. Langda) Core thrown (e.g. Kanzi; Langda) Core held in support (e.g. for pressure blades)

Table 3.1. Some variants of 8 idiosyncracies in modern-day experimental knappers.

3.1.2. Three hypothesised markers of handedness

The aim of the experiments was to test the assumptions underlying three hypotheses for identifying handedness from Lower Palaeolithic lithic production. These are:

(1) the single-platform flaking sequence (Toth 1985),
(2) the trajectory of the hammer arm when making large flakes (Rugg & Mullane 2001),
(3) the holding position for tranchet flake production (based on Cornford 1986).

The video experiment was also intended to collect (4) observational data on the knappers' bodily postures when knapping, with a special focus on their bimanual configuration. In a future stage, these data from "industrialised" archaeological knappers can be compared to the ethnographic data from traditional, subsistence-based knappers synthesised by Desrosiers (1997).

In both experiments, willing knappers were asked to produce two single-platform cores, eight large flakes, and four tranchet flakes on bifaces. The methods of analysing the data are described below in section 3.2.4.

(1) Core Rotation experiment: Subjects were asked to strike flakes from a single platform with no other intention. By giving the subjects a simple instruction to flake from a single platform without attending to the shape of the core, it was hoped this task would reveal whether knappers have a natural tendency to remove each flake to the right of the previous one. Toth (1985) claimed that when making Karari scrapers (the supposed products of the archaeological flakes at Koobi Fora), right-handed knappers tend to rotate the core clockwise in the left hand, thus removing each flake to the right of the previous flake. When the nodule blank is cortical, the struck flakes supposedly retain cortex on half their dorsal surface: the right half if struck to the right of the preceding flake, and left half if to the left. The second experiment repeated the video analysis and added data on the cortical retention of the knapped flakes. For this latter, entirely cortical cores with a platform were provided in order to maximise the possibilities for dorsal cortex to occur on the flakes.

(2) Cone of Percussion experiment: The large flakes provided material to check for differences between right-handed and left-handed knappers, with respect to the hypothesis put forward by Rugg & Mullane (2001). As explained above, these authors suggested this might be due to the trajectory of the hand holding the hammer, in that a blow aimed downwards at 90 degrees to the striking platform can be slightly, unintentionally skewed towards the body. A close

examination of the hammer arm trajectories in the video data, compared with the skew in the cone of percussion in the resulting flakes, was expected to shed some light on this hypothesis.

(3) Tranchet experiment: The tranchet flakes were intended to replicate the archaeological material from Boxgrove (UK) that was begun to be studied by the present author before the experiments. These consist of bifaces with one or two visible tranchet negatives. It was hypothesised that these tranchet flakes should be subject to the same production constraints as those mentioned in Cornford's (1986) study of long and transverse sharpening flakes made on scrapers at La Cotte de St. Brelade (Jersey). In particular, it was hoped that video and interview data could reveal the presence of constraints leading to right- or left-struck tranchet flakes. For example, some knappers believe that the biface should be held with the tip pointing towards the knapper's body in order to properly support the force propagating within the core. Other knappers disagree, preferring to hold the tip away from oneself (N. Toth & K. Schick, pers. comm. 2007). Personal observation suggests that small changes in the position of the core hand and arm make large differences in the orientation of the striking platform with respect to the knapper's visual field and the hammer trajectory (cf. Takeoka 1991).

3.2. METHODS

The first experiment was carried out at the Lejre Historical-Archaeological Research Centre, Denmark for one week in July 2005, as part of a flint workshop in which several other knapping experiments were taking place. The second experiment was done at Southampton University, UK in February and April 2007.

3.2.1. Subjects and materials

The subjects for the first experiment consisted of most of the workshop knappers (n=11), plus one visitor who was recruited on the spot. These are identified in this text by two- or three-letter codes. Because of differing ability levels and time constraints, not all data were collected for all subjects. The subjects of the second experiment were three members of the Archaeology Department at the University of Southampton.

The flint at Lejre was collected by three participants (the author and Steve Watts, led by Soeren Moses) before the workshop, from a private beach several dozen kilometres away on which could be found small to large flint nodules, ranging from hammerstone size up to several kg in weight. The repeated visits by flintknappers has nearly depleted this source of workable-sized nodules. The flint was Danish Danian and Senonian types (as classified by Högberg & Olausson in press). The second experiment in Southampton used English chalk flint from a quarry near Lyme Regis, Dorset.

Figure 3.1. The raw material source in Denmark.

3.2.2. Setup

Subjects at Lejre were filmed and photographed while they knapped, in an informal and spontaneous setting, as shown in Figure 3.2.

Figure 3.2. The author filming a subject (MS) while tourists look on.
Photo J. Chambers.

The knapping subjects only produced what they felt capable of. Only the most experienced knappers attempted to make tranchet flakes on bifaces. These were a new concept for most of the knappers; as examples they were shown drawings of archaeological tranchet bifaces and the concept was explained in terms of its morpho-technical properties.

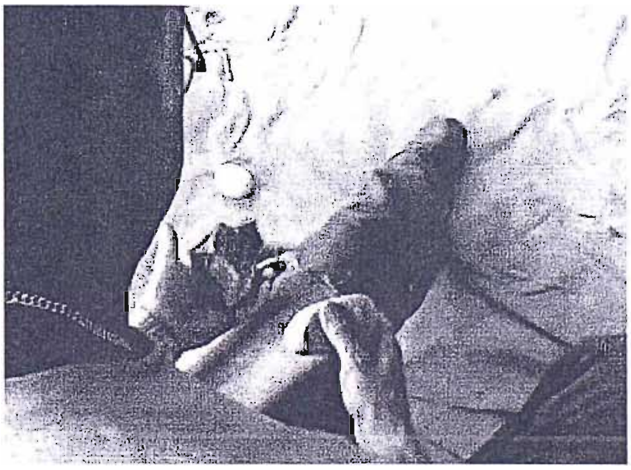


Figure 3.3. Example of knapping filmed over the shoulder of subject JA.

Video sequences were recorded for each knapper producing single-platform cores, Oldowan flakes, and tranchet flakes. Video recording was done with a hand-held mini-DV camera (digital, 12 frames per second). A new way of filming was attempted in order to more accurately represent the knapper's visual input: the camera was held behind and to the side of the knapper's head, aimed over his/her shoulder to get a knapper's-eye view of the object as it was being flaked (Figure 3.3).

3.2.3. Questionnaire

In order to subjectively assess the influences which might have contributed to shaping each knapper's "style", semi-structured interviews were carried out at some point during the experiments. These questions were aimed at recovering the following information:

1. What, when, with whom, where, how did you learn to knap?
2. What were you told to do? *[e.g. how to hold the hammerstone & core]*
3. How has this changed? *[e.g. have you adopted different techniques]*
4. How often do you knap?
5. What, where, with whom do you usually knap?
6. What do you consider your "proficiency level" to be? *[i.e. how confident are you that you can produce XYZ, in the way that you want]*
7. Have you ever taught / do you now teach knapping, or have you written anything about knapping? *[this question, and the next, are aimed at revealing the extent to which declarative and explicit knowledge is involved]*
8. Have you ever / do you discuss knapping with anyone?
9. What is your preferred position for knapping?
10. What do you think of ... *[list alternates to what was answered in question 9]*?

3.2.4. Analyses

Three sets of data from the first experiment were analysed: the interview, the video, and the lithic. Every subject in this study was interviewed. As part of the cataloguing project for the range of variation in bimanual configurations, these latter were described based on the videos and notes taken during the workshop. It was not possible for the author alone to film every knapping event in the time available. As a result, the lithic analysis included both filmed and non-filmed knapped material. The list below summarises the video and lithic data collected per knapper. The second experiment only collected video and lithic data.

Subjects	single-platform cores	direct percussion flakes	tranchet
AH		video	
EC		video & lithic	lithic
EK		video	
FR		video & lithic	
FS	video & lithic	video & lithic	lithic
JA		video & lithic	
JCC (left-hander)	video & lithic	video & lithic	
LG (left-hander)		video	
JM	video & lithic	video & lithic	video & lithic
MDS	video & lithic		
MP		video & photo	
MS	video	video	video & lithic
PW		video & lithic	video & lithic
SM		video	
SW	video & lithic	video & lithic	video & lithic

Table 3.2. Type of data collected per knapper.

3.2.4.1. Video analysis

The three hypothesised markers of handedness, as explained above, are based on assumptions which can be phrased as testable questions:

- Do knappers have a natural tendency to flake anti-clockwise around a single platform?
- Are cones of percussion on flakes skewed because of the hammer-arm trajectory?
- Is the laterality of tranchet flakes constrained by biface holding positions?

The single-platform flaking sequences were recorded by watching each one, frame-by-frame, several times on several different occasions until the precise sequence could be established. Repeatability was assured through this process, meaning that absolute agreement was necessary between successive viewings. The first experiment focussed only on the video sequences, while the second experiment collected the resulting flakes for dorsal cortex analysis. The removal sequence was noted using a graphical notation in which schematic flake scars are numbered on a circle representing the core viewed from the top (platform). Each flake removal is drawn in its position relative to the other scars. The analysis was aided by colour-coding the numbered scars such that each series of unidirectional removals was assigned a different colour.

The Oldowan flaking videos were analysed frame-by-frame. The trajectory of the knapping arm was inferred by overlaying successive still images and drawing a line between the positions of the knapping hand. The orientation of the line relative to the striking platform was then noted.

For the tranchet flaking, the hand configuration can be seen on the video frames. In addition, subjects were asked to explicitly demonstrate their holding position for the tranchet removal. It appears to be salient in their memories, possibly because it is such a specific technique that it may require some degree of conscious reflection (i.e. putting it into declarative or explicit knowledge) on the exact positioning and angles required. Subjects were always able to demonstrate their configurations, either in a static position or with a slow-motion pretend gesture of striking the tranchet, either before they struck an actual tranchet or afterwards. These sequences allow repeatability information through comparison with the actual video stills; the trajectories of the slow-motion gestures are nearly identical to the actual tranchet striking gestures. Holding configurations were noted according to the position and orientation of the biface on the leg (tip towards or away from the knapper; top, side, left or right side of the leg), and the manner of holding the biface (freehand or leg-support, wrist extension or supination, arm support).

3.2.4.2. Lithic analysis

The flint material was studied with the same methodologies as the archaeological assemblages reviewed in Chapter 2:

(1) Core Rotation experiment: In the first experiment, data collection focussed on the flaking sequence as relating to core rotation, shown in the videos. In the second experiment the flakes were analysed according to the Toth (1985) method. This classifies flakes by right-lateral and left-lateral dorsal cortex retention, relative to the flake scar(s) visible on the dorsal surface. The

flake is viewed with its dorsal surface up and platform distal to the observer, in the direction opposite to the standard viewing orientation. Non-lateralised cortical patterns include central cortex (a strip of cortex bounded on both sides by flake scars), upper (cortex proximal and flake scar distal), lower (cortex distal and flake scar proximal), fully cortical, and no cortex.

(2) Cone of Percussion experiment: The direct percussion flakes were measured for cone skew using the same method as in Uomini (2001). In this procedure, the flake is viewed with its ventral face up and the platform distal to the observer. A pencil is aligned horizontally with the striking platform that remains on the butt of the flake and the cone skew is visually assessed according to how the bulb's bisector diverges from the vertical. A cone is classified as right-skewed if it is oriented to the right of the vertical and left-skewed if it is oriented to the left of the vertical. Cone skew was only noted when it was judged to be unquestionably skewed; all others were classified as vertical. In addition, this method was only applied when enough of the platform was present to determine its horizontal alignment.

(3) Tranchet experiment: The tranchet bifaces and flakes were examined applying the same criteria as for the archaeological assemblages in Chapter 4. Biface features analysed were the direction of the tranchet blow, the order of removal of multiple tranchets flakes, and the angle of the tranchet negative's long axis relative to the long axis of the biface. Flake features analysed were the condition of the flake and the direction it was struck from. Each face of the biface is viewed with the tip distal to the observer. The direction of the tranchet blow is indicated by the orientation of the tranchet scar's long axis relative to the long axis (tip to butt) of the biface, combined with the location of the point of percussion seen on the tranchet scar. Scars are classified as left-struck when the point of percussion is on the left edge of the biface tip and the negative extends towards the right edge of the biface; a right-struck scar has the point of percussion on the right edge of the biface and negative oriented towards the left edge. In cases where multiple tranchet negatives occurred on one biface, their relative order of removal was determined through a technological analysis of the biface tip. In particular, this was aided by evidence of one tranchet blow having removed part of another tranchet negative. When the relative removal order could not be determined, each negatives was coded as one of a pair or triplet. The angle was measured with a protractor and yields the angle between the long axis of the piece and the long axis of the tranchet negative. The raw angle is between 0° and 180°, whereas absolute value angles are acute angles between 0° and 90°, obtained through a translation of the raw angles between 90° and 180° into their respective mirror counterparts in the 0° to 90° range (170° is translated into 10°, and so on; cf. section 4.3.1.3.3). This translation was used to facilitate comparison of left-struck and right-struck angles. Flakes are viewed with the bulb distal to the observer. Consistently with the classification of tranchet negatives, flakes are classified as left-struck when the left side of the flake's ventral surface consists of the removed edge of the handaxe.

3.3. RESULTS

3.3.1. Interview analyses

Subject AH, a Swedish male archaeologist, began knapping ten years ago. He learned to knap from Thorbjorn Petersen and from attending knap-ins in Sweden. He claims to have learned his knapping positions by observation, from Thorbjorn Petersen, and from his contacts with other Swedish knappers. He does not teach knapping.

EC is a male from the U.S. who was a self-taught knapper for the first ten years, and changed his style many times over his lifetime. At first he mainly tried to reproduce artefacts from nature and from books, using pressure. His experimentations even led him to knap roofing slates with the bipolar technique. He made himself a thumb/palm pad when he saw a photo of an Indian hand holding a stone point with a thumb pad. He began doing direct percussion in 1966 when he saw a photo of Bordes knapping and when he met the Leakeys in Nairobi. From then on, he made written contact with Bordes, Crabtree, and Mewhinney, made efforts to meet these and other knappers whenever he travelled, and read everything he could find about knapping. He knapped "freehand" for some time, but now no longer does. At the first Primitive Technology conference in Calgary, 1974, he met Crabtree, who was knapping on the outside of his left leg. EC saw the high precision enabled by this position, so adopted it. He also took private knapping lessons with Bordes and Crabtree, who coached him in holding positions, thinning techniques, and Levallois. EC teaches field schools for university students and experiments in all aspects of archaeology. In the 1970s he taught students how to make Oldowan choppers without using language. Then he worked at Pamunkey Indian Reservation to build an Indian village using exclusively stone tools. In 1981 he completed a PhD and first went to Lejre in 1979 for seven months, where he met Hans Ole. In his lifetime he has developed many techniques, including a pressure technique using a curved deer antler, called "backhand", the anvil technique ("block-on-block"), the between-feet position, and the side-underarm position.

EK, a Swedish male, has been knapping for several years and is self-taught. He reports having better control when knapping freehand above the legs. He chooses hammers based on sensorimotor experience rather than theory. He teaches in a classroom for 10-12 year-olds, and does Stone Age demonstrations and pressure flaking. He has invented several direct percussion hammers, including a small stone taped to a flexible rubber tube.

FS, an Irish female archaeologist, first tried to knap without any knowledge. Then in 2001 she undertook a three-month daily knapping training with MS, whom she copied. She had already been knapping on her right leg, and MS showed her how to knap on the inside of the right leg.

She also tried inside the left leg but abandoned this position. She now teaches knapping to university students on a casual basis.

JA is a Swedish male archaeologist who has been knapping since 1993. He learned the theory of angles and platforms from Kjel Knutsson at Upssala University. Then he spent five weeks with EC making daggers, and four weeks in Lejre doing experiments. He knaps once or twice per year, demonstrating to students, and has also made arrowheads for a museum.

JCC, a British female archaeologist and one of two left-handed subjects, began knapping 12 years ago. After one year of self-taught knapping, she took private tuition with John Lord, who is considered the best left-handed knapper in the UK. She claims she always knaps on her right leg, even when knapping right-handed, or knaps between the legs. She now teaches university students to knap, demonstrates, and makes bifaces for archaeology experiments.

LG is a Danish male and left-handed. He began knapping during the week of the workshop, learning from SM, and practised several hours per day. He was told to hold the stone on his right leg. For small objects he holds the core freehand with his core (right) arm resting on his right leg.

MP, an Italian male archaeologist, began knapping with a group in Holland. He attended the workshop every day with EC and produced flake axes. He works at Lejre and demonstrates knapping to visitors. He is not included in the posture analysis because this was not captured on video.

MS is a Danish male archaeologist who started knapping at age 12. His grandfather was a knapper although MS never saw him knap, but he was familiar with his artefact collection. He met SM at age 15 with an intensive knapping workshop for 14 days. This involved imitation only. His knapping was generally aimed at reproducing Mesolithic artefacts. At age 18 and 19 he attended another Lejre workshop with Bo Madsen, mainly to learn indirect percussion. He was working at Lejre when he met Jacques Pelegrin, and watched him produce blades. He teaches students and demonstrates knapping every year.

PW, a Swedish male, first saw Rolf Sundborg, Sweden's best knapper, doing pressure flaking. PW began knapping eight years ago, and attended Thorbjorn Petersen's workshop in 2002 for one week in Copenhagen, where he improved his manufacture of four-sided axes by changing the angle of his left hand. He claims he always knaps between the legs because he feels better control of his aim, except for large roughing-out flakes which are knapped on the outside of his left leg. He now demonstrates knapping.

SM is a self-taught Danish male archaeologist who runs regular knapping workshops for children at Lejre since 1995. Therefore his influence can potentially be seen in many students. He attended EC's first seminars at Lejre in 1979 and 1981, where he learned knapping positions; then he worked at Lejre full-time until 1987.

SW is a U.S. male archaeologist who has been knapping for many years. He reports that he usually knaps between the legs, but often on the outside of his left leg. When his left thigh becomes sore, he moves to the right leg, but he is aware that this changes the angle of his knapping arm. He now teaches primitive skills workshops and organises a yearly aboriginal-style knap-in.

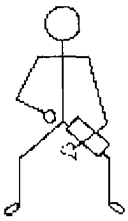
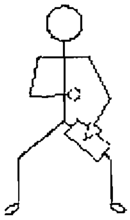
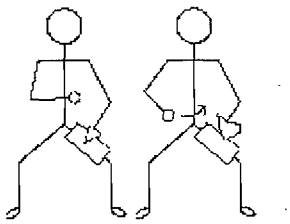
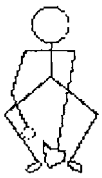
To summarise the interviews, the knappers whose earliest stages were self-taught are EC, EK, JCC, PW, SM, and SW. These knappers made later contacts with other knappers, but always continued to experiment for themselves as well. The knappers who first learned with guidance are AH, FS, JA, LG, MP, and MS. They all developed personal preferences at later stages (LG and MP had just started learning at the time of the workshop and were still under guidance from other knappers).

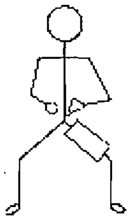
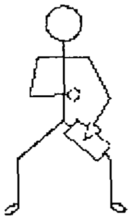
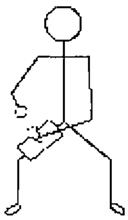
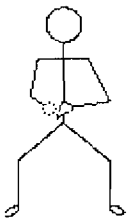
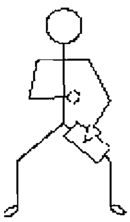
3.3.1.1. Variation in configurations

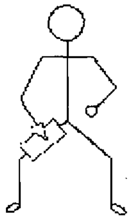
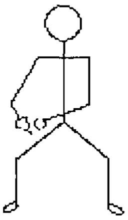
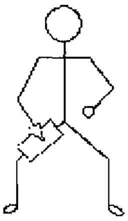
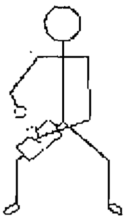
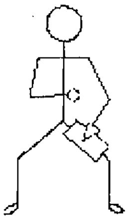
In this section the focus on bimanual configurations is restricted to direct percussion. Postures were given one data point if they were used once by a subject. This analysis is broken down into four descriptive parts:

Body posture - the knapper's seated position including the positions of core and hammer;
Core support - the specific placement of the core on the leg or in the hand;
Flake support - the detachment context of struck flakes;
Visual field - in which hemifield occurs the moment of contact between core and hammer.

Terminology in Table 3.3 refers to terms used in the text. Body postures are shown with diagrams. Core support is described by the location on the leg in the case of leg support, and by the position of the wrist muscles in the case of freehand holding. Flake support refers to 'freefall' if the flakes are allowed to fall to the ground, and 'leg support' or 'finger support' if the flakes are caught by the fingers or sandwiched between leg and core. Following the standard terminology in cognitive science, LVF = Left Visual Field and RVF = Right Visual Field.

Subject (n = 11)	Body posture	Core support	Flake support	Visual field
AH	1. Freehand: rest L elbow on L thigh pad 	1. supinated wrist	1. finger support	1. mid
	 2. rest core on L leg	2a. top of thigh 2b. outside of low knee	2. freefall	2. LVF
EC	1a+b. hold core against pad on L leg 	1. top of thigh	1. freefall	1. LVF
	2. prop core against ground with platform closest to eyes 	2. L hand supports core in place, platform angled forward + downward	2. freefall	2. mid

Subject (n = 11)	Body posture	Core support	Flake support	Visual field
EK	hide across lap 1. freehand, no arm support   2. core on L leg	1. semi-prone wrist 2. top of thigh	1. freefall or fingers in leather 2. leg support	1 & 2. mid
FS	1. core on R leg pad, resting or gripped, L forearm on L leg  2. core against stomach, no arm support 	1. outside of thigh, core resting or supported from below with back of hand resting on thigh 2. wrist midprone, fingers below and distal to core	1. freefall or leg support, pushed or slide off to R 2. finger support	1 & 2. RVF
JA	 core on L leg pad	outside of thigh	leg support	LVF

Subject (n = 11)	Body posture	Core support	Flake support	Visual field
JCC (left-hander)	1. core on R leg pad  2. freehand to R of body, no arm support 	1. top of thigh 2. R hand	1. leg support, pushed off to mid 2. freefall	1. RVF 2. RVF
LG (left-hander)	core on R leg 	top of thigh	leg support	RVF
MS	1. core rest on R leg pad, body twisted to R  2. core on L leg 	1. top of thigh 2. top of thigh	1&2. leg support, pushed off or fall to R	1. RVF 2. mid

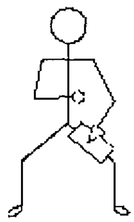
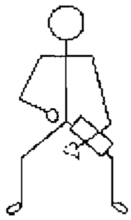
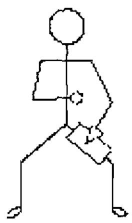
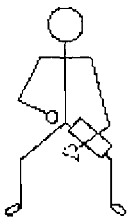
Subject (n = 11)	Body posture	Core support	Flake support	Visual field
PW	 1. core on L leg pad 2. L elbow on L leg, hide across both legs or on L leg 	1. top of thigh 2a. wrist very supinated 2b. wrist midprone, thumb pointing up	1. freefall 2a. finger support 2b. freefall	1, 2a & 2b. mid
SM	legs crossed, L on top, core on L 	outside / near top of thigh	leg support or fall to L	LVF
SW	1. core on L leg pad  2. L arm on L leg 	1. top or outside of thigh 2. wrist midprone	1. leg support 2. freefall	1 & 2. LVF

Table 3.3. Summary of knapping configurations for all subjects during direct percussion.

3.3.1.1.1. Explanation of descriptive features

3.3.1.1.1.1. Body posture

There was little variation in the knappers' seated positions. This was probably because of the freely available log stools provided by the Centre. However, when asked about their seated positions, many subjects remarked that the shortness of these stools was causing them to fold their legs in strange ways to put the cores in the right position for knapping.

SW once knapped sitting on a rock, both legs bent, left knee up (for the single-platform sequence). EC knapped without a stool when using the anvil technique, which involved kneeling on a pad (Figure 3.4).

Figure 3.4. Kneeling position used by EC for inverse direct percussion on anvil.

The most common body posture was to sit on the stool with both knees bent (angle depending on leg length), or sometimes with one leg straight out, and rest the core or the core-arm on one leg (nine knappers used the ipsilateral leg, and two the contralateral leg: FS and her teacher MS). Eight of the 11 knappers were recorded using two different positions during the two studies, and the three subjects with only one recorded position were thus because they only appeared in one video sequence. The most popular position was to support the weight of the core on one leg (observed in all eleven subjects). Four subjects rested their core arm on one leg. This position, called "freehand" by Newcomer (Newcomer & Sieveking 1980), was also used without arm support by two subjects. One knapper, JCC when trying to knap with the wrong hand, rested both the core arm and the hammer arm on one leg each, perhaps to reduce degrees of freedom for this novel task (Steele *et al* 1995).

A typical core-on-leg position is shown in Figure 3.5 and a typical arm-on-leg freehand position is shown in Figure 3.6. Two subjects held the core freehand against their stomach; although EK was not filmed doing this, it is known that FS learned it from EK. One subject supported the core on the ground: EC demonstrating the between-feet flaking technique. This position involves placing the core on the ground, holding it either between the feet or with the left hand. The striking platform is at the uppermost part of the core, facing forward, at a steep angle. The right hand swings from the front towards the body, in between the legs. This technique is quite effective in preventing facial injury from flying flakes, and is useful for very heavy cores that cannot be held on the lap.

3.3.1.1.1.2. Core support

The core could be supported either freehand or on the leg, as mentioned in the previous paragraph. The leg positions are broken down further into specific locations, which directly affect the way the flakes fall. Seven subjects held the core on the top of the thigh, while five held it on the outside of the thigh and one on the ground (mentioned above). An idiosyncratic support position was used by EC (posture 1b in Table 3.3), in which the core is held vertically on top of the leg and the hammer strikes horizontally inward towards the body. This vertical support is also described by Whittaker (1994:185 and figure 8.7), although the striking gesture in that case is directed downward towards the leg. For the experimental subjects' freehand positions, the finger grips and wrist configurations were noted. Two showed grips with supinated wrists, and three showed grips with midprone wrists. These wrist positions are illustrated in Figure 3.7 overleaf.

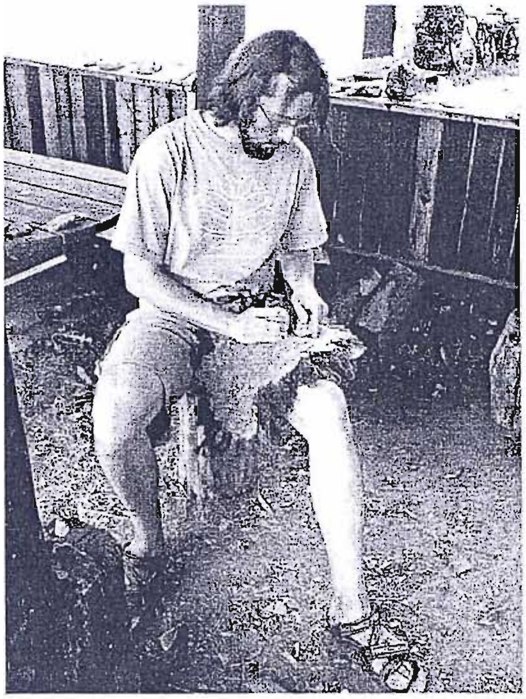


Figure 3.5. Subject MP using the leg-supported core configuration.

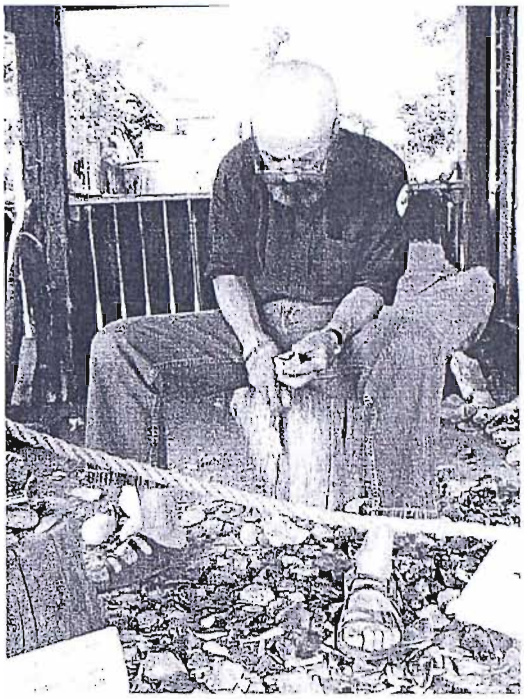


Figure 3.6. Subject SW using the arm-supported freehand configuration.

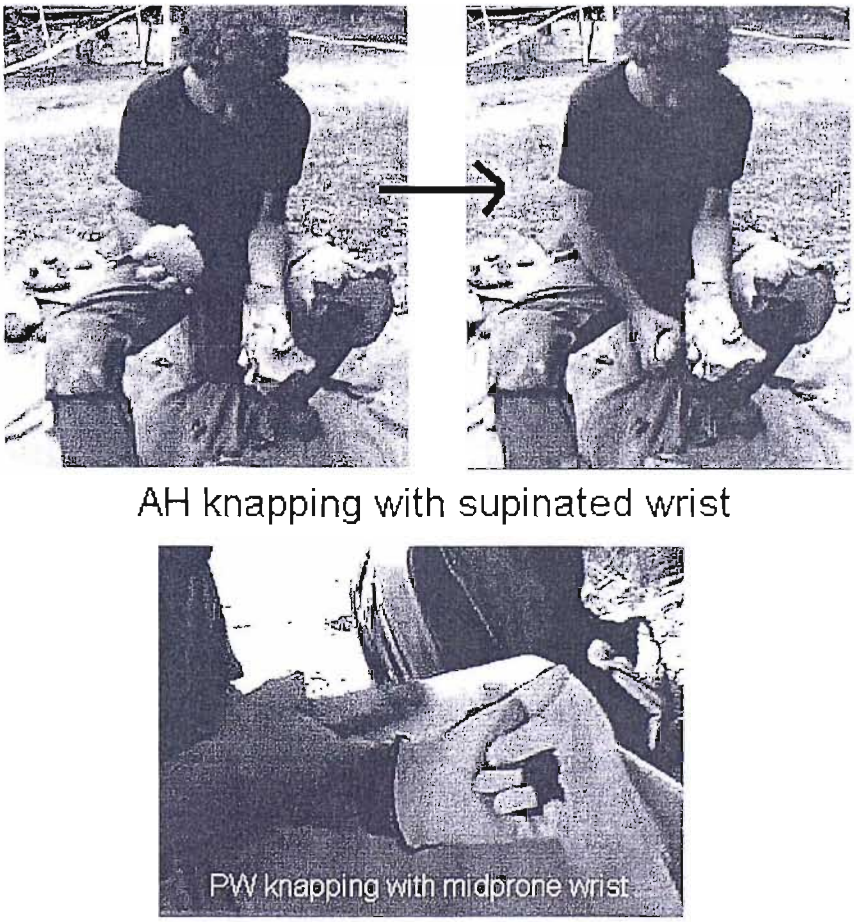


Figure 3.7. Examples of freehand core grips: AH with supinated wrist; PW with midprone wrist.

3.3.1.1.1.3. Flake support

The way the flakes are treated as soon as they are detached from the core is idiosyncratic, although it can be to some extent dictated by the intended product ("first intention", cf. Pelegrin 2001-02). Namely, when shaping a handaxe, the flakes are waste products so can be left to freefall, whereas in blade production, the flakes are the intended product so preferably supported in the fingers or on the leg. The subjects also showed high flexibility in that many used two or three detachment contexts interchangeably. Freefall means the flakes are allowed to fall directly to the ground as they are knapped. If a hide is worn across the lap, they can fall onto the lap. In contrast, with a leg or finger support, the flakes come off between the core and the leg or are caught by the fingers. The most popular context was the leg support (due to the high proportion of core-on-leg postures) seen in eight subjects, then the freefall (n=7) and finger support (n=4). It must be noted that the freehand holding position does not necessarily correspond to freefall flake detachment; a core held in freehand can be held to catch the flakes in the fingers.

3.3.1.1.1.4. Visual field

When the flaking was done freehand, this often took place in the middle of the knapper's visual field (five subjects). When supported on the leg, the core finds itself in one visual field; four subjects knapped in the RVF (including both left-handers), and five in the LVF. This variable is of course linked to the leg on which the core is supported, and this leads to the question of whether knappers choose the leg based on their preferred visual field or vice versa. It is worthwhile to note that some knappers turned their body and/or head to one side even when using freehand: AH and EK both were slightly left-oriented in freehand. Because of the nature of the human visual system, the visual field is not expected to affect core positioning, since that action is slow enough for the visual input to be perceived by both hemispheres (A. Kyriacou, pers. comm. 2006). It is possible that the moment of hammer impact could be brief enough that only one hemifield receives the input. Even so, the visual signals preceding and succeeding this moment would still be transferred to both hemispheres equally. For this reason, the visual field assessment is only used in the table as a general guide to understanding how the knapper's torso might be twisted to one side.

3.3.1.1.2. Universals and idiosyncracies in knapping positions

The interview data from Lejre can be summarised with respect to conscious and unconscious influences on the subjects' knapping positions. Since many of these subjects have a long history of connection with the Lejre Research Center, there has been much contact with the various knapping workshops that have taken place there. These were taught by Thorbjorn Petersen and subjects EC and SM, who have both worked with the Center, and whose styles could be visible in their students and traceable as they pass down the chains of apprenticeship.

Questioning the subjects about their knapping history revealed two kinds of learning contexts, one which relies exclusively or heavily on individual experimentation and self-teaching, and one which relies on the example of a more experienced knapper (by teaching or imitation, in a group setting or with one-to-one teaching). Personal experience, of course, plays a role in all knappers' later development, but people differ in the stage (i.e. proficiency level) at which it starts to affect their knapping.

This difference can be seen as a shift in the complement between declarative and procedural learning (cf. Apel 2001). Namely, lonesome trial-and-error knappers engage in a higher proportion of procedural earliest learning whereas guided pupils receive more declarative instruction early on. While it is likely that knappers who were guided from the start usually begin with more declarative knowledge, it appears that self-taught knappers eventually come to reflect on the act of knapping, bringing their procedural knowledge into the declarative domain. As evidence of this conscious reflection upon one's knapping actions, all subjects reported having tried different configurations and changing positions at least once. Furthermore, all subjects were able to describe and demonstrate their preferred knapping position (these were independently confirmed by observation).

3.3.1.2. Chains of apprenticeship

Among the interviewed subjects, several have past or present teacher-student relationships. These provide either direct influence, in the form of guidance in formal lessons, or indirect influence, through exposure. This transmission is often vertical (based on age), but can also be horizontal (based on proficiency level). Therefore influences on elements of a knapper's style can come from his/her teacher(s). Thus EC was a teacher to JA, LG, MP, and SM. Subject SM taught LG and MS, and subject MS taught FS. These relationships can be schematised hierarchically (Figure 3.8).

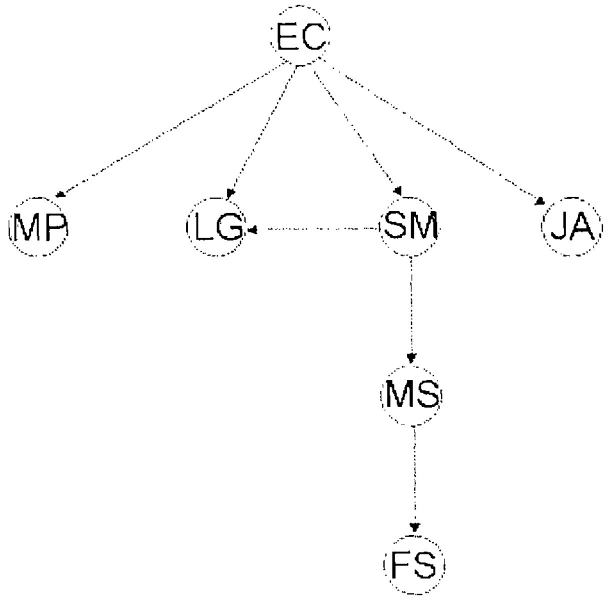


Figure 3.8. Hierarchical diagram of apprenticeship chains at Lejre.

Taking into account the factors of age (subject's age in years) or a crude scale of self-reported proficiency level, the diagrams reveal slightly different structures (Figure 3.9).

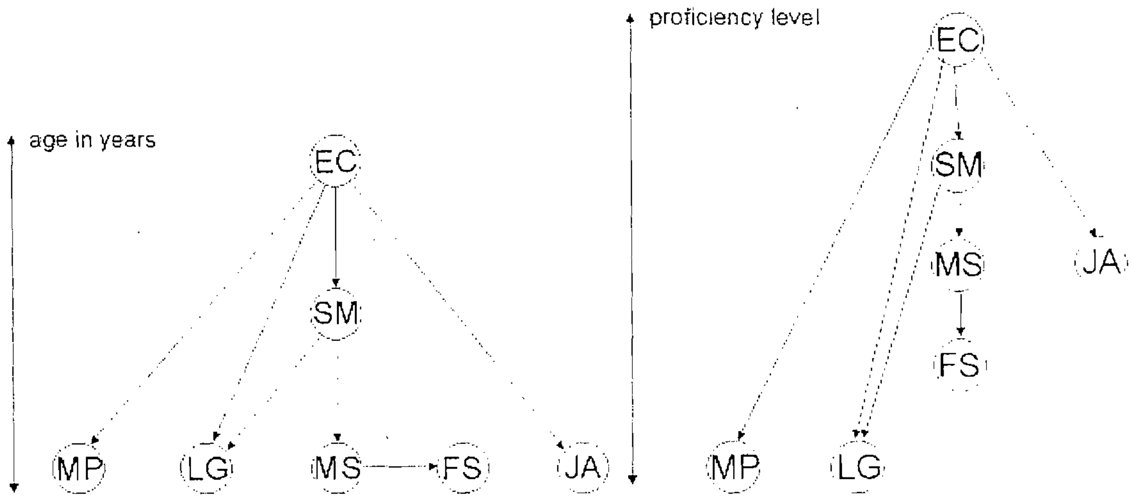


Figure 3.9. Age-based and proficiency-based diagrams of the same apprenticeship chains.

What elements are transmitted through these chains? For body position, JCC used the ipsilateral (R) leg core support, as does her teacher John Lord (pers. comm. 2004). Figure 3.10 shows this position, observed at Cambridge in November 2003.

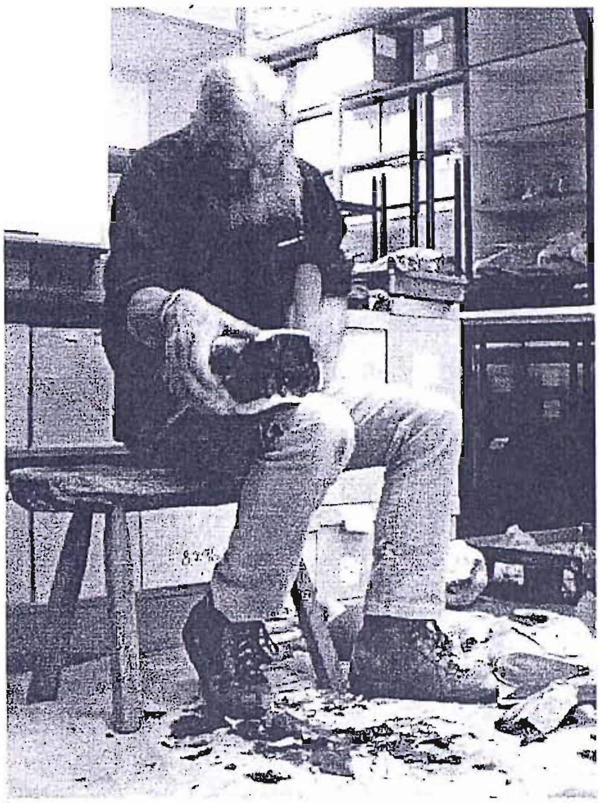
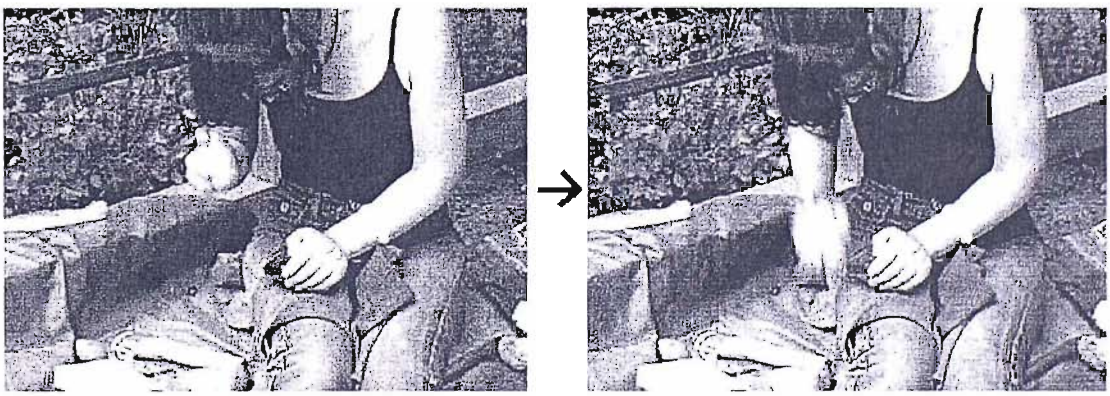


Figure 3.10. John Lord using the left-handed ipsilateral leg-supporting posture.

Interestingly, the only two knappers to use the contralateral leg frequently are FS and her teacher MS, although they both used other positions as well (SW was also photographed using this position). LG, who was learning from EC and SM, and EC's former students JA and SM all used the leg core support. For core positioning on the leg, FS was discordant with her teacher MS but matched his teacher SM. For flake support and visual field, there were no clear matches between knappers and their teachers.



FS knapping on contralateral leg

Figure 3.11. Example of contralateral leg support, FS.

3.3.2. Video analyses

Video of single-platform flaking was obtained for four subjects FS, JCC, MS, and SW in the first experiment and two subjects JM and MDS in the second experiment.

Video sequences of direct percussion (large flakes or other) were obtained for the ten subjects AH, EK, FS, JA, JCC, LG, MS, PW, SM, and SW in the first experiment and two subjects JM and FR in the second. Subject EC was recorded photographically.

Video of tranchet flake production was obtained for three subjects MS, PW, and SW in the first experiment and for JM in the second experiment.

3.3.2.1. Single-platform reduction sequences (video)

Toth (1985) hypothesised that Karari scrapers (single-platform cores) were produced by flaking anti-clockwise around the edge, thus producing flakes with previous margins on the left of their dorsal surface. He also suggested that the tendency to flake to the right of each preceding flake might be driven by the left hand's preference to rotate the core clockwise. Naïve subjects were asked to knap single-platform cores; these reduction sequences are schematised in the figures below. To check for wrist rotation preferences, the motion of the core hand is described based on the first experiment. The diagrams (Figures 3.12 to 3.18 on pages 101-102) show the order of removal of the flakes, with each colour representing a discrete unidirectional sequence of three or more flake removals. From the second experiment, the dorsal patterns are reported and compared with Toth's method: cortex on the right corresponds to a right-handed flake, and vice versa for left-lateral cortex. Single-platform reduction sequences were filmed for FS, JCC, JM, MDS, MS, and SW.

FS made opportunistic removals with frequent platform preparation in between. She tended to flake on the far right or left to exploit the fresh ridges, but also used middle ridges created by her previous flakes. She failed an attempt to make the second blow to the left of the first, then made two flakes to the right of the previous, then two flaking leftwards, then one on the far right, five leftwards, then a set of three failed attempts on a spot at the far right, then after examining the core she began a new sequence from beyond the far left, making three rightward removals, of which the final one joined onto the previously far-left negative. The analysis stopped there because the edge/platform angle on the left prevented further flaking from the platform, inciting FS to resort to bifacial flaking. As Figure 3.12 shows, FS made two unidirectional flaking sequences once she was well into the core. These are removals 6 to 11 (rotating the core anticlockwise) and removals 13 to 15 (rotating clockwise).

When flaking, FS held the core on her right leg (as normal) with a firm, constant left-handed grip in which she rotated the core, and only changed the grip when moving the flaking point to the other side of the core. She knapped fairly quickly: the number of seconds between the first few removals was estimated as less than 6. In between most removals she tended to make a few quick edge-scraping motions in guise of platform preparation.

JCC, the left-hander, reduced two cores without using platform preparation (Figures 3.13a, b). On one, she showed a beginning tendency to remove each flake from the right of the previous one (according to Toth, this represents rotating the core outward, the opposite of his prediction). On the first core, she removed the first five flakes rightward, then she returned to the starting point for one removal, then returned to the end point for two leftward removals. On the second core, she removed the second flake to the right of the first, although not contiguously. The third fell between these two, the fourth to the left of this, the fifth on top of the fourth, sixth to the far right, seventh to the far left, the eighth was a failure to remove a flake on top of the seventh, and the ninth was a flake to the right of this.

On JCC's core 1, she knapped quickly with occasional pauses. On core 2, the maximum time between removals was about 14 seconds, the longer time caused by the awkward core shape after a chunk broke off. In between blows, her grip on the core was changed and repositioned often, so it cannot be said that she rotated the core at all. Instead, she used the core-on-leg support to move the core's position.

In both cases it was clear that JCC simply exploited the best ridges available, as she did not prepare any platforms. If anything, she showed a natural preference to flake around the core clockwise, not anti-clockwise as Toth would predict for a left-hander. The clockwise sequence of flakes 1 to 5 shown in Figure 3.13a is a good example.

Subject JM knapped three single-platform cores. He held them in a loose left-handed grip which was constantly ready to reposition the core. Sometimes he used both hands to turn the core (keeping the hammerstone in the right hand). He made use of wrist rotation whenever possible, namely when making certain serial removals on one section of the platform.

The first core from JM consisted of 26 removals and showed a clear tendency to flake serially, preferentially rotating the core anticlockwise (Figure 3.14a). He made the first five removals leftward, then two rightward, then flaked from a different part of the platform in three rightward blows; then he made four sequences of leftward removals totalling sixteen flakes. He knapped fairly quickly but sometimes paused for a few seconds to study the core for the next suitable platform. The second core was knapped with five leftward removals followed by two rightward and then a single removal on the other side of the platform. Next were removed three rightward, three leftward, one, and four leftward flakes (Figure 3.14b). The third core began with three rightward removals that were followed by four leftward then four rightward flakes, two isolated rightward removals, and three leftward blow (Figure 3.14c). For all three cores subject JM showed a strong preference to flake serially in an anti-clockwise (leftward) direction. This is shown by his greater total of leftward sequences (9) and number of removals in these sequences (36), compared to only 4 rightward sequences and 13 rightward removals (sequences counted as more than two removals in one direction).

Subject MDS knapped her first core (Figure 3.15a) standing up, with a firm left-handed hold on this large nodule. She removed the second and third flakes on either side of the first, followed by a fourth to the right of the third. Next she knapped two leftward flakes. Following these she removed five flakes alternating between the left and right sides of the platform's perimeter, then a leftward removal from the last left-sided one, and three rightward removals from the last right-sided one. Finally she removed the sixteenth flake from the middle of the sequence.

On the second core (Figure 3.15b), MDS removed a second rightward flake, then a leftward flake. This was followed by a new initial removal and one to the left of that one. Next she made a removal between the third and fourth. The seventh removal, to the left of the sixth, resulted in half the core snapping off. She attempted one more removal on the snapped platform before abandoning the core. This was also a large core but she still hand-held it with freehand, while half-kneeling.

MDS's third core (Figure 3.15c), a small core with an almost perfectly circular platform, was knapped in the same position as for the second, with a half-kneel and holding the core freehand. This yielded 26 removals. The first three were knapped rightward, the fourth and fifth were knapped separately leftward, and the next four were rightward but interrupted by a leftward blow (#8). Numbers 11 to 13 were knapped leftward from the left side of the core, followed by 6 leftward removals from the middle of the knapped perimeter to the end (14 to 19). The next one was struck to the right of the last. Removals 21 and 22 were struck from the right side of the core to the right, then 23 was removed from the ridge left by the last two, and the final three flakes were removed rightward from the right end of the platform.

MDS tended to knap fairly quickly, with estimated pauses of up to 10 seconds to study the core. The second was a large core but she still hand-held it with freehand, while half-kneeling (the left knee on the ground, sitting on her left heel, and the right knee bent with the right foot on the ground, Figure 3.16). The first and second cores were turned with both hands because they were too large to rotate with the wrist; the third core was small enough to fit in the hand and so MDS used wrist rotation. However, she preferred to rotate her wrist anti-clockwise, by extension and supination rather than flexion (Figure 3.16). Her preference was clearly not for serial flaking but rather to alternate removals on the un-knapped ends of the platform perimeter. She made a total of two leftward sequences and three rightward sequences, indicating her inclination against unidirectional flaking. Instead she chose the next available ridge, often knapping from an untouched spot on the core's perimeter.

MS produced a blade core from a single platform, using much preparation in the form of carefully scraping the platform edges. He made the following removals: the second was a blade to the right of the first; third and fourth were trimming flakes to the right of the first; fifth and sixth two blades to the left of the second; seventh and eighth were trimming flakes to smooth out the edge for easier gripping with the left index finger; ninth was near the far left; the tenth one, to the right of the previous, failed to remove a blade. The sequence shows no tendency to move right or left, and from the video it is evident that he selected the ridge that was most prominent at the time. In fact, MS did not knap more than two flakes at a time in the same direction, as the colours in Figure 3.17 show.

The time in seconds between removals for MS was the longest of all subjects, estimated between 6 and 30. Between blows, his grip on the core changed constantly as he prepared platforms (sometimes a different platform from the one about to be struck), repositioned the core on the leg, and changed hammerstone grips. The longer times between blows testifies to the careful platform preparation he invested in this blade core.

SW tended to flake serially around the edge (Figure 3.18). This was because the shape of the nodule was homogeneous and the edge angle was more or less constant all the way around, the ideal conditions for revealing any "natural" tendency. He removed flakes 2 and 3 to the right of the first, then removed six leftwards, then two on the far right, one to the left, one far right again, then three leftwards. Next he removed three on the far right, then four flaking leftwards, two rightwards, and finally five leftwards until the core was too small to hold. In this case, with quick flaking and no platform preparation, he showed both a rightward and a leftward rotational tendency, combined with the ability to interrupt the sequence if a better ridge elsewhere afforded it.

The time between blows for SW was less than about four seconds, showing fairly fast knapping. His multiple, leftward sequences (4-9, 13-16, 20-23, and 27-30) which are longer than the rightward ones (1-3, 10-11, and 17-19) indicate a wrist "rotation" preference outward (i.e. supination and extension), like JCC, contra Toth (1985).

In summary, all six subjects in the Core Rotation experiment flaked single-platform cores without showing a unidirectional clockwise rotation as Toth (1985) assumed. The next removal tended to be dictated by the shape of the core and the relative prominence of ridges rather than by any biomechanical constraints on wrist motion. The subjects who did show serial flaking actually favoured a direction that was the opposite of what Toth predicted (FS, JCC, JM, SW). If there were a biomechanical explanation for this, it would suggest an outward rotation direction (wrist extension + supination) was favoured by these experimental knappers.

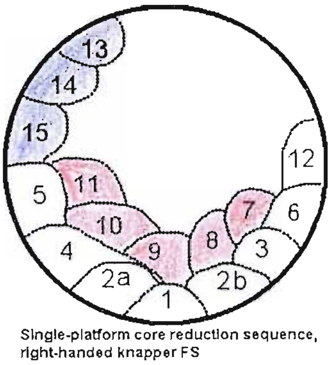


Figure 3.12. Single-platform core reduction order for subject FS.

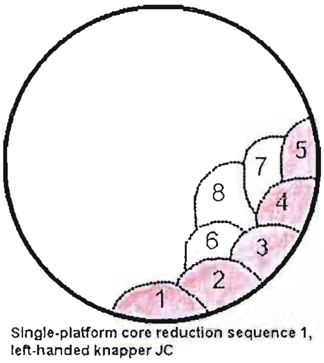


Figure 3.13a. Single-platform core 1 reduction order for subject JCC.

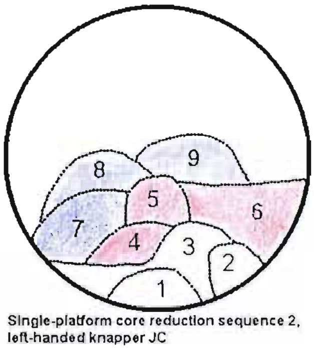


Figure 3.13b. Single-platform core 2 reduction order for subject JCC.

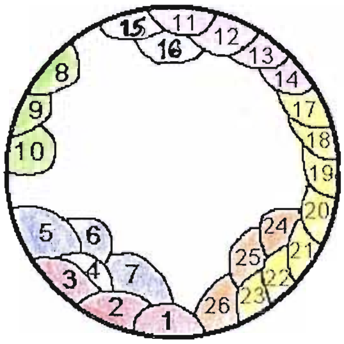


Figure 3.14a. Single-platform core 1 reduction order for subject JM.

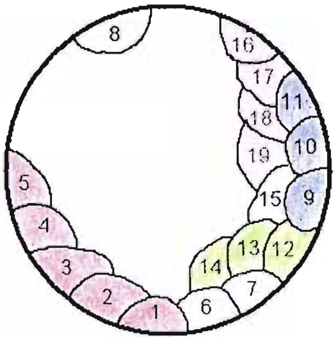


Figure 3.14b. Single-platform core 2 reduction order for subject JM.

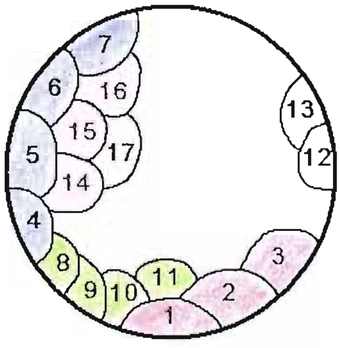


Figure 3.14c. Single-platform core 3 reduction order for subject JM.

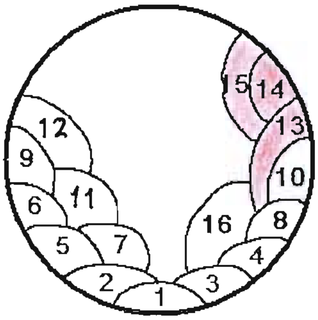


Figure 3.15a. Single-platform core 1 reduction order for subject MDS.

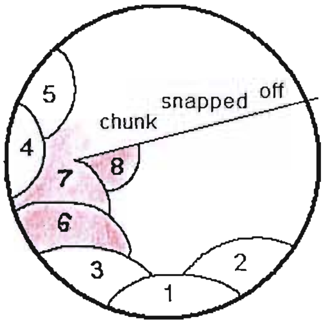


Figure 3.15b. Single-platform core 2 reduction order for subject MDS.

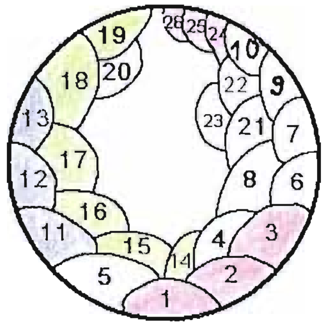


Figure 3.15c. Single-platform core 3 reduction order for subject MDS.

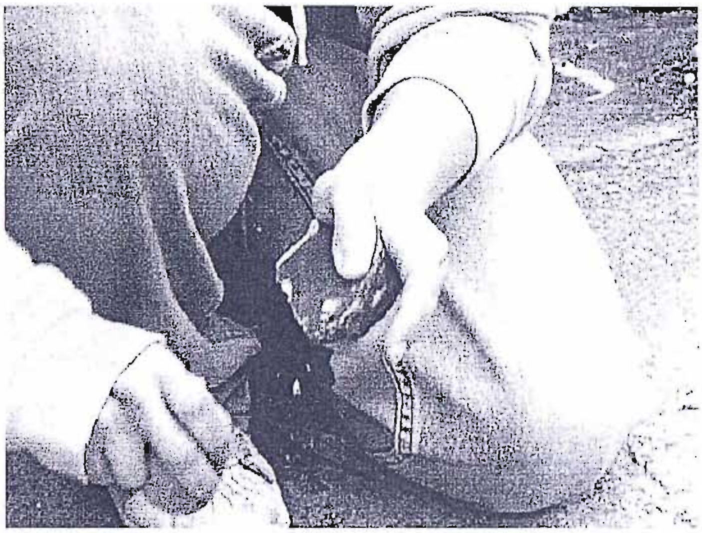


Figure 3.16. MDS showing knapping posture and extensor wrist rotation.

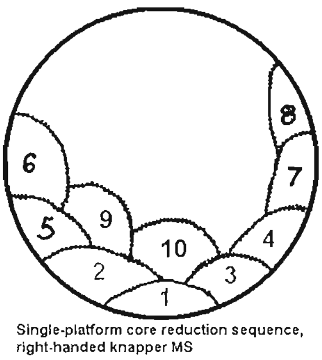


Figure 3.17. Single-platform core reduction order for subject MS.

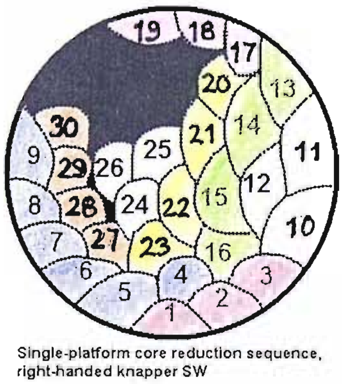


Figure 3.18. Single-platform core reduction order for subject SW.

3.3.2.2. Direct percussion (video): trajectory skew?

According to the hypothesis of Rugg & Mullane (2001), the slanted cones of percussion were due to an unintended skewing in the hammerstone trajectory which should always be inward towards the body (hence a right-hander should produce a right-skewed cone, and vice versa). Owing to the quality of the video (frame speed too slow to capture the hammer's motion) and the video-producer (hand-held camera too wobbly), it was impossible to measure the hammer arm trajectories at Lejre. However, for the left-handed subjects LG and JCC, outward trajectories were suspected based on observation. If this were the case, then the Cone of Percussion hypothesis would become untestable, since right-skewed cones could be produced by both the inward right-handers and the outward left-handers. The second experiment attempted to capture the trajectory by fixing the camera to a tripod positioned beside the hammer arm (Figure 3.19).

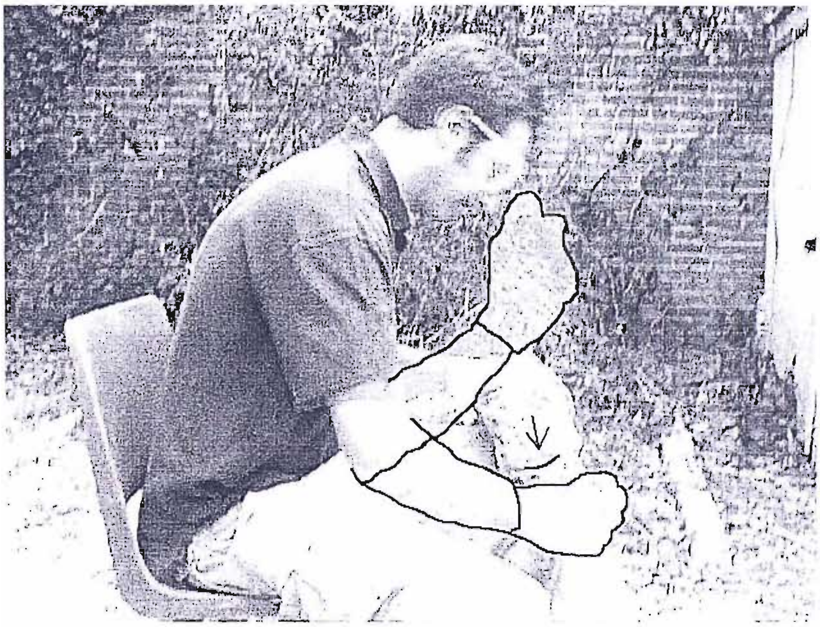


Figure 3.19. Reconstructed trajectory of subject FR's percussion gesture.

The video data from the second experiment provided more information. Subject FR showed a tendency to strike outward from his body (Figure 3.19), which led to the expectation of finding left-skewed flakes. Subject JM struck downward in a trajectory that was perpendicular to the platform. Therefore, JM's flakes were predicted to show no skew.

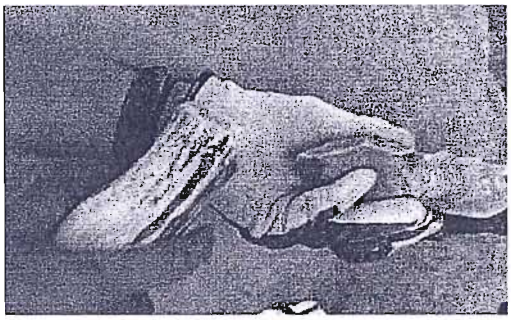
3.3.2.3. Tranchet flaking (video): holding position?

It was the hypothesis of Cornford (1986) that sharpening flakes were lateralised due to a constrained blank holding position. This idea was transposed to tranchet flakes on Lower Palaeolithic bifaces: it was suggested that right-handers should be required to grip the handaxe by the proximal edge and thus should produce a right-struck tranchet (where the flake detaches within the left palm). Tranchet flake removals were captured live on video for four knappers (PW, SW, MS, and JM).

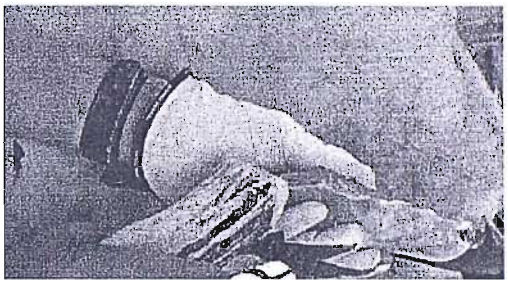
PW failed a first attempt to produce a rightward tranchet flake. It resulted in a small thinning flake which hinged halfway across the face of the biface. This was perhaps because the point of percussion was too far from the tip, and therefore the flake was not strong enough to take the tip with it. His second attempt was not filmed. This rightward tranchet (on a handaxe made by FS) resulted in a hinged termination, although it did create a sharp cutting edge. On his third attempt he produced a very long, steeply-angled rightward tranchet flake which extended beyond halfway down the edge of a large grey biface.

In all three cases PW used the same freehand grip in which his left elbow rested on his thigh, his left hand holding the biface edge with the tip pointing towards him and his wrist very extended and supinated (Figures 3.20 and 3.21). In this position, the tranchet flakes were caught by his fingers as they detached.

Figure 3.20. Holding position for PW's tranchet 1.



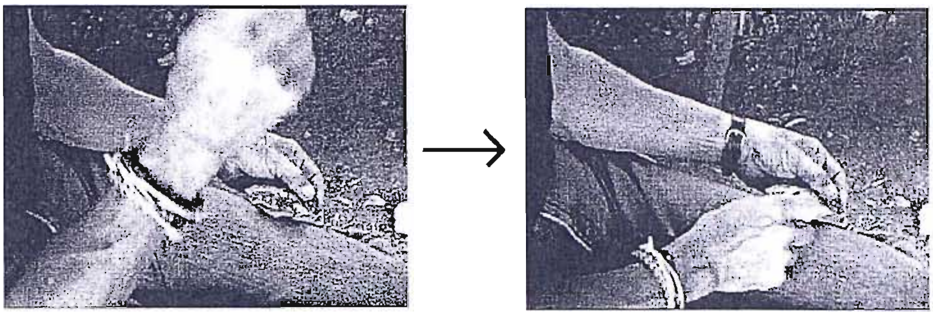
PW showing striking platform for Tranchet 3



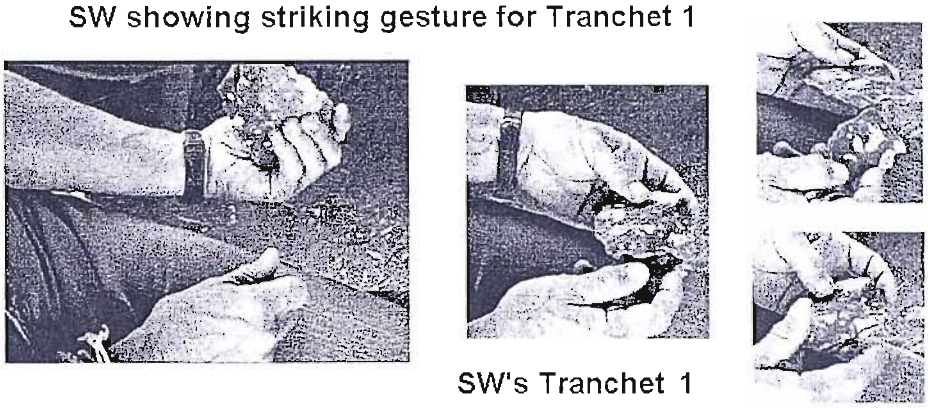
PW showing striking point for Tranchet 3

Figure 3.21. Holding position for PW 's tranchet 3.

On the large grey biface (#3), during tip shaping PW produced a sequence which could be termed a tranchet flake: first he removed the tip at a near-vertical angle; then the handaxe was turned onto its other face and this platform was used to remove a flake, in a direction perpendicular to the new edge, which removed some of the left margin. In this sequence he also used a supinated wrist position to support the biface.



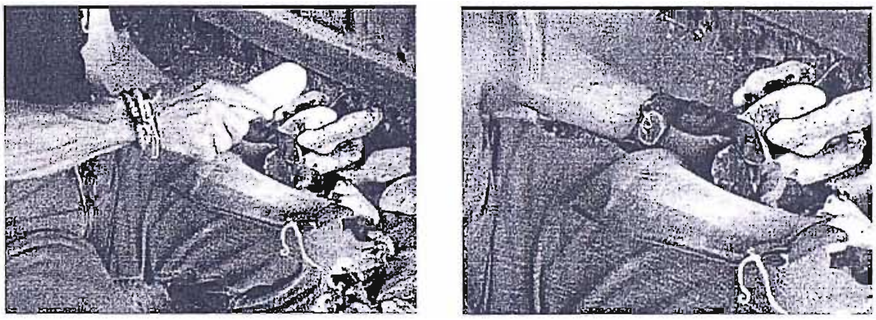
SW showing striking gesture for Tranchet 1



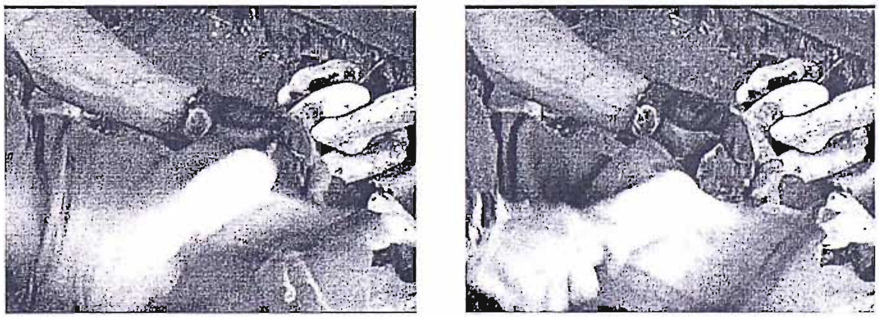
SW's Tranchet 1

Figure 3.22. Holding position for SW's tranchet 1.

SW strikes Tranchet 2



1. Preparing the hammer position 2. Raising the hammer for strike

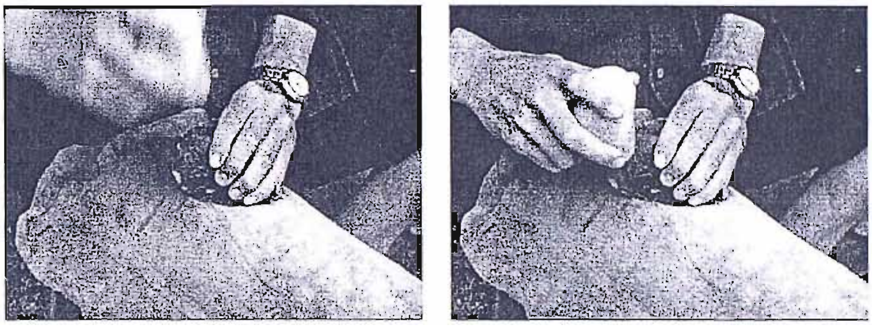


3. The hammer strikes the tranchet

4. Hammer rebounding on the leg

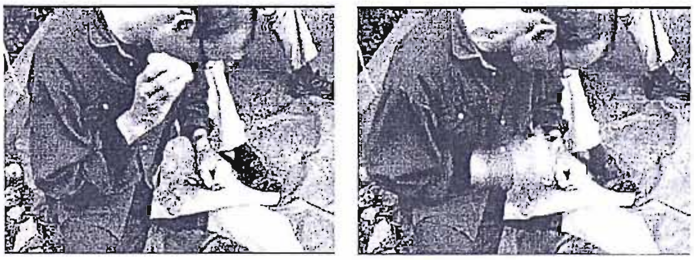
Figure 3.23. Holding position for SW's tranchet 2.

SW made two successful left-struck tranchet flakes using a hammerstone. He supported both on his left leg, although in different ways. The first one, a light grey flint, he held with the tranchet face pressed against his left thigh, his left palm gripping the butt, and the handaxe tip pointing towards the right of his visual field. The hammer blow was directed outward. In the second position, on a dark flint, he pressed the edge of the handaxe against his left leg, with the tranchet face downward and slightly inclined, and tip pointing towards the right. This position resulted in the tranchet flake detaching from the edge which was in contact with his thigh pad (Figures 3.22 and 3.23).



MS shows striking gesture for Tranchet 1

Figure 3.24. Holding position for MS's tranchet 1.



MS strikes Tranchet 2

Figure 3.25. Holding position for MS's tranchet 2.

MS made a sequence of two tranchet flakes (Figures 3.24 and 3.25) with a soft hammerstone on the same handaxe (produced by JCC), although they were removed from the butt. The first removal was leftward, the second rightward, but there was considerable preparation in between, so that the handaxe bears only about half of the first tranchet's negative. For the first (left-struck) tranchet, he supported the biface on his right leg, with his fingers around the base, tip pointing to 45 degrees (rightward towards himself), and struck outward. For the second, he held the handaxe on his left leg, holding the base (which was actually the tip) in his palm, the tip (actually the butt) pointing rightward towards him; the left (tranchet) edge was resting on his leg. This right-struck hammer blow was directed inward to the left.

Subject JM made five tranchet blows on two handaxes of his own production. The first tranchet attempt was made on an ovate handaxe. His left arm rested on his left leg and he held the handaxe in his left hand with the write supinated. The tip pointed to his right, so that the butt and left edge of the biface rested in his palm. This resulted in him striking a flake from the left, which should have removed part of the right edge but did not. JM's second tranchet attempt, on the same ovate handaxe, was also left-struck but did not remove any edge. He used the same configuration as for the first, with the handaxe tip pointing to his right. His third attempt on the same ovate, this time on the other face as the first two flakes, resulted in snapping off the tip of the handaxe.

JM's fourth tranchet flake was removed from a handaxe with a pointed tip. It was held in the same position but with the tip pointing slightly away from him, to his right. He apparently struck directly onto the tip following the long axis of the biface, but the resulting flake was left-struck. The fifth tranchet flake was removed from the same handaxe as the fourth, on the same face as this previous. He held the tip oriented to his right but clearly more towards himself than previously, and the left edge of the handaxe was raised so that it did not make full contact with his palm (Figure 3.26). This blow resulted in a second left-struck tranchet flake that overlapped part of the distal edge of the negative from the previous removal. His sixth tranchet flake was struck on the same pointed handaxe but from the opposite face as the previous two. He held the tip oriented to his right as for the first three removals (Figure 3.26) and this resulted in a left-struck tranchet flake.

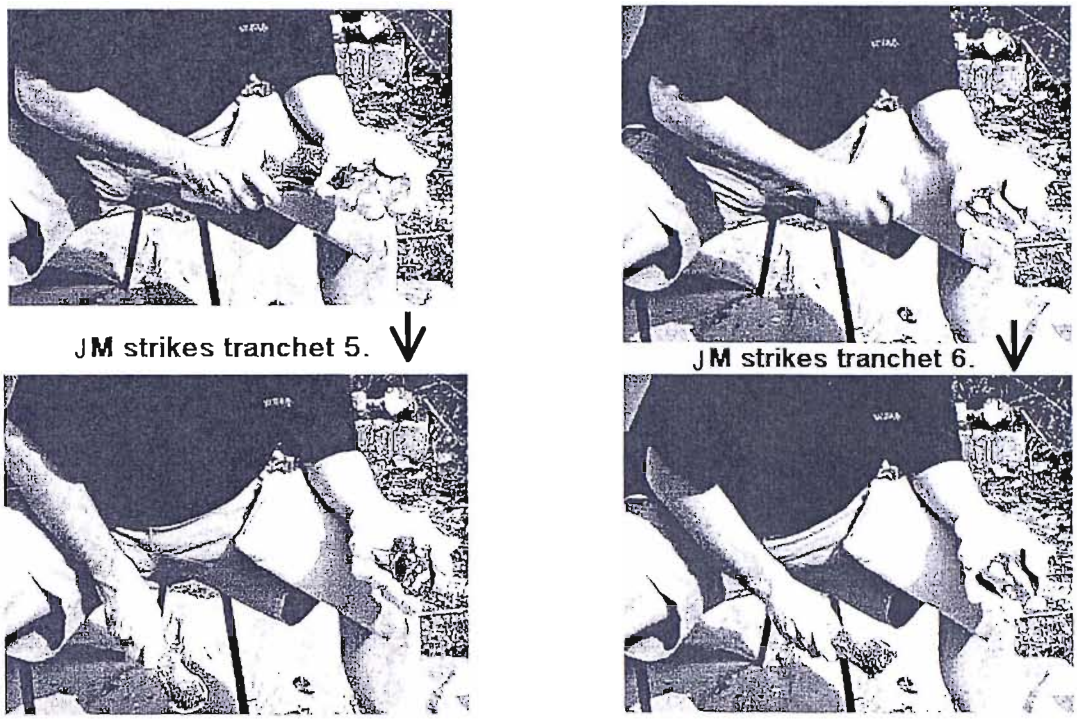


Figure 3.26. Holding position for JM's tranchets 5 (tip inward) and 6 (tip to the right).

It is interesting to note that the knapper (MS) who produced one right and one left tranchet used two different core supports, on the right and left legs respectively. However, although MS and SW both used a similar holding position (biface supported on the left leg with the tranchet edge against the leg), MS made a right-struck and SW a left-struck flake. The two left-struck flakes made by SW were made with two different holding positions on the left leg. JM made five left-struck flakes and always used the same freehand configuration. PW only held the biface freehand and used the same bimanual configuration for all three right-struck tranchet flakes. In sum, these four knappers demonstrated that there is more than one way to make a tranchet flake, and more than one holding position possible for similar flakes. Because these knappers come from different apprenticeship chains (indeed, the three at Lejre had never met before the workshop), different countries, and distinct cultural backgrounds, they can be considered a representative sample of modern-day stone knappers. However, their expertise level (cf. Olausson in press) for tranchet flake production does not approach that of the British Lower Palaeolithic hominins. The latter were knapping tranchet flakes regularly, probably in relation to subsistence.

3.3.3. Lithic analyses (experimentally produced material)

3.3.3.1. Single-platform flakes (experimental): dorsal cortex

The patterns of dorsal cortex on the 39 flakes produced by JM for core 1 yielded 2 non-cortical flakes, 2 fully-cortical, one with cortex in the middle, 5 indeterminate chunks, and 14 left-cortical for 5 right-cortical flakes. The second core produced 18 flakes of which 4 are non-cortical, 5 are chunks, 7 are left-cortical and 2 right-cortical. The third core yielded 28 flakes consisting of 11 non-cortical, one chunk, 11 left-cortical and 5 right-cortical. JM's flakes show a high proportion of left-cortical dorsal patterns, which are expected given the leftward serial flaking pattern preferred by this subject.

However, a comparison with the expected numbers shows only an imperfect correspondence. On the first core JM knapped 13 leftward removals and 3 rightward, while two were initial removals and 7 were removed from previous scars. On the second core he struck 4 leftward and 4 rightward flakes, 4 initial flakes, and 5 non-cortical flakes. From the third core were knapped 3 leftward, 5 rightward, 3 initial, and 5 non-cortical removals. Table 3.4 shows these compared to the actual numbers of flakes recovered from each flaking episode. There are too few numbers to test for statistical significance.

core number		left cortex	right cortex	fully cortical	no cortex	mid cortex
1	predicted	13	3	2	7	0
	actual	14	5	2	12	0
2	predicted	4	4	4	5	1
	actual	7	2	0	4	0
3	predicted	3	5	3	5	1
	actual	11	5	0	11	0

Table 3.4. Dorsal cortical patterns of predicted and actual flakes from JM's cores.

Table 3.4 shows that the first and second cores have a close match between the expected and actual numbers of left and right flakes. The third core produced double the number of predicted left-cortical flakes, and non-cortical flakes. Despite the lack of evidence for clockwise core rotation, the flake data from JM do lend support to one aspect of Toth's (1985) study: the connection between dorsal cortex patterns and the direction of flaking. The preferential leftward direction of JM's serial flaking did indeed produce more left-cortical flakes. However, this can be explained purely by technological properties of flaking.

The second Southampton subject, MDS, produced a total of 16 flakes in the first episode. These are 5 left-cortical, 7 right-cortical, 1 fully-cortical, and 3 non-cortical. The second core yielded 3 left-struck, 1 right-struck, 2 fully-cortical, and 1 non-cortical flake. On the third episode MDS produced 6 left-struck flakes, 9 right-struck, 1 fully-cortical, 10 non-cortical, and one of each with cortex in the middle and on the distal area (both listed under the 'mid cortex' column). These are listed in Table 3.5; again there are too few numbers for statistical analysis.

core number		left cortex	right cortex	fully cortical	no cortex	mid cortex
1	predicted	5	7	1	3	0
	actual	0	0	0	3	0
2	predicted	3	1	2	1	0
	actual	2	4	12	2	0
3	predicted	6	9	1	10	0
	actual	3	4	4	10	2

Table 3.5. Dorsal cortical patterns of predicted and actual flakes from MDS's cores.

The correspondence between predicted and actual cortical patterns for MDS is very weak, except in the case of the non-cortical flakes. The first core was particularly poor because most of the flakes got lost in the grass beyond the tarpaulin (they flew far from the core). The second core yielded many more fully-cortical flakes than expected.

3.3.3.2. Oldowan flakes (experimental): cone skew?

Large flakes were obtained from FR, FS, JA, JCC (left-handed and right-handed), JM, PW, and SW. The other left-hander, LG, was not proficient enough to produce large flakes at the time.

Producing a biface, SW made 5 left-skewed cones, 7 vertical, and 3 right-skewed. Left-handed JCC made 2 were left-skewed, 6 vertical, and 2 right-skewed flakes. With her right hand, as a first attempt at a wrong-handed biface with an antler hammer, she made 3 left-skewed, 5 vertical, 4 right-skewed. These are shown as (r) in Table 3.6. PW made, with a hammerstone, 1 left-skewed and 4 vertical, and with antler, 4 left-skewed, 2 vertical, 2 right-skewed. FS made

6 left-skewed, 5 vertical, and 1 right-skewed cone. F made 1 left-skewed cone, 2 right-skewed, and 5 vertical cones. JM was the only consistent subject, with 8 vertical cones. Table 3.6 summarises the results.

Subject	hand used	L cones	V cones	R cones
FR	R	1	5	2
FS	R	6	5	1
JCC	L	2	6	2
JCC	(r)	3	5	4
JM	R	0	8	0
PW	R (antler)	4	2	2
PW	R (hammerstone)	1	4	0
SW	R	5	7	3
TOTAL	--	22	42	14

Table 3.6. Summary table of experimental cone of percussion skew.

The even distribution of right- and left-skewed cones in all subjects fails to support the skewed Cone of Percussion hypothesis. Although the small number of data points precludes any statistical analysis, the data demonstrate that handedness does not constrain the cone skew to exclusively one direction since left-handers and right-handers produced cones skewed in both directions. Matching the posture of subjects JM and FR to their cones adds further confusion: the outward trajectory shown by FR did not produce a high proportion of left-skewed cones. Even so, the perpendicular trajectory that was inferred from JM's video seems to correlate well with his total lack of skewed cones.

3.3.3.3. Tranchet flakes and bifaces (experimental)

3.3.3.3.1. Tranchet production per subject

EC produced two tranchet flakes. The first was removed upward from the right at an angle of 207°; the corresponding flake is correctly classified as a right-struck flake because it has the edge margin on the right. But because the negative outline of the biface's tip on this flake is not obviously pointed, there is no way to tell it was struck towards the tip. The second flake (Figure 3.27) is a leftward removal at 57°, thin and extending to one-third down the edge of the handaxe; the flake is broken just beyond half of its length. The second flake can be correctly identified as a left-struck flake from its proximal half, but the distal half does not carry this information; thus the distal end would not be classified as belonging to a tranchet flake. Because EC tends to support cores on his left leg, his holding position is interpreted as similar to SW's (biface held against left leg, tip pointing rightward in order to put the axis of the intended flake into the trajectory of the knapping arm). The interpretation of EC's position here was not discussed above because his position was neither filmed nor photographed.

FS made two tranchet flakes. The first is a leftward removal at 53°; the second a rightward removal although both were supported against the right leg. The first one is thin and extends halfway down the edge of the ovate handaxe although it removed little of the edge; this flake broke into two halves plus one narrow mesial fragment. The negative is wide and flat. The second tranchet flake (Figure 3.28) successfully removed part of the left edge and remained whole, leaving a narrow yet flat negative angled to 117°. The first flake would not be recognised as a tranchet flake from its distal or mesial parts, and the proximal portion looks like a biface thinning flake and so would be incorrectly classified as well. The second flake is clearly identified as a tranchet flake with the correct laterality (right-struck).

MS made a double-tranchet (Figure 3.29) on the butt of one handaxe that had been produced by JCC. The first was left-struck at 65°. The second, after heavy preparation, was right-struck at 120°. The combination of the two created a single sharp cutting edge. T1 successfully removed a length of the edge and a portion of the opposite face, but the flake broke near the distal end, probably related with the ripple that is visible on the negative. The future platform for the second removal was prepared by removing a substantial amount of the edge, as can be seen in the image. T2 extended along a section of the sharp edge created by T1. The second flake is smaller than the first and has a feathered termination. These two removals together produced a single sharp cutting edge along the butt of this handaxe. Both flakes are correctly classified as tranchet flakes, although the first flake's distal piece would not be recognised as coming from a tranchet flake.

The author (NTU) produced one tranchet flake at Lejre. It was struck from the left at 25° and did not break, thanks to its thickness. It only removed a minimal part of the edge and ended in a small hinge near the centre of the upper third of the handaxe. However, it has just enough of the opposite face to be identifiable as a tranchet flake. In March 2006 NTU also produced two tranchet removals on the tip of a small round biface roughout, using a hard hammerstone. T2 was right-struck at 115° and is wider than it is long, with a thick bulb tapering to a normal termination. The negative is thus concave. T3 was also right-struck, with an angle of 125°, and used the T2 scar as a platform. It is three times as long as its width and removed the biface edge along its entire length until a tiny hinge termination. The negative is narrow and flat with conspicuous rightward flaps (see Chapter 4). In both cases the edge of the biface was held in the left hand, wrist supinated and extended, the biface almost vertical, so that the tranchet flakes detached inside the palm. Both flakes have their edge margin on the right, giving the correct classification since they were struck from the biface's tip. The fact that both were right-struck testifies to NTU's preferred holding position when making all kinds of flakes. These three removals were excluded from the positional data above since NTU's knapping was not filmed or photographed.

PW produced, on video, a first failed tranchet struck from the right. It must be noted that the flake is indistinguishable from a generic biface thinning flake, since it has no margin from the opposite face of the handaxe. The biface of that removal was not kept for analysis; PW chose to turn it into a ground axe. His second attempt was also right-struck at 100°, on a handaxe previously made by FS. It successfully took part of the edge and opposite face, but it ended abruptly at about one-third the way along the edge. PW's third attempt, on a large grey handaxe made on a flake, produced a long right-struck tranchet flake at 123°, which took nearly equal amounts of material from both faces (Figure 3.30). This fact and its acute angle makes it very similar to a blade-core preparation flake. It was originally interpreted as a hinge based on its result on the handaxe, but on the flake it is better interpreted as a shatter break at 90 degrees to the fracture front. Even so, the last two flakes are easily classified as tranchet flakes.

SW made two left-struck tranchet flakes: the second, on dark flint, broke in half and the proximal portion disappeared into the rubbish heap. From the remaining distal end the flake is not recognisable as a tranchet flake. The negative is narrow, flat, and long, and has an angle of 57°. The first flake, on light grey flint, remained whole, produced a wide, flat negative at 65°, and removed small parts of the edge. Thus the first flake is correctly classified as a left-struck flake, whereas the second fragment is totally unrecognisable as such.

The greatest number of tranchet flake attempts was made by subject JM in Southampton. His first removal produced a biface thinning flake that is about as wide as it is long with a spall where the bulb was. The second attempt on the same handaxe produced a thinning flake following a ridge which extends almost to the butt of the biface, but broke into three parts: a small bulb fragment plus mesial and distal fragments of about the same size. Because neither of these flakes removed part of the edge of the handaxe, they would not be recognisable as tranchet flakes. The next three removals were made on another handaxe. These consist of a very long, narrow flake which extends to the distal 2/3 of the biface along a ridge without removing any edge. The bulb broke off, leaving a long distal fragment. The second flake removed a small portion of the edge and is very flat and thin. However, too little of the edge is present for it to be identified as a tranchet flake. The third removal was made on the opposite face of the handaxe, is thick, and has a wide, thick platform and hinged termination. It removed part of the first flake's negative and this is seen on the flake's platform. The central orientation of the platform with respect to the flake body makes it unclassifiable as a lateralised tranchet flake, so it would fall into the vertical category.

The tranchet negatives made by JM on the first handaxe are wide in both cases and have angles of 65° and 58°. However, it must be noted that because both removals were made in the same place, the final form of the handaxe shows only one removal. The second handaxe shows two negatives, one long and narrow and the other closer to the tip of the biface, both with angles of 65°. The third and final tranchet scar on the opposite face has an angle of 60° and is deep and wide. These five angles show that JM prefers the narrow angle range between 55° and 65°, which is much more homogeneous than the other knappers in the Tranchet experiment.

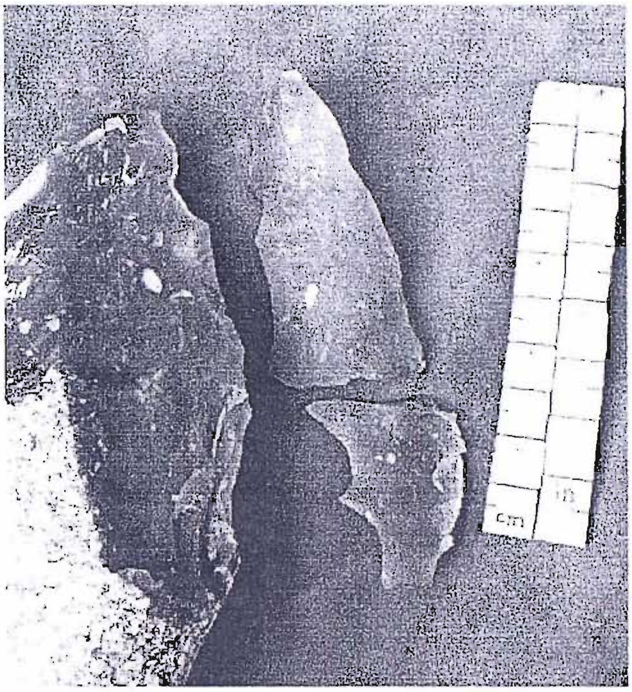


Figure 3.27. Tranchet flake made by EC.

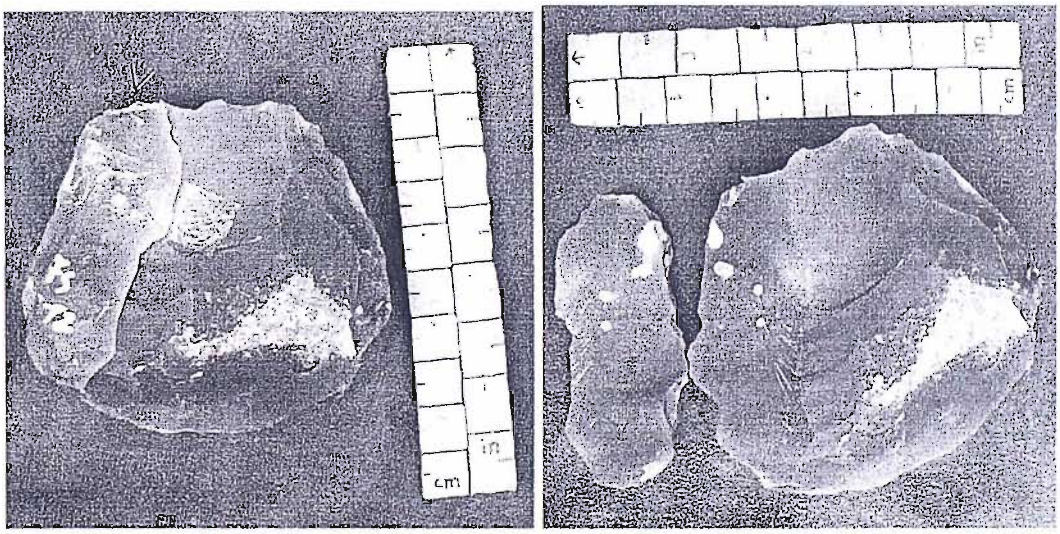


Figure 3.28. Tranchet flake made by FS.

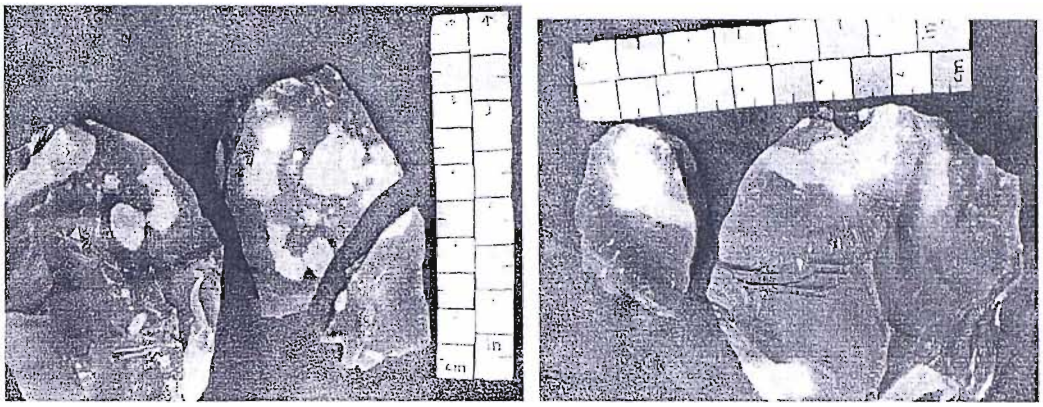


Figure 3.29. Tranchet flakes made by MS.

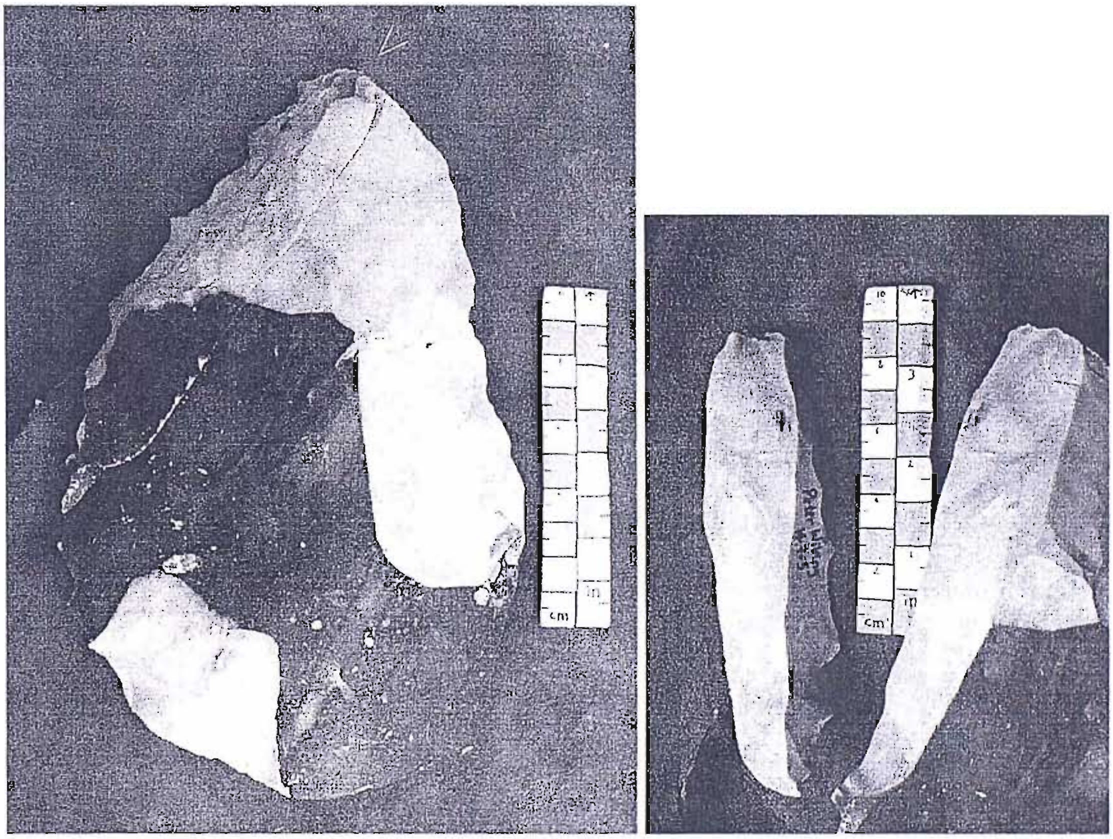


Figure 3.30. Tranchet flake made by PW.

3.3.3.3.2. Summary of tranchet flakes and scars

The subjects in both experiments made a total of 18 tranchet flake attempts, consisting of 10 left-struck and 8 right-struck, as Figures 3.31 and 3.32 illustrate. They are listed in Table 3.7.

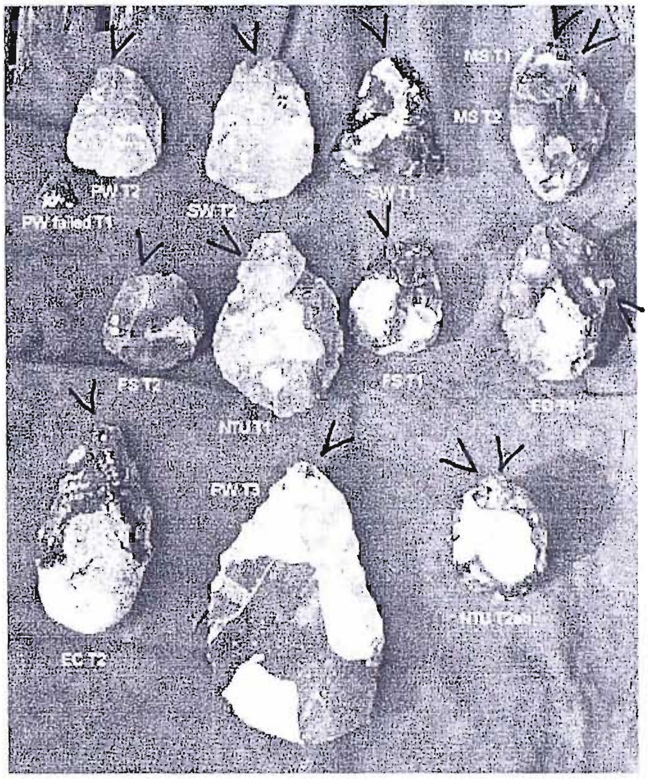


Figure 3.31. Experimental tranchet-struck bifaces (a).

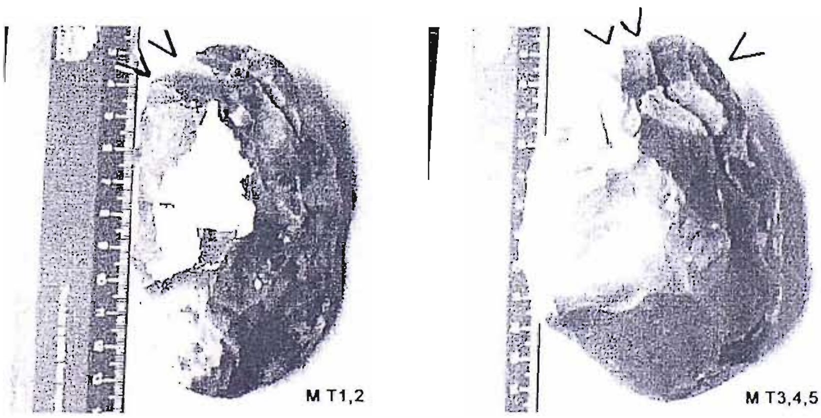


Figure 3.32. Experimental tranchet-struck bifaces (b).

Left-struck	Right-struck
EC-t2	EC-t1
FS-t1	FS-t2
MS-t1	MS-t2
SW-t1	PW-t1
SW-t2	PW-t2
NTU-t1	PW-t3
JM-t1	NTU-t2
JM-t2	NTU-t3
JM-t3	
JM-t4	
JM-t5	

Table 3.7. Experimental tranchet flakes, laterality breakdown (N=19).

The tranchet scars on the 13 experimental handaxes are combined for angle analysis in Table 3.8. The first (T1a) negative made by JM was not included in the table, following the observation that T1b obliterated it, thus leaving only one scar in the location of both. To summarise the angle measurements on the 17 experimental tranchet negatives, there was a strong preference among the six knappers to strike tranchet flakes at an angle between 50° and 70° from the horizontal, whether struck from the left or right. Twelve of 17 negatives fall within this range. The exceptions are the second removal from PW with an absolute angle value of 80°, the first removal by NTU which was leftward at an angle of 25°, and EC's first removal which was struck in the opposite direction from normal (towards the tip, termed 'upward' in Table 3.8 and in the text).

flake scar number	knapper	direction	raw angle	absolute value angle
T1	NTU	L	25	25
T1	EC	R upward	207	27
T1	FS	L	53	53
T2b	NTU	R	125	55
T2	EC	L	57	57
T1	SW	L	57	57
T1b	JM	L	58	58
T1b	MS	R butt	120	60
T2c	JM	L	60	60
T2	FS	R	117	63
T1a	MS	L butt	65	65
T2a	NTU	R	115	65
T2	SW	L	65	65
T2a	JM	L	65	65
T2b	JM	L	65	65
T3	PW	R	123	67
T2	PW	R	100	80

Table 3.8. Raw and absolute values for experimental tranchet scar angles.

Together the subjects produced an assemblage of 11 recognisable tranchet flakes. Judging them only by their features, the flakes consist of four left-struck and seven right-struck tranchet flakes. Seven of the eight unidentifiable pieces were left-struck; most of these broke. In summary, the experimental assemblage consisted of 11 identifiable tranchet flakes which were struck from 13 bifaces with 18 tranchet negatives. The proportion of left-struck to right-struck tranchet flakes and scars is close to half in both cases, and neither shows a statistically significant bias (for flakes: binomial two-tailed $p = 0.65$; for scars $p = 0.62$). The preferred angle range for striking tranchet flakes is between 50° and 70° from the horizontal, showing great homogeneity among these unrelated knappers.

3.4. DISCUSSION

3.4.1. Knapping configurations

Regarding the range of variation present in bimanual configurations for direct percussion, the interviews and observations evidenced high flexibility in all knappers. A few "universal" positions appeared, such as the arm-on-leg freehand and the core-on-leg support. E-mail interviews with UK expert knappers Bruce Bradley and John Lord, both in 2004, confirmed this universality and revealed some idiosyncracies. For example, Bruce Bradley uses the between-feet holding position on the ground shown by EC, in addition to the leg-supported vertical core position. John Lord reported using an arm-on-leg support for freehand, or a core-on-leg position with the core hand supporting the detaching flakes in the palm and fingers. Bruce Bradley reported using either a core-on-leg support on the outside of the left thigh, or a freehand holding position with varying amounts of finger support (ranging from much to none) in the core hand. John Whittaker (1994:93,184-185) describes his preferred position for hard- and soft-hammer direct percussion as "with the core either held in my left hand with the left wrist steadied on my left leg, or resting against the outside of my left leg". These correspond to the freehand arm-on-leg position, and the ipsilateral-outside core-on-leg position, respectively. French expert knapper Eric Boëda prefers an arm-on-leg or an ipsilateral-outside core-on-leg support (Desrosiers 1997: Appendix p. 62). Eric Boëda uses this core support when sitting on a seat, squatting, or sitting on the ground. A core support on the ipsilateral leg is also used by French expert knapper Jacques Pelegrin (Desrosiers 1997:37).

The "universality" of configurations among these Western European experimental knappers remains to be compared with those of traditional, third-world knappers for whom this activity is vital. For example, Stout (2005:331, 334 figures 22.1, 3, 4) shows photographs of Langda knappers crouching on the ground with their left elbows apparently resting on the left thigh. Stout (2002) describes the typical Langda knapping position:

> "During knapping, the rough-out is held cradled in the nondominant (left) hand, with particularly large roughouts being supported by the forearm as well. The fingers of the left hand are placed directly underneath the intended flake removal. Experts in Langda state that this is an important part of proper technique and that the fingers serve the same function as the wooden anvils used during quarrying (i.e., to absorb shock and direct the force of the blow). The careful placement of the fingers may also help in aiming. After a successful strike, the detached flake is caught and discarded with a stereotyped flick of the wrist."
> Stout (2002:698-699)

This wrist-flick can be observed in some of the Lejre subjects as well, and thus can probably be characterised as a universal gesture for knappers. In addition, at Langda a common position for removing flake blanks from large boulders on the ground is standing, with a two-handed between-legs blow (Stout 2002:697 and figure 7 on page 700) that could resemble the between-legs position of EC.

The use of seats is also very common (Hewes 1957). This is where ethnographic comparisons can be useful. Do ethnographic knappers use seats, or sit on the ground? According to Stout (2002, 2005), many knappers at Langda in Papua New Guinea do direct percussion while crouching on both feet in a deep squat. The catalogue of knapping postures from traditional knappers by Desrosiers (1997) shows that supporting the core on the leg is specific to industrialised, experimental knappers who have the habit of sitting on chairs for knapping. Most traditional people support the core on the ground (as sometimes done by D.C. Waldorf), on an anvil, or in the hand (Desrosiers 1997:40-41). In fact, Desrosiers suggests that the postures used for knapping are related to the range of resting postures that are habitually used in one's culture.

The relevance of these results for archaeology is only indirect. Given that no biomechanical study has yet established clear links between flakes and their makers (but see Ploux 1989, 1991; Gunn 1975, 1977 for non-biomechanical proposals about how to recognise a knapper's individual style), prehistoric flakes cannot yet indicate prehistoric knapping configurations. Nonetheless, by finding human universals in knapping postures (e.g. Desrosiers 1997), we can constrain our hypotheses. For example, if we find that many unrelated knappers tend to support the core on one leg, this behaviour can be attributed to efficiency preferences. Hewes's (1957) worldwide survey of the stable postures that people use around the world while resting and working revealed that the most common and widespread positions are the deep squat and the cross-legged postures. Similarly, Desrosiers (1997) also found that most knappers sit, squat, or kneel on the ground, in various configurations. Hewes (1957) found that very few peoples sit with the legs extended, and that this position is almost exclusively restricted to females. Some American Indians and Melanesians sit with the legs out, either together or crossed. Considering that the Boxgrove Q1B *in situ* knapping scatter is hypothesised to represent a knapper sitting with one leg out and one leg folded, could this knapper have been female?

Despite the lack of knapping seats in the Desrosiers (1997) catalogue, the universality of sitting on seats that Hewes (1957) found must be considered. For the earliest known knappers in East Africa, it would be useful to know what features of the environment could have offered seating possibilities. For example, a forested environment would have provided fallen tree trunks and branches; stone seats could be found in a dry desert or in a raw material quarry. From late Palaeolithic times onwards, there are documented findings of flint scatters around large stones (Bodu *et al* 1990; Fischer 1990; Högberg 1999), and these are often interpreted as seats. The conclusion is that at least *Homo sapiens* knappers were sitting on stones, sometimes near a fire. Hearths are frequent in Magdalenian habitations of the Paris basin (Olive 1988:109); hearths were sometimes reserved for the best knappers at Étiolles (Karlin *et al* 1993:333), and they are also attested in modern hunter-gatherers (Fisher & Strickland 1991:221-222). It unlikely that palaeohominins knapped under the rain or snow, given common sense and the properties of raw materials. Flint fractures differently when it is dry, roasted, wet, or frozen. Soaking and heating both facilitate crack formation (Patten 1999:45; Whittaker 1994:73), whereas flint that is full of frost fractures tends to break unpredictably. Hearths would also have provided light for the knappers (Perlès 1977:60-69).

Newcomer & Sieveking (1980) demonstrated that knapping can be done in any position from standing to sitting. However, the only case in which the position of a single knapper or single knapping event can leave traces in the archaeological record is being seated directly on the ground, such as at Boxgrove and others (see section 2.2.1.2.1). Therefore it is fortunate that most ethnographic knappers sit on the ground: they can be the subjects of experiments to study the knapping scatters (cf. Desrosiers 1997).

Concerning the recognition of special techniques, the production of a large biface with the direct anvil technique (inverse direct percussion), shown by EC at Lejre, can extend our knowledge base of percussion features. Although there is no mention of distinct features for this technique in Pelegrin (1986, 2005) or Wenban-Smith (1989), a preliminary analysis of the flakes made by EC hints at some features that may be specific to inverse direct percussion (such as twin bulbs and double ring cracks, scrape marks on the butt, and heavy wear on the anvil itself). These will be investigated in future experiments.

3.4.2. Transmission and learning

Although broad tendencies can be seen, each knapper has an idiosyncratic bimanual position which is partially learned from direct or indirect teaching, and partially developed from one's own experiences and trial-and-error. Because knappers quickly reach a stage where they begin to experiment with positions, the influence of their teachers cannot be inferred beyond a certain proficiency level. In the present study, only the beginners MP and LG were clearly still under their teachers' influence. For all the other subjects, the only proof of transmission is what they report; this can only reflect conscious transmission, as for example when FS imitated EK's stomach-supporting position and found it useful. The transmission of knapping postures was both vertical and horizontal, which matches the pattern of craft skill transmission in Hosfield's (2004; in press) survey of ethnographic populations.

Apprenticeship chains in the Lejre study evidenced some idiosyncracies which were potentially transmitted, such as the contralateral-leg core support and the stomach-press position. It is clear that postures are transmitted through apprenticeship, whether explicitly or unconsciously. For example, Desrosiers (1997:36) notes that French knapper Laurence Bourguignon adopts the same posture as Eric Boëda probably because she learned from him. Another of Eric Boëda's students, Sylvain Soriano, favours a posture seen at Lejre: sitting on a low seat with the left leg straight out and the right knee bent, with the core supported on the top or outside of the left (ipsilateral) leg (Desrosiers 1997: Appendix p. 7-8). Bimanual knapping configurations are thus optionally transmitted, without excluding each knapper from developing new postures.

3.4.3. Three markers of handedness

With respect to the three hypothesised markers of handedness, the experiments revealed that none of the underlying assumptions could be confirmed:

- single-platform cores are not flaked unidirectionally based on a clockwise wrist rotation (Core Rotation experiment);
- cones of percussion, at least in a small sample of flakes, are not reliably skewed, for both handedness types (Cone of Percussion experiment);
- tranchet flakes can be produced either right-struck or left-struck by knappers who are proficient enough to produce a tranchet flake in the first place (Tranchet experiment).

3.4.3.1. The Core Rotation paradigm

The Core Scraper method demonstrates that Toth (1985) made erroneous assumptions and conclusions. For all five subjects who produced single-platform cores, the shape of the core and the relative prominence of ridges tended to dictate the next removal. This result was previously found by Pobiner (1999) in her large-scale study. In the absence of strong constraints on the next ridge, the experimental subjects tended to turn the core outward (i.e. wrist extension + supination), failing to support Toth's (1985) hypothesis. In the Lejre and Southampton experiments, a tendency to flake serially in one direction appeared only when the core afforded it. This suggests that in order for the Koobi Fora material to be knapped in a unidirectional serial manner (as Toth defends), this raw material should be of excellent quality. Furthermore, the subjects in the present study were asked to produce single-platform cores; they had no goal in mind other than removing flakes from a platform, reducing the core as far as possible. If there were an underlying natural tendency to flake serially in one direction, then it should be most strongly expressed when the knapper is inattentive to the shape of the object produced. But even without attending to core shape, subjects only minimally followed a unidirectional serial flaking order. The subject who was most attentive to the core shape was MS, and he showed the most random sequence. One prediction is that the intention to produce a Karari scraper based on a conceptual template, as in the Toth (1985) replications, should present an added constraint to flaking order. In addition to the constraint posed by finding a sufficiently prominent ridge for the next removal, this would therefore add even more difficulty to flaking serially in one direction. Even if the Koobi Fora knappers had a preference to flake unidirectionally anticlockwise, it would not have been expressed due to the priority of imposing form on their Core Scrapers. In conclusion, the assumptions underlying the interpretation of handedness at the Lower Palaeolithic site of Koobi Fora are not validated, which means that this site's claim to the oldest evidence for handedness is not supported.

3.4.3.2. Arm trajectories and cone skew

The experiments were not able to provide information about the trajectory of the knapping arm when flaking, to complement the Rugg & Mullane (2001) laterality study. Furthermore, the experiments showed that cone skew is difficult to assess, as Uomini (2001) found previously. The perpendicular cones of percussion seemed to conform to some degree to the predictions made by the trajectory of the knapping arm, at least in the subject with the most perpendicular knapping gesture. Forthcoming results from L. Harlacker and B. Bril and her colleagues, using high-speed video and electromagnetic detectors respectively, should provide more rigorous information about direct percussion knapping gestures (e.g. Biryukova *et al* 2003; Harlacker 2004; Bril *et al* 2005; Ivanova 2005).

3.4.3.3. Tranchet flake production constraints

Nearly every subject (EC, FS, MS, NTU) produced one of each right-struck and left-struck tranchet removal; only three knappers always used the same direction: JM with five left-struck, SW with two left-struck flakes, and PW with three right-struck. The most frequently-occurring angle was around 60° from the horizontal, with 12 of 17 negatives in the absolute value angle range of 55°-65° (4 were right-struck and 8 left-struck). Despite the variation in holding positions, both right and left flakes could be produced with every position. Therefore the Cornford (1986) hypothesis of holding restrictions did not apply to these knappers; their handedness does not constrain the laterality of their tranchet removals.

Although this study tested a small number of subjects, it has revealed the important fact that, once they are proficient enough to knap a tranchet flake, knappers can produce many different kinds of intended flakes. Therefore there is no biomechanical constraint inducing the production of lateralised tranchet flakes. The variety of angles used for the experimental tranchet flakes shows that proficient knappers can produce flakes in any direction. Given this absence of physical constraints on tranchet flaking, any evidence of cultural constraints, if they exist, would be expected to appear in the archaeological assemblages. Chapter 4 explores this avenue, with a large-scale analysis of British Lower Palaeolithic tranchet bifaces. The analysis starts from the null hypothesis that there is no pattern in the proportions of right- and left-struck tranchet flakes and negatives.

Chapter 4. Archaeological case studies

4.1. Hypotheses behind the methodology

4.1.1. Handedness constraints

The handedness markers reviewed in Chapter 2 left many shortcomings in terms of their biomechanical, ethnographic, or experimental validity. In particular there is clearly a large gap in the handedness data for the time period between 2.5 mya (end of the Pliocene) and about 100 kya (beginning of the Upper Pleistocene). While handedness is well-documented from the Upper Palaeolithic onwards, this gives us no information about hominin species other than *Homo sapiens*. Identifying handedness in the stone artefact record will require methodologies that can be applied to the oldest known lithics. Two methodologies explored in Chapter 3 were potentially useful for these, in the form of single-platform flaking and flake production. The single-platform assumption was based on methods (sequences), while the flake cone skew assumption was based on techniques (gestures). Unfortunately, the experiments failed to validate them. Therefore it was necessary to develop a new methodology. The special combination of methods and techniques was sought in order to approach the two-level characterisation of stone knapping that was discussed in Chapter 1. Namely, the new methodology was devised to provide for both levels of analysis by including constraints on both production sequences and production gestures.

For this purpose, the premises of Cornford (1986) were found to be suitable for artefacts with similar technological attributes to the Long Sharpening Flakes (LSFs) in her study. Specifically, the combination of lateralised resharpening and holding constraints was identified in the tranchet sharpening scars (*coup du tranchet*) that are found on the Acheulean handaxes at Boxgrove, UK. The tranchet blows were expected to reveal similar constraints on production as at La Cotte. Namely, the holding position on the (scraper) blank regulated the side of flake removal, such that it was much easier to strike the flakes from the same edge as where the grip was.

In the first phase of lithic analyses, the new methodology was adapted for tranchet flakes on Lower Palaeolithic bifaces. Specifically, the hypothesised constraint was that removing a tranchet flake from the tip is much more easily done on the same edge as the grip, because it is necessary to hold the biface with the tip pointing towards the knapper's body. This constraint was identified based on communications with other stone knappers. According to this hypothesis, when the knapper holds the biface in the left hand, he/she will tend to strike the tranchet flake from what s/he sees as the right edge, towards the left. When viewing the handaxe with the tip up and the tranchet scar face up, as done in the archaeological analyses, the result is a negative tranchet scar running down the left edge of the tip of the handaxe (termed right-struck because the blow came from the right, Figure 4.1).

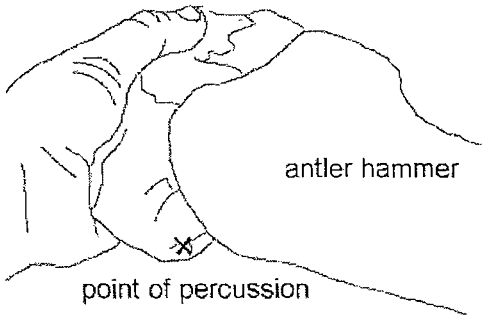


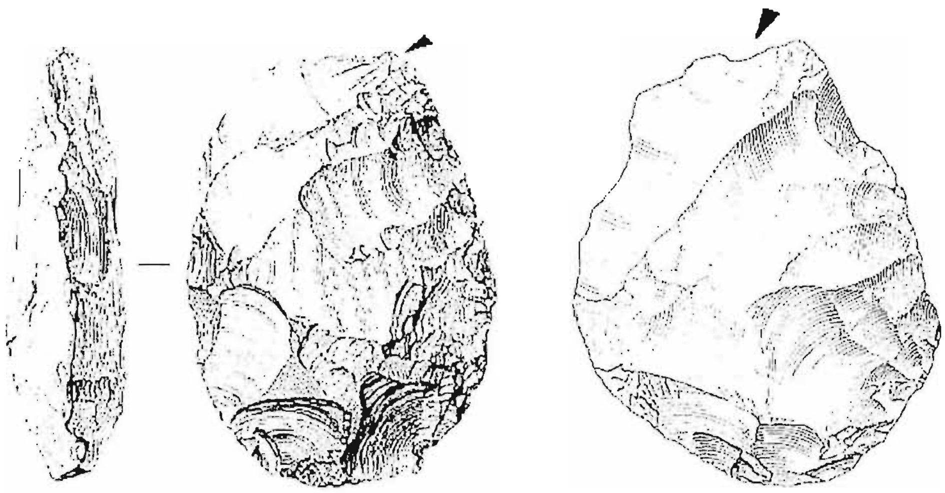
Figure 4.1. Line drawing of the hypothesised grip manner for tranchet flake removal.

The experimental programme and the assemblage analyses were carried out in parallel. The first goal of the archaeological analyses was to replicate Cornford's methodology in the search for handedness constraints in tranchet flaking. However, experimental trials failed to confirm this holding constraint (see Chapter 3). It is likely that the La Cotte scrapers are not analogous to the bifaces in terms of their sharpening flakes' purpose, technique, and morphology. Because there was apparently no biomechanical constraint on holding positions, any cultural constraints on tranchet laterality should have free expression. Thus the archaeological lithic analyses were concluded with the null hypothesis of no difference between the proportions of right-struck and left-struck tranchet removals in the Lower Palaeolithic handaxes. Any bias to one side could therefore reflect an intentional (i.e. cultural) practice.

Tranchet flaking was not constrained by holding position for the sample of modern knappers tested in the experiments. By implication, the knappers who created the British Lower Palaeolithic assemblages (*H. heidelbergensis*) should not have felt any biomechanical constraints on tranchet removal. Therefore, if a cultural pattern existed, it should be evident from the sample of tranchet bifaces. In other words, the absence of physical constraints can allow cultural constraints to express themselves. The presence of a bias in one assemblage would indicate either that there was a cultural constraint imposed on the production of tranchet flakes, or that the many repetitions of tranchet knapping induced the palaeohominins to stabilise their motor patterns. In sum, handedness is not expressed in tranchet flaking, but tranchet flakes can give information about cultural biases and motor patterns that become established through practice. The handaxe is considered to be the most symmetrical lithic object in prehistory (Wynn 2000). The strong symmetry present in Acheulean bifaces suggests that any asymmetrical features would appear prominent. Therefore, the assemblages studied consist of handaxes with strong symmetry. The null hypothesis was that these should not display any asymmetry in their tranchet flake scars.

4.1.2. Angles and holding positions

After seeing the many bifaces with double tranchet removals, in the two assemblages studied, a second hypothesis was formulated about the angles of tranchet removals. This was that a right-handed knapper would produce the right-struck tranchet flake at an angle closer to the long axis of the biface, because the hammerstone blow can be directed along the edge of the biface when the left hand holds the tip towards his/her body. In contrast, the left-struck flake of the same right-hander would be more skewed relative to this axis, because the handaxe must be gripped at the base end if one wants to align the striking arm's trajectory with the projected tranchet removal along the right edge. To test this hypothesis, the angles of the tranchet negatives were measured (see below) to look for differences between the right- and left-struck angles. Angles closer to 90° are closer to the long axis (as in Pradnik knives or the La Cotte LSFs), and 180 or 0° represent a tranchet blow directed horizontally across the tip (as in Neolithic tranchet axes). The two examples from High Lodge illustrate these differences, both right-struck: #3228 is more horizontally-oriented and #3196 is more vertically-oriented.



High Lodge # 3228 High Lodge #3196

Figure 4.2. Examples of horizontally-oriented (High Lodge #3228) and vertically-oriented (High Lodge #3196) right-struck tranchet scars. From Ashton *et al* (1992).

In addition, the homogeneity of angles was expected to give clues to individual signatures, following Gunn (1975), the same person should produce similar angles. In other words, if the two tranchet removals on a handaxe were knapped by the same individual, then they could show similar angles (provided the shape of the tip allows it). On the opposite, if the angles are very different, then they could be the product of two knappers. However, these logical inferences must be used with caution, since a single knapper is capable of producing different angles, and also different people can produce the same angles. The purpose of the angle comparisons was simply to assess the homogeneity of removals on single handaxes and within each laterality group.

4.2. ASSEMBLAGES

The analyses were carried out in the Sturge storeroom at Franks House of the British Museum in London, UK during several visits in November 2004 and October to December 2005, with the reliability visit in February 2006. As mentioned previously, the experimental programme was undertaken in the summer of 2005, in between two bouts of museum analyses.

4.2.1. High Lodge site

The assemblage consists of 20 handaxes from High Lodge, which is a Lower Palaeolithic site from the Breckland region of Suffolk. This was chosen as a practice assemblage for the methodology. The Sturge Collection of bifaces was studied. These form the Old Collection, which were found by workers during the 1860s excavations and lack information about layer provenance. However, it is certain that all the archaeological layers were deposited in the pre-Anglian (480-428 kya) complex, then transported by glacier ice (Lewis, in Ashton *et al* 1992:84). These bifaces are all illustrated in the Catalogue of Ashton *et al* (1992).

4.2.2. Boxgrove site

The Middle Pleistocene site of Boxgrove (UK) has been described in the 1997 and 1998 monographs (Roberts & Parfitt 1997; 1998) and in the first volume of the published monograph by Roberts & Parfitt (1999); a few of the main results are summarised in Roberts *et al* (1997). The site is unique in that it has preserved many *in situ* remains, both lithic and faunal. The archaeological horizon was formed in a time span of about 100 years between 525 and 428 kya (Roberts & Parfitt 1998). The main lithic horizons are attributed to OIS 13 (~500 kya) until early OIS 12 (428 kya) (see Results for a description of unit layers). The right-handed knapping scatter with the leg outlines was found at Q1A, in unit layer 4b; the handaxe with three conjoining tranchet flakes was located at Q2A in unit layer 4c; the only hominin remains (a partial tibia of *Homo heidelbergensis*) are from unit 8ac at Q1B; the two lower incisors of *Homo heidelbergensis*, originally from adjacent positions in the mandible, were also recovered at Q1B in the base of unit 4u (Parfitt *et al*, in Roberts & Parfitt 1997:99). These teeth show signs of severe periodontal disease in addition to the right-handed striations (Hillson, in *ibid.*:104). Butchered horse remains near a former waterhole are found at Q2-GTP17 in unit 4b (Pope & Roberts 2005), surrounded by eight *in situ* scatters of biface or biface roughout production containing all stages of debitage except for the bifaces themselves (Pope 2004:41); several species of large mammals were also butchered at Q1B.

4.2.2.1. Boxgrove handaxes

The entire handaxe assemblage from Quarry 1B (abbreviated Q1B) present in the Museum, consisting of 406 bifacially worked pieces (complete handaxes, bifacially flaked pieces, and broken biface halves) was scrutinised. 306 of these, namely 75 % of the assemblage, were found to have one or more remaining visible tranchet negative. These occurred either on the tip or the base of the handaxe, as outlined in the methodology above.

4.2.2.2. Boxgrove flakes

The flakes analysed were located in a drawer labelled "tranchet flakes" which had been assembled by Dimitri De Loecker for a previous study (M. Roberts, pers. comm. 2005) and were all recovered in Q1B project D. There were 79 flakes in this drawer, but only 66 were found to have measurable or definite tranchet features. Also included here are laterality data for 43 additional flakes from Quarries 2C and 2D, flakes previously identified by F. Wenban-Smith (pers. comm. 2005).

4.3. METHODOLOGY

Statistics were computed with SPSS 12.0.0 and graphs were produced with SPSS 12.0.0 and Excel 2000 (9.0.3821 SR-1).

In this study, asymmetrical features were analysed on the High Lodge and Boxgrove handaxes (H) based upon the tranchet (henceforth abbreviated as T) negatives, and on the Boxgrove tranchet flakes (F). These are tranchet laterality (H, F), tranchet removal order (H)[7], and tranchet angle (H).

4.3.1. Order of analyses

The High Lodge bifaces were analysed in the order of their find numbers. Because the sample size was so small, it was not deemed useful to randomise them.

The Boxgrove bifaces were analysed in the order they were found in their storage drawers. These did not appear to be organised in any particular order (find numbers, layers, and excavation years were randomly distributed), with the exception of a small number of drawers containing items that were apparently grouped together for their similar appearance (such as small size, e.g. drawer 54, or identical overall shape and reduction sequence, e.g. drawer 52).

The Boxgrove flakes were analysed by picking randomly from the drawer they were in.
The tranchet flake analyses proceeded first by determining the direction of the tranchet removal and second by drawing the flake and noting its percussion features

Because the percussion features are the same on flakes as on negatives, see below for the description of analysis. The tranchet direction on the flakes was ascertained by orienting the ventral face up, bulb up, and locating the margin of the opposite face along one edge. The flakes are left-struck if the margin is on the left, and right-struck if the margin is on the right (these reflect the corresponding result on the biface). Figure 4.3 shows archaeological tranchet flakes.

[7] It was not judged possible to determine removal order from the isolated tranchet flakes in this collection.

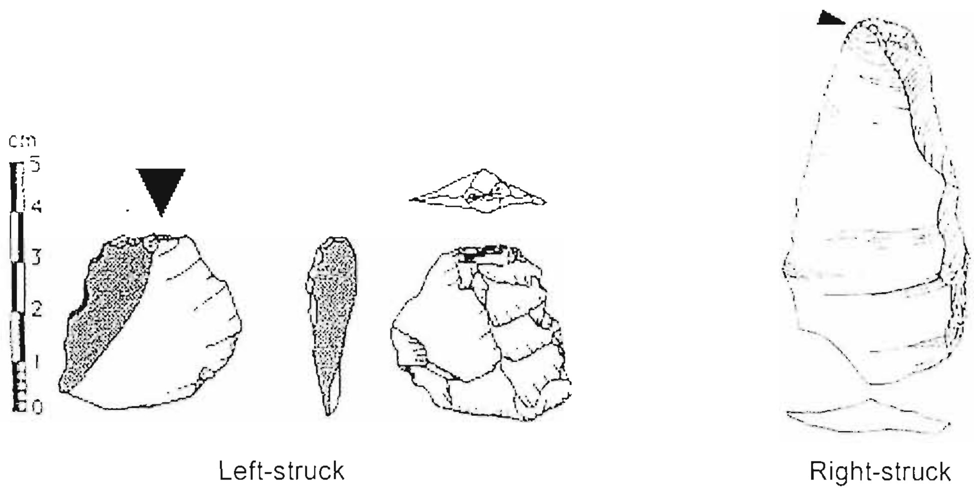


Figure 4.3. Drawings of left-struck (from Bourguignon 1992) and right-struck (from Roberts *et al* 1997) Palaeolithic tranchet flakes.

The biface analyses proceeded with the following five steps, which are detailed below:

1. Locate tranchet negative(s) on each face
2. Note removals prior to and subsequent to tranchet (including other tranchet blows on the same piece)
3. Determine direction of tranchet
4. Note percussion traits on tranchet negative
5. Measure angle of tranchet

4.3.1.1. Step 1. Identify tranchet negative(s) on each face

4.3.1.1.1. Location of tranchet

First it was necessary to locate the tranchet negative, if present. This was facilitated by identifying the tip of the handaxe, which was invariably the thinnest and narrowest part of the piece. The tip of a Boxgrove Q1B biface can be identified by any or all of the following features, relative to the middle part or base of the handaxe: a narrowing width, leading to a point or rounded point; a markedly thinned cross-section, obtained by flaking towards the centre of the piece or by a tranchet flake; a flat edge perpendicular to the axis of the piece; a tranchet scar which has been further retouched in order to finalise the edge to prepare for use.

The base of the handaxe can be identified by any or all of the following features relative to the tip: widest, thickest, and/or heaviest part; absence of use-wear; carefully rounded outline, irregular or rough profile and outline. In general, it appeared that many Q1B bifaces were produced to obtain one straight working edge extending from the tip to the midpoint or base, as is suggested by the frequent presence of use-wear on these (implied by tiny irregular spalls, hinges, steps, and chips), and the asymmetrical outline of the handaxe. The tips were probably also intended for use, as many tips are broken, used, or retouched.

4.3.1.1.2. Definition of tranchet

Bourguignon (1992:70) defines *le coup du tranchet* as "a technique resulting in a removal along one of the edges, slightly overshooting part of the other face" which results in an acute and rectilinear crest formed by the intersection of the two faces; in addition, Bourguignon adds to the definition with features of the tranchet production and its subsequent usage. Regardless of subsequent removals, the constant feature of tranchet flakes in the Boxgrove assemblage is that they remove part of the tip and part of the opposite face to produce a fresh edge. This is the simplified morphological definition used to identify tranchet negatives and flakes. It corresponds to Shafer's (1970) unifacial retouch Methods B and C, to Frison's (1968) retouch flakes from bifaces, or to Bordes' (1961:16) flakes of bifacial retouch. A reconstructed example from Boxgrove illustrates the way the flake fits on the handaxe (Figure 4.4). The pieces shown do not fit together in reality, but their dimensions are similar and they show the alignment of the flake's opposite edge margin with the tranchet edge of the handaxe tip.

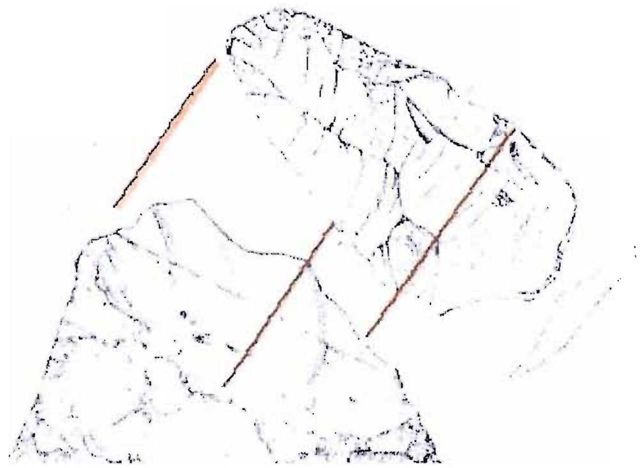


Figure 4.4. Hypothetical example of Boxgrove tranchet flake fitting onto handaxe tip. Combined into one image from Roberts & Parfitt (1999) and Roberts *et al* (1997).

Although some of the removals found on the bases of some Boxgrove bifaces fit the simplified definition, several other features place these into a separate category. In particular, tranchet removals on the tip are part of a sequence of tip finalisation which aims to create a thin, sharp section of flint. The tranchet scars on bases were not further retouched as they were on tips (whether to thin the lower ridge, to remove the bulb area, or to regularise the edge); they have no thinning effect on the cross-section of the base as they do on the tip; they are often steep, in contrast to tip tranchet removals which form an acute angle; and they contribute to shaping the curvature of the base outline, as do the other removals in the base area.

For these reasons, it appears that the intention behind a tranchet removal on the tip is not the same as one on the base (J. McNabb, pers. comm. 2005). The definition of a tranchet flake used here includes the intention of the maker, that is, to remove part of the edge on the biface's tip. Some suggest the intention of a tranchet removal is to sharpen the tip of a handaxe during use (Pope 2004, Pope & Roberts 2005), which would make the tip functionally different from the base. Furthermore, the biomechanics of the striking gesture might be affected by the thickness of the base, since the manner of holding the biface tip or base depends on its thickness. This is especially true for freehand holding, where the main weight of the handaxe (in the lower third, i.e. the base) is supported in the palm, putting the tip into the knapper's visual field (cf. subject PW's tranchet position in section 3.3.2.3 of Chapter 3).

Only a few removals that removed part of the edge and part of both faces were found on the base (N=10), but these were not included in the analysis (Table 4.1):

negative number	direction of base negative	tranchet's place in sequence
10188	L	single
10351	L	single
3852*	L	one of a pair or triple*
4193	L	single
4216	L	single
13726-3	R	third
30864-3	R	third
11572*	R	one of a pair or triple*
31665*	R	one of a pair or triple*
5561	V	single

* indicates a scar that occurs as part of pairs or triples, but whose order could not be ascertained. L = left-struck, R = right-struck, V = vertical

Table 4.1. List of Boxgrove tranchet negatives located on the bases of bifaces.

In these ten cases, the identification of base and tip were unambiguous. As detailed above, these base-shaping negatives were found to be dissimilar to tip tranchet removals in that they are unretouched, are steep so do not contribute to thinning the biface, and are used to shape the base's outline.

The identification of a tranchet negative underwent many changes throughout the analyses. I began with the traditional definition in mind, looking for evidence of any final removals that created a fresh, unmodified cutting edge. However, it soon became clear that most of these were not final, as they had been subsequently retouched, used, or flaked over.

4.3.1.2. Step 2. Note removals before and after tranchet

In order to determine the tranchet's position in the removal history of the handaxe, a close examination of removals around it on the same face and on the opposite face is necessary. The finality of the tranchet, and the nature of later removals, were noted. These features served to identify the tranchet negative. It was important to distinguish the boundary of the tranchet scar in order to establish its existence, and it was necessary to know its axis of percussion in order to measure the angle. An example of such an analysis is given at the end of this section. The example at the end of this chapter illustrates some of the typical flake scar patterns for the Boxgrove Q1B handaxes, with face (b) showing some of the typical subsequent removals on the distal end of the tranchet's negative.

For example, many tranchet negatives are followed by a parallel removal, struck at the same angle relative to the long axis of the biface, just below the tranchet (i.e. removing the protruding lower ridge of the tranchet negative). The experiments (Chapter 3) revealed that the production of a tranchet flake almost always created a protruding ridge at the lower margin of the tranchet negative, which interrupts the thinned cross-section of the tranchet face. In order to restore the regular thinned aspect of the face, it is necessary to remove this ridge with such a removal as observed on the Boxgrove material.

Many tranchet negatives were also retouched on the opposite face, to remove the bulb negative and impact marks. Some were simply followed by thinning flakes on the distal, lateral, or proximal parts. In many cases the tranchet negative was used as a platform for opposite-face flaking, probably to continue thinning the biface. Most tranchet scars have been further retouched in order to finalise the edge to prepare for use, which suggests that the tranchet itself was not sufficient to create a useable edge. According to the expanded definition given above, the removals were only counted as tranchet if they were located on the handaxe tip.

4.3.1.3. Step 3. Determine direction of tranchet

The direction of tranchet removal can be assessed by the basic features of flint fracture: presence of a negative bulb of percussion (the proximal part of the bulb negative is rarely found in Q1B, due to the frequent occurrence of retouching to remove the bulb in order to regularise the profile), concentric ripples, flaps and hackles, lancettes, eraillure scars. Any of these features alone is sufficient to indicate direction (the flaps and hackles are correlated to the direction, as seen in 4.3.1.3.1 below). When comparing frequencies of left and right tranchet negatives and flakes, the binomial test and/or chi-square test were used to decide if differences were statistically significant at the $p<0.05$ level.

The fracture features that were observed to be lateralised are the flaps and hackles located on the tranchet negative's surface. The inherently asymmetrical nature of flaps and hackles made them candidates for indicating skew in the percussion gesture. In fact, they can be reliably used to infer the direction of the tranchet, either on a negative scar or on a flake. This information was most useful on tranchet flakes that were missing parts such as the bulb and distal ends, where the only feature indicating direction was on the fracture surface itself. The mechanics of their formation are described next.

4.3.1.3.1. Basics of brittle Mode I fracture

Cracks are the primary mechanism for accommodating brittle deformation in rocks. They are defined as planar to curviplanar surfaces of opening-mode (Mode 1) displacement continuity, which means the fracture's walls have been displaced normal to the fracture surface (Schultz in press: chapter 1).

The type of fracture that normally occurs in direct percussion with stone (knapping), either with a hard hammer (stone) or soft hammer (antler or boxwood, or bone), is an unbounded (i.e. the flake detaches fully) dynamic brittle Mode 1. Very few archaeologists and materials scientists have studied the other's field, but Cotterell, Tsirk, and Odell are the most outstanding examples of cross-disciplinary researchers in these fields (Odell 1981; Tsirk 1981; Cotterell *et al* 1985; Cotterell & Kamminga 1987; Tsirk & Perry 2000).

The features that are visible macro- to microscopically on knapped stone flakes and their corresponding negatives are features which occur on huge scales, studied by geologists. Because the physical mechanisms are analogous, geologists can extract the same information from a 20-meter high outcrop of rock as an archaeologist can from a flint piece: origin of the crack, propagation direction, and termination (e.g. Pelcin 1997). These are indicated by the following features: rib marks, hackles, and flaps. Only the latter two are relevant to laterality, and they are described in detail below.

4.3.1.3.1.1. Rib marks

Concentric or conchoidal rib marks are "curvilinear ridges or furrows oriented at right angles to hackles" (Pollard & Aydin 1988:1189). To identify them, "in a profile that is parallel to hackle, rib marks express themselves as curves and kinks. They may be rounded in profile or have sharp apexes" (*ibid.*). They are concave back to the crack origin (Schultz in press:29). In the context of metallic fatigue fractures, they are also called beach marks, which are "macroscopically visible semielliptical lines running perpendicular to the overall direction of fatigue crack propagation and marking successive positions of the advancing crack front" (Parrington 2002:37).

From the archaeology it appears that these rib marks sometimes occur on Boxgrove tranchet flakes, usually as a single large rib mark, at the base of the bulb. They do not appear to be asymmetrical: macroscopically, their width extends for equal distances on either side of the bulb.

4.3.1.3.1.2. Hackles

Hackles are linear marks which radiate from the origin or fan away from a curvilinear axis (Pollard & Aydin 1988; Parrington 2002:36). According to Schultz (in press:26-27), they "typically define the intersection surfaces that separate twisting parts of the crack wall", or they can be "associated with minor reorientations of the propagating crack front due to mixed-mode I-III stresses at the grain scale". These facts can be interpreted to mean that hackles arise from the motion of different fracture surfaces at the moment of flake detachment. It was noticed that they often occur distal to a local inclusion on the fracture surface, i.e. after the crack front has passed an inclusion, it can change direction as a result of that inclusion.

The French term of *lancettes* does not quite account for the hackles observed. *Lancettes* mainly refer mainly to the tiny clusters of linear marks located along the periphery of the negative, which are used to identify which negative was struck last. Figure 4.5 shows some rightward *lancettes*, on the distal right area of the last-struck negative above the thumb. Hackles were also noticed by Semenov (1964:11), who wrote, "During our searches with the binocular microscope for traces of striation on the surface of tools of flint, chalcedony, quartz and obsidian we often noticed, and were delayed by, lines with a stepped or rib-like relief."

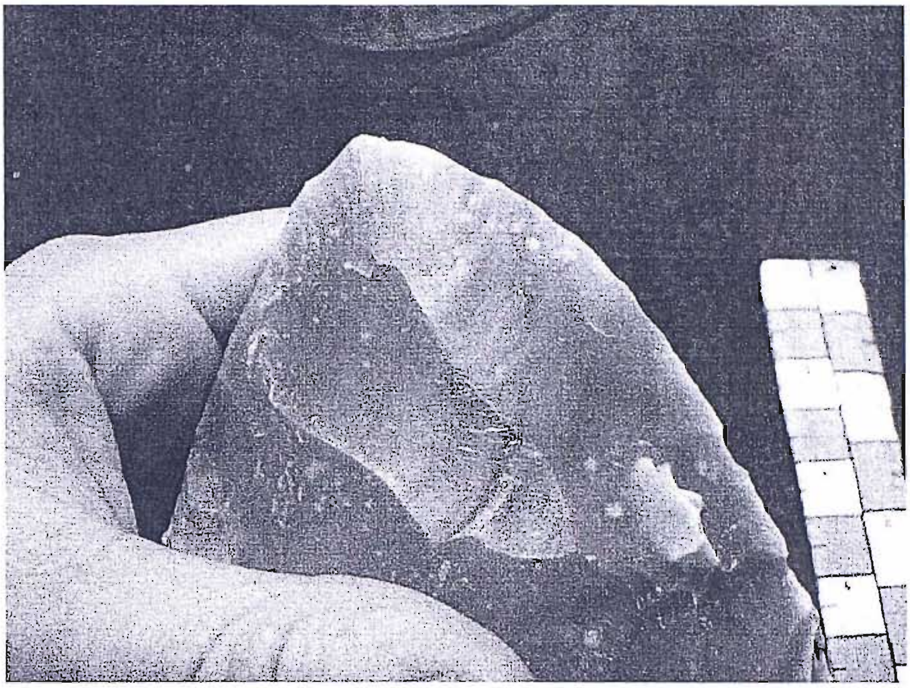


Figure 4.5. Rightward lancettes on a negative. Boxgrove Q1B #1708.

When viewed directly on the flint surface, the length of hackles, which is variable, extends parallel to the direction of crack propagation (Varner 1991); thus their proximal end is always pointing toward the cone of percussion. Their width is also variable, directly depending on the vertical angle of the segment between the upper and lower parts of the ledge. Whereas the upper part is always straight, the lower part can form a rounded segment with the maximal width in the middle of the hackle's length (Figure 4.6).

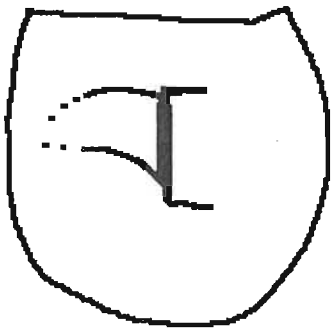


Figure 4.6. Schema of S-hackle, looking straight onto the flint fracture surface.

In cross-section (Figure 4.7) the hackles look like a step or ledge, with one side higher than the other (jutting out from the surface of the fracture plane). The depth of the step can vary, as can the vertical angle of the segment connecting the two different height steps: this can range from vertical to nearly horizontal, and the more horizontal it is, the wider is the cross-section. In addition, this can vary from an S-shape (where the lower side gently rises to rejoins the surface) to a V-shape (where the lower side actually rising sharply to join the normal height of the surface).

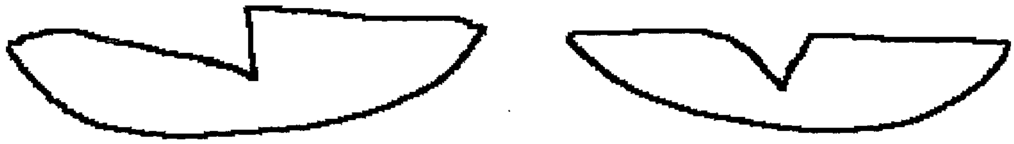


Figure 4.7. Cross-section of hackle: a) S-profile, b) V-profile.

These hackles or twist hackles are identifiable by holding the piece at a certain angle with the light coming from one side (right or left, depending on hackle's laterality). If the viewing angle is correct, the hackle appears as a line which is dark; this is the bottom of the V. If the piece is turned so the hackle is illuminated from the other side, the hackle often becomes invisible, or else it appears as a white line. Thus it is possible to identify the hackle's laterality with a light source from the left: when a dark line is evident, it is the result of the shadow caused by the steep vertical segment of the V, so it is a Z hackle. If it looks like a white line or a white strip, this means the light is striking the wide area of the V, so it is an S hackle.

In summary, the hackles are most visible when the upper part of the hackle is closest to the light source and the lower part is furthest from the light, so that the shadow generated by the steep part of the V is salient. In other words, viewing the ventral surface of the flake with the bulb up (furthest from the observer) and the light source from the left (as is standard in archaeology) will reveal a Z hackle in the form of a dark line, and an S hackle will be best revealed by holding the bulb closer to oneself.

Another way to check the hackle's laterality is by feeling with a fingernail: this can lightly hook the steepest part of it, so that a Z hackle can be most easily felt with the left fingernail and an S hackle can be best felt with the right fingernail.

The hackle is termed S if it descends to the left, and Z if the low part is on the right (these names are intended to reflect the shape of the cross-section).

Figure 4.8 shows some large Z hackles near the bulb, the light source on the left making the vertical segment of the hackle appear dark.

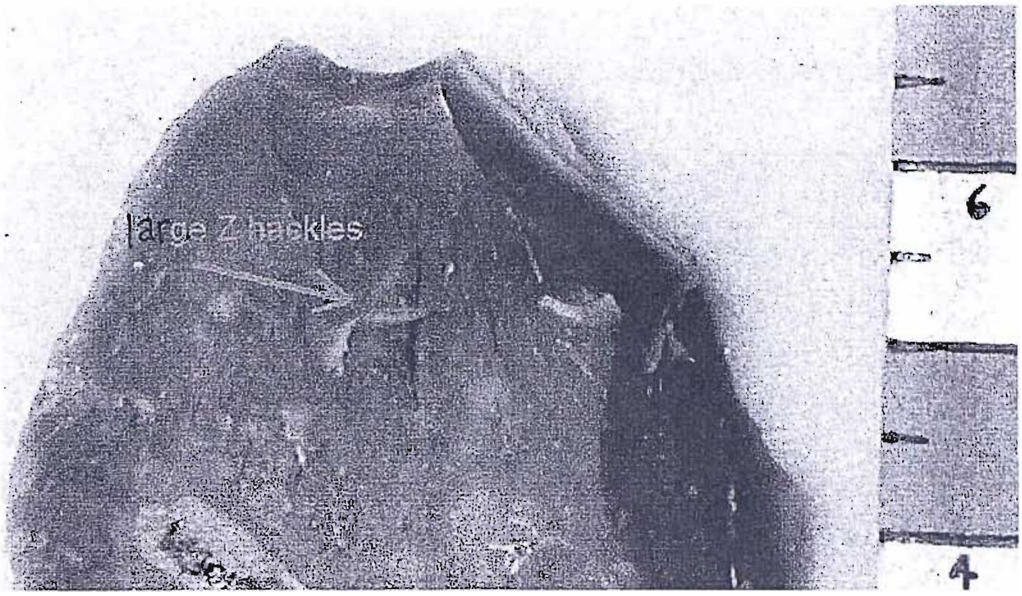


Figure 4.8. Large Z hackles with light source on left, showing dark vertical segment. Boxgrove Q1B #10579.

A cluster of echelon joints can be seen on the lower left edge of the tranchet negative (near the thumb in the picture) in Figure 4.9.

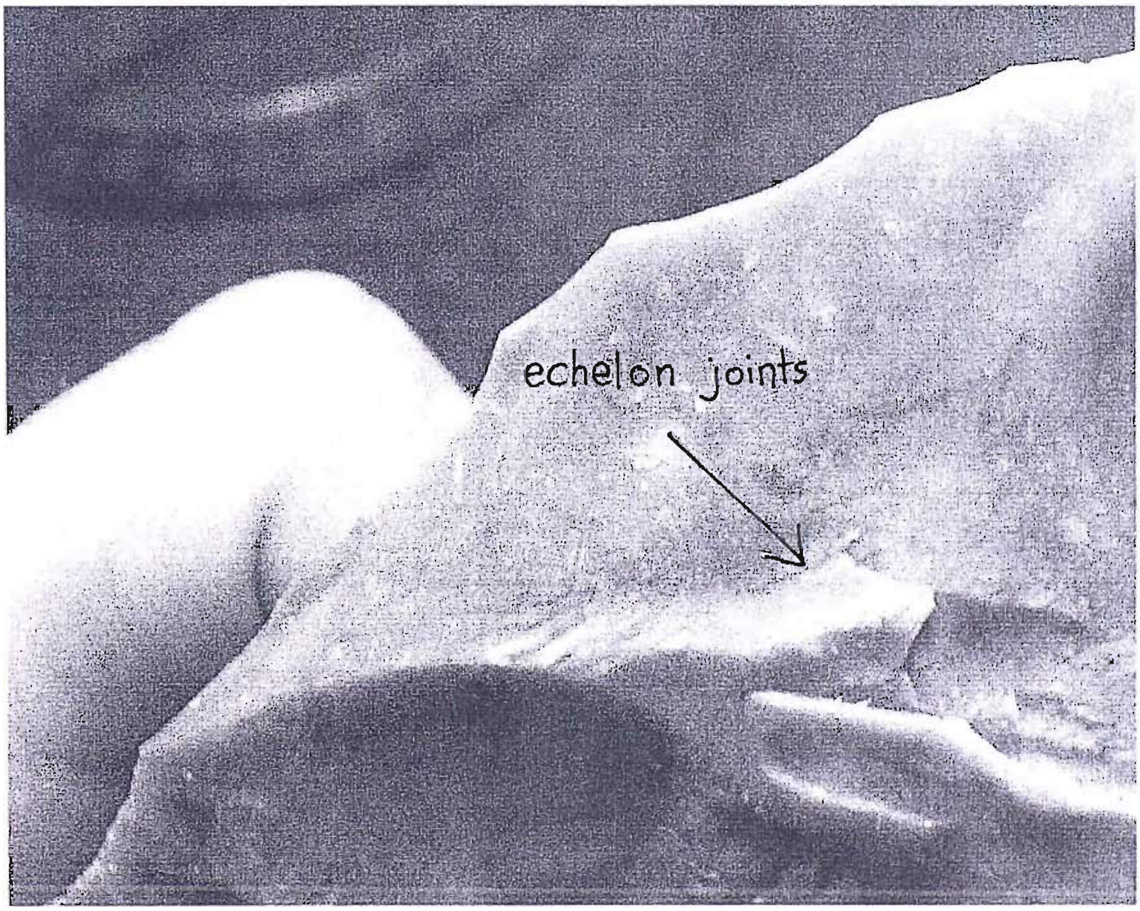


Figure 4.9. Cluster of echelon joints. Boxgrove Q1B #1462.

Some very large S hackles can be seen aligned on a previous negative in Figure 4.10.

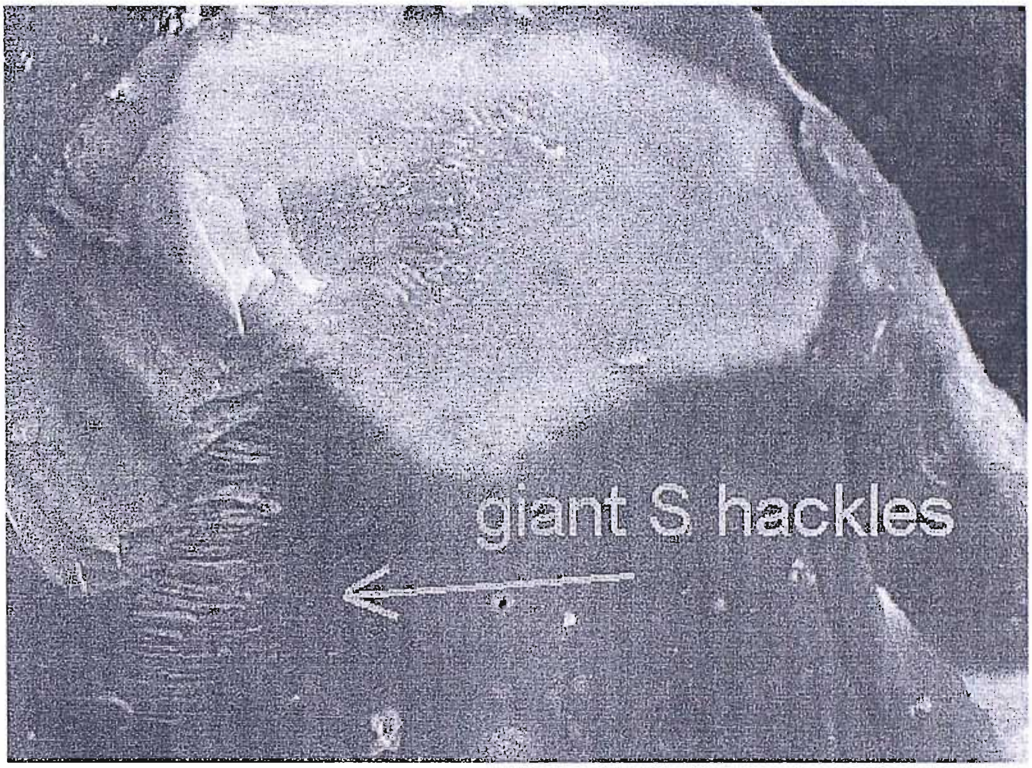


Figure 4.10. Giant S hackles aligned on a negative. Boxgrove Q1B #30311.

4.3.1.3.1.3. Flaps

Flaps are also linear marks radiating from the origin; their distribution tends to resemble that of hackles. The term was coined due to their appearance, because no reference to such things could be found in the fractology literature. They consist of partially detached segments of flint and their length always points toward the origin, as do hackles. Figure 4.11 illustrates the variations in shapes with leftward flaps.

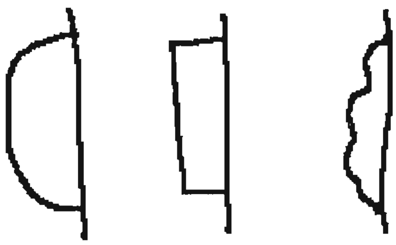


Figure 4.11. Schema of flap variations, looking straight onto the flint fracture surface.

In a rectangular-shaped flap, one long edge is attached. The other long edge is parallel but detached, and the two short edges (one proximal, one distal) are also detached. In an elliptical or triangular-shaped flap, one long edge is attached, and the other long edge forms a curved or triangular (often jagged) length of detached material. The attached edge can also be curved, as in Figure 4.12. These flaps are highly visible due to the fact that the partially detached lithic material is much lighter in colour than the surrounding material.

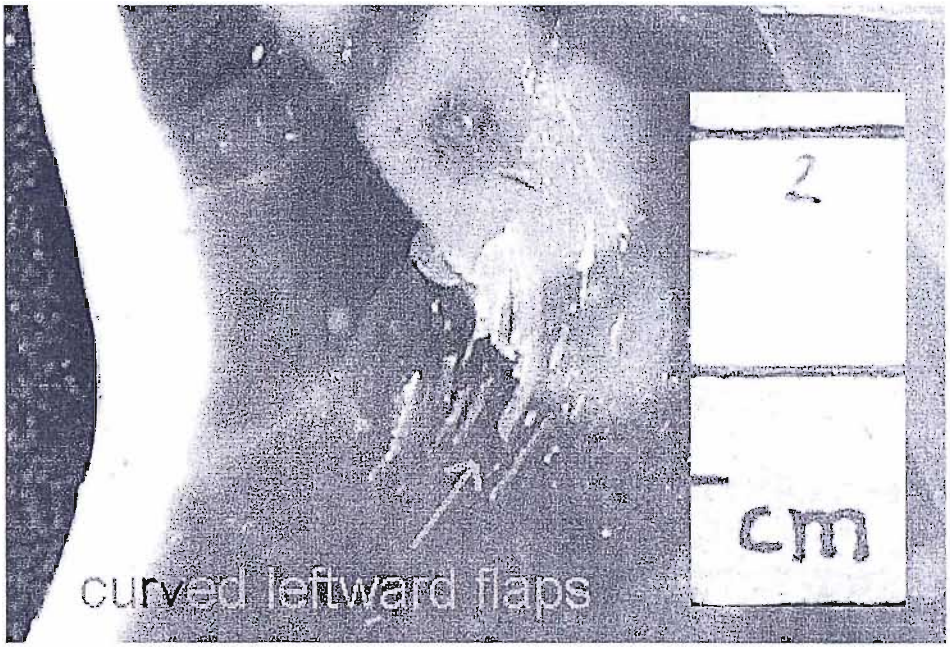


Figure 4.12. Leftward flap with curved attached edge. Boxgrove Q1B #5058.

Flaps are termed leftward if the attachment length is on the right and rightward if the detached portions are on the right (Figure 4.13).

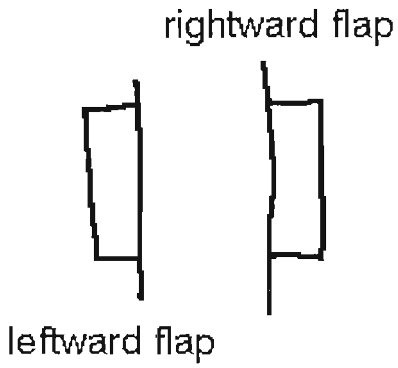


Figure 4.13. Left and right flap terminology.

Figure 4.14 shows some leftward flaps, including one large triangular-shaped one.

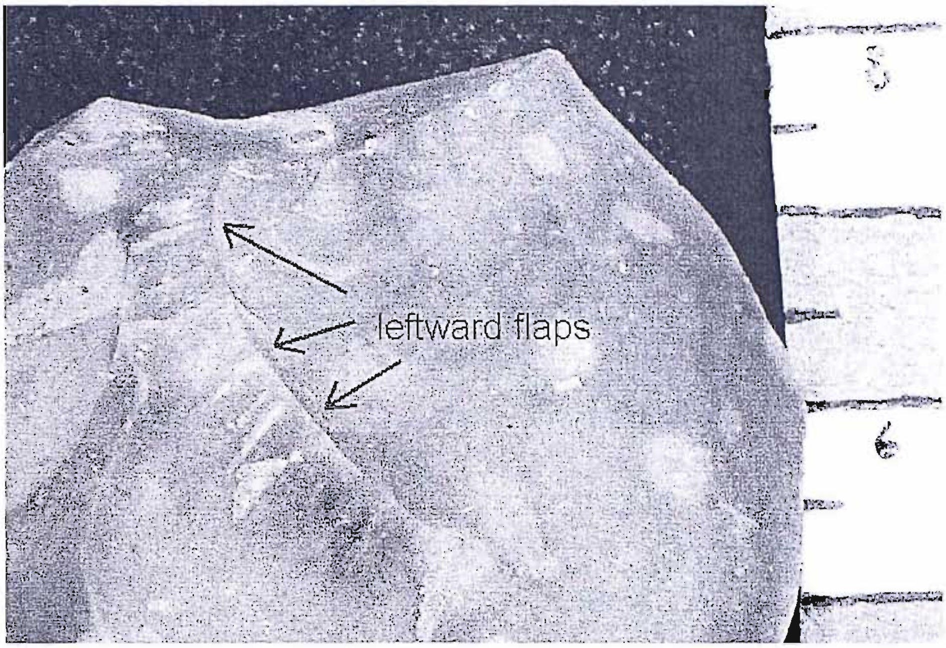


Figure 4.14. Leftward flaps. Boxgrove Q1B #5700.

Figure 4.15 shows a very long rightward flap and a short one at its distal end surrounded by more small flaps.

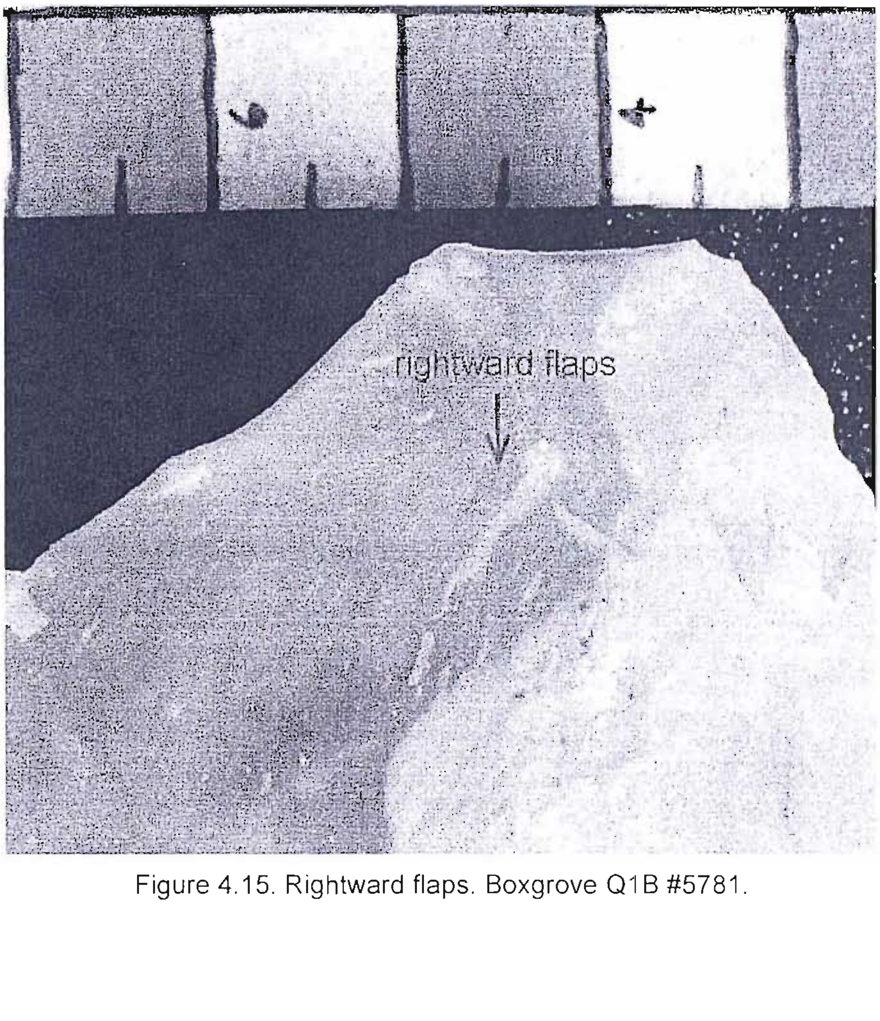


Figure 4.15. Rightward flaps. Boxgrove Q1B #5781.

Figure 4.16 shows two curvilinear clusters of rightward flaps and hackles following the contour of the base of the bulb (a bulb negative in this case).

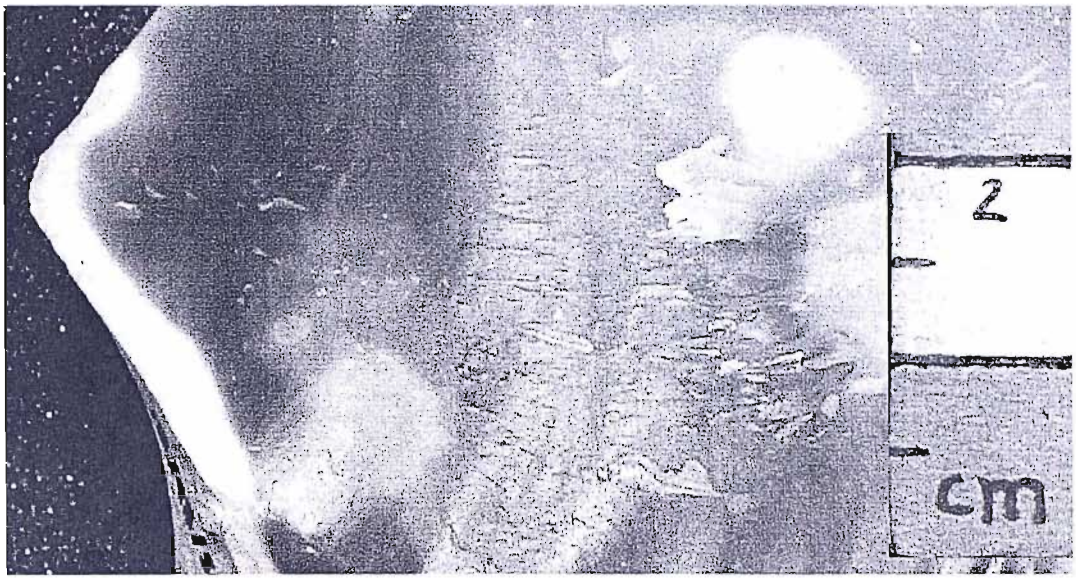


Figure 4.16. Curvilinear clusters of rightward flaps and Z hackles. Boxgrove Q1B #L587.

In Figure 4.17 are visible two main clusters of leftward flaps, one just below the bulb, and the other at the distal end of the negative.

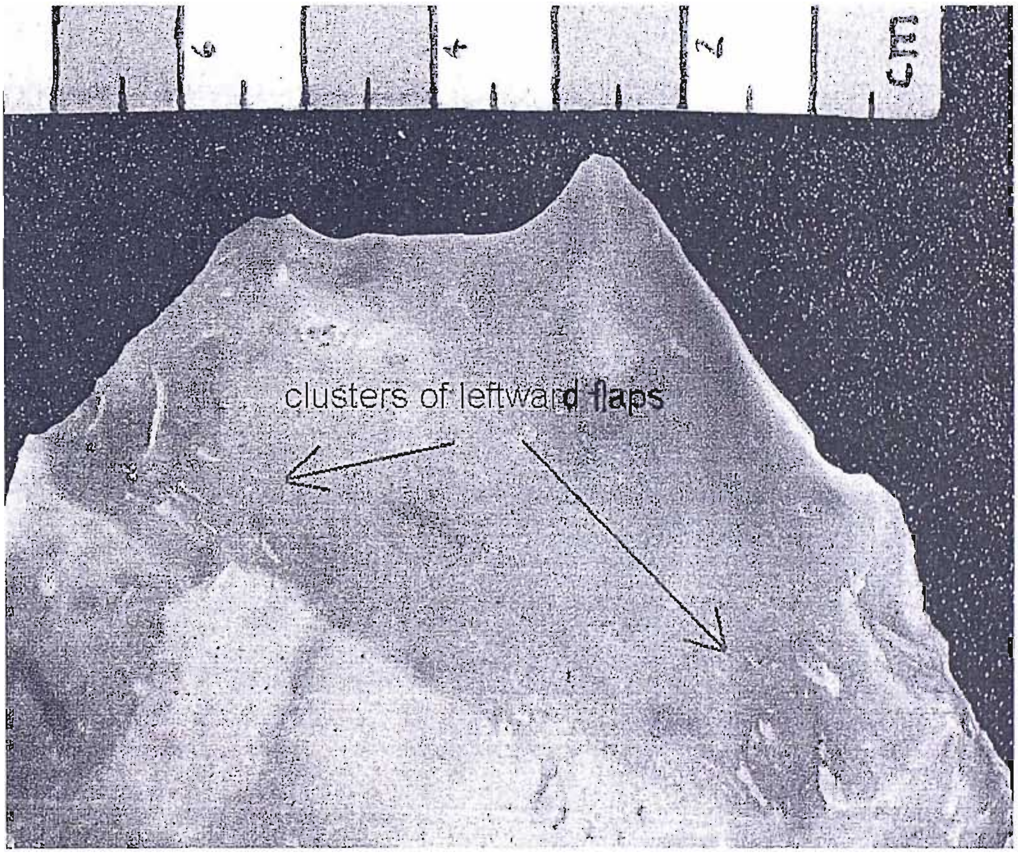


Figure 4.17. Clusters of leftward flaps. Boxgrove Q1B #5774.

4.3.1.3.1.4. Distribution of the features

Hackles and flaps are found on any portion of a fracture surface (on the bulb; connected to the cone or not; at the base of the bulb; at the edges of the flake), in any distribution (isolated; in clusters, especially in parallel lines spreading along the curved concave bulb base; in groups along the flake edge), and of any size (several mm to several cm length, width increasing proportionately.

In fact, hackles and flaps are just the counterparts of each other on two surfaces of a fractured stone. Because they are products of the fracture process, i.e. the flake detachment process, each hackle and flap on a flake has its corresponding other feature on the negative. Hence, a rightward flap on a tranchet negative has a matching Z hackle on the resulting flake, and vice versa, and respectively for leftward features: left flap on a flake has a matching S hackle on the handaxe. The next two images illustrate this principle.

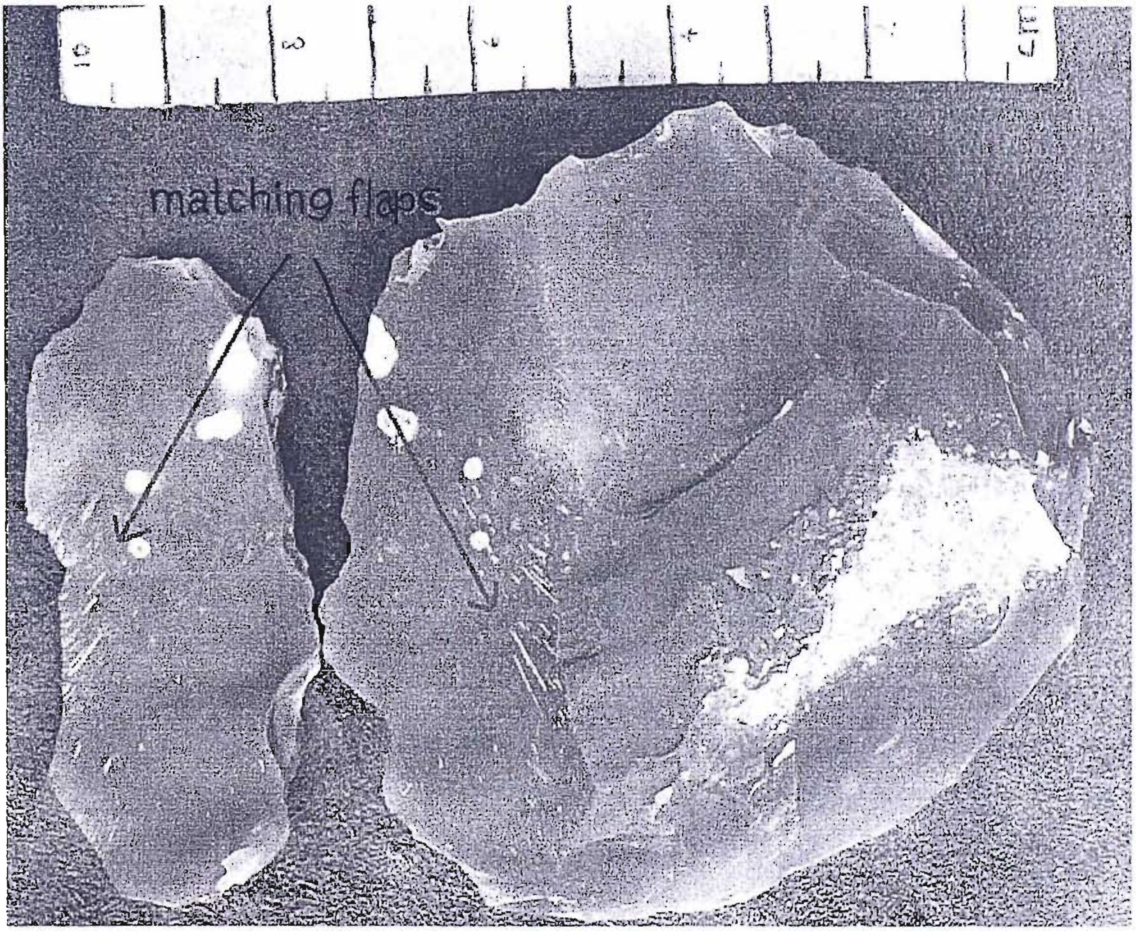


Figure 4.18. Matching flaps on flake and negative. Experimental (FS).

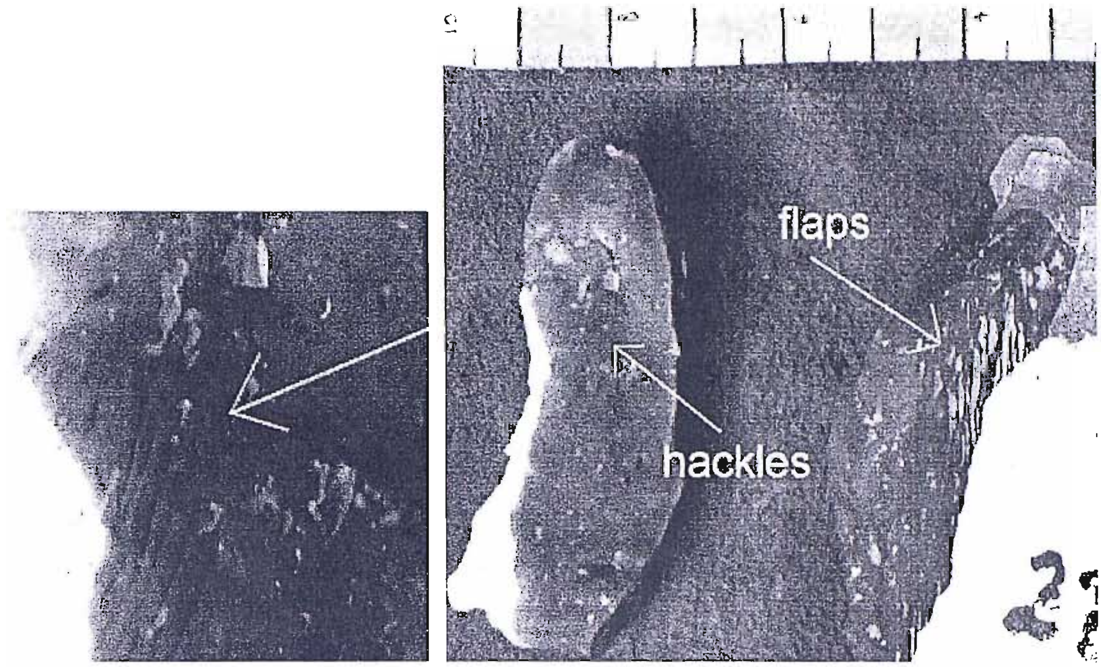


Figure 4.19. Matching hackles (on flake) and flaps (on negative).

It was originally thought that flaps were simply partially-detached hackles, but that does not seem to be the case given the above. A further literature search is currently under way to investigate this question.

In coding the negative scars for hackles and flaps, each of these features was scored as present or absent, and their direction noted (right or left for flaps, S or Z for hackles). In general, the flaps and/or hackles on a negative scar all pointed in the same direction. Occasionally an isolated feature pointed in the opposite direction from the majority of features on that scar, but these could always be attributed to a localised disruption in the fracture propagation caused by an inclusion (fossil, crystal, area of coarse-grained flint). On a very few cases there was a cluster of opposite-pointing features along part of the thin distal edge, which are interpreted as a shift in the direction of flake detachment as it neared the end of the flake: the final, thinnest part of the flake might have a different resonant frequency from the central, thicker part (Baker 2003).

If there were conflicting features, only those were counted which were thought to reflect the main fracture event. Only one error was found in this coding, in which there were two opposing sets of features; the wrong set was coded, but the error was revealed by the statistical analyses.

4.3.1.4. Step 4. Measure angle of tranchet

4.3.1.4.1. Angle measurement

Once the direction is ascertained the angle of removal can be measured. To measure tranchet angles on bifaces, a round, transparent protractor with a rotating arrow dial was used (shown in Figure 4.20). The measure consisted of aligning the protractor's 90 degree mark parallel to the vertical (long) axis of the biface, viewed with the tip up and the tranchet face up. This defines the horizontal axis as the line passing through the point of impact and orthogonal to the vertical axis of the biface. The dial hinge was placed on the known or supposed point of impact, and the moveable arrow was aligned with the scar's axis of percussion (Figure 4.21). The angle recorded is (α+90) as shown in Figure 4.21.

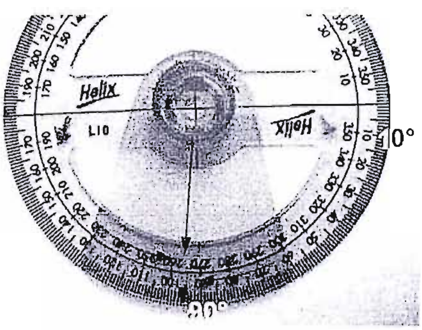


Figure 4.20. The protractor used for the tranchet angle measurements.

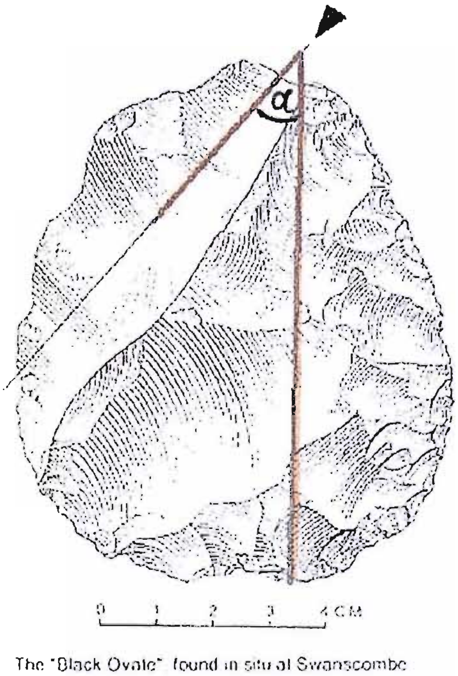


Figure 4.21. Method of measuring tranchet angles on the bifaces. Biface drawing used with kind permission from J. McNabb.

Angles between 0° and 89° were defined as struck from the left, and angles 91° to 180° as struck from the right. Angles are grouped within ten degrees, as this is the best precision that can be obtained with this hand-held tool (see below in Reliability).

4.3.1.4.2. Reliability

Precision was judged to be about 10 degrees, since measuring with the protractor is imprecise. Repeat measurements done on a subsample of 19 randomly-drawn Boxgrove handaxes, several months after the last visit, revealed a high intra-observer reliability (Cronbach's alpha = .989; inter-item correlations = .983; type A intraclass correlation coefficient using an absolute agreement definition on single measures = .979; N = 23) in the measures of 23 tranchet scar angles (Table 4.2):

handaxe number	first measure	second measure	raw difference	absolute difference	difference from horizontal	negative laterality
11568	150	157	7	7	7	R
12043	143	135	-8	8	-8	R
12191	150	130	-20	20	-20	R
12806	153	145	-8	8	-8	R
12878	45	37	-8	8	8	L
13720	35	40	5	5	-5	L
13858	37	53	16	16	-16	L
1410	147	143	-4	4	-4	R
30098	45	30	-15	15	15	L
30259-L	27	30	3	3	-3	L
30265-L	47	50	3	3	-3	L
30265-R	167	160	-7	7	-7	R
30650	80	80	0	0	0	L
30817	100	95	-5	5	-5	R
3837	38	47	9	9	-9	L
4524	23	37	14	14	-14	L
4892-1	164	160	-4	4	-4	R
4892-2	32	25	-7	7	7	L
6706-1	22	34	12	12	-12	L
6706-2	148	144	-4	4	-4	R
7474	165	130	-35	35	-35	R
FL. 149-1	65	60	-5	5	-5	L
FL. 149-2	153	154	1	1	1	R

Table 4.2. Reliability data for angle measures

Using raw values of measurement difference (column Raw Difference) between the 23 repeated protractor angles, the values ranged from -35 to +16 (mean = -2.61, median = -4, SD = 11.38). Interestingly, there was a tendency for the second measurement to be closer to the vertical axis than the first, as shown by taking the acute angle between the horizontal line and the tranchet scar axis. In the column Difference from Horizontal, positive delta means a move towards the horizontal of 0° or 180°; negative delta means a move towards the vertical of 90°. In these data, the average was -5.39 (median = 2.15, SD = 10.31).

To reflect the discrepancies in protractor angle regardless of tranchet direction, the absolute values of angle measurement difference are used (column Absolute Difference). Here the average was 8.7 (median = 7, SD = 7.6, N = 23); minimum delta was 0° and maximum 35°. This means that first and second measures were on average 8.7° apart, and they could be as much as 35° discrepant, although they were also sometimes in absolute agreement.

A further test was for a difference between right and left angle repeat measurements, using the delta in column Difference from Horizontal. The mean difference between horizontal differences of 4.83 is not significant (two-tailed p=.272). As the significance value of the Levene test (.980) is over .05, the two groups have equal variances. The mean discrepancy between repeated left angle measurements was -3 (SD=9.4, N=12) and for right angles it was -8 (SD=11, N=11). The extreme values of the left angle discrepancies ranged from -16 to +15, and the right angles' extreme deltas ranged from -35 to +7. Since a more negative delta means that the second measure was more vertical than the first (and vice versa for positive delta), this indicates that repeated right angle measures were slightly more vertically-biased than the left angle repeats. However, these are only extremes, and most of the repeat measurements are still close to zero (although on the negative side, as mentioned in the preceding paragraph).

These results suggest that most tranchet scar angles can be reliably measured to within 10 degrees by the author.

Some of the reasons for which measurements disagree are due to the nature of the tranchet negative: a scar that is complete, with bulb and its full surface area present, is easier to read than a partially obliterated scar. For example, when the lower half of the scar has been removed along with the lower ridge, it can be impossible to know where the lower boundary of the negative was located, and thus the line bisecting the area from bulb to distal end cannot be precisely placed. For this reason the axis of percussion must be estimated, and this leads to high inconsistency when not all fracture features are present. One possible explanation, that can be eliminated, for the bias towards more vertical angle readings in the second (i.e. repeat) measurements is practice effects. The repeat measures were taken two months after the final visit, so they should have been as expertly-measured as the original samples.

4.3.1.4.3. Angle interpretation

Ranges fall between 1° and 179° for tranchet negative scars struck from the tip of the handaxe towards the base (the most common pattern), and between 181° and 359° for scars struck from a point further down the edge up towards the tip (here named "upward" removals). Negatives struck horizontally measure 0° (left-struck) or 180° (right-struck), and vertically-struck scars measure 90°.

Because of the imprecision in measuring with the protractor, the tranchet angles are given in 10-degree ranges (as discussed above in Reliability, see table 4.2), shown in Figure 4.22. These are 355°-5° (the left-struck horizontal), 5°-15° until 75°-85° for the left-struck negatives, and 85°-95° for vertical removals; the right-struck negatives fall into ranges 95°-105° until 165°-175°, and 175°-185° represents the right-struck horizontal. The same rules apply to the upward-struck flakes: the right-struck upward removals range from 185°-195° until 255°-265°, the upward vertical is 265°-275°, and the left-struck upward tranchets fall into ranges 275°-285° until 345°-355°.

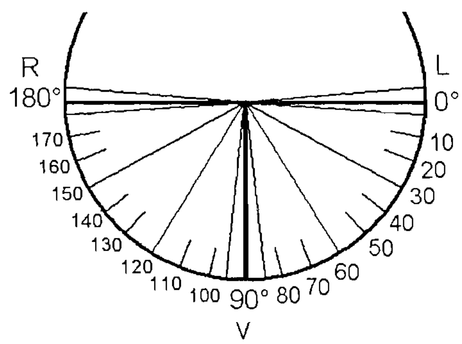


Figure 4.22. Diagram of the ten-degree angle ranges for tranchet negatives.

For comparing and contrasting the left and right angles, the values were translated into their corresponding "absolute values" between 0° and 90° in order to express the acute angle with respect to the horizontal line. This translates right-struck angles into their corresponding mirror values in the left-struck ranges. Hence, the right-struck angle range of 145°-155° is translated into an absolute value range of 25°-35°. Working with these absolute value angles allows a better view of the differences between the angles of rightward and leftward negatives. Figure 4.23 shows examples of a left-struck and a right-struck negative from Boxgrove.

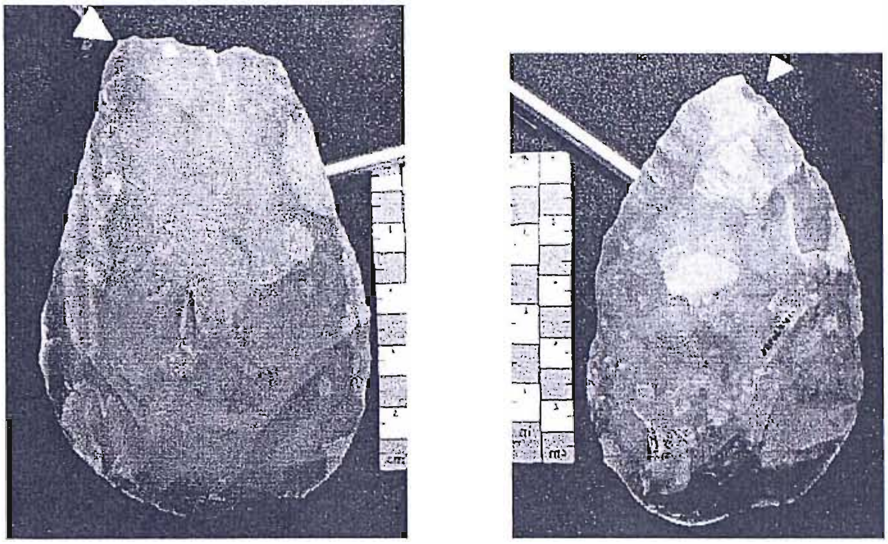


Figure 4.23. Examples of tranchet negatives: Boxgrove Q1B #6717 (L) and #30956 (R).

4.3.2. Examples

In order to illustrate the process of reading negative features, Boxgrove biface number 2891 [FL.102] is shown in the two photographs (Figure 4.24) with the flake scars outlined (some are outlined just beside the edge of the scar so as not to obscure this latter on the photo). On face (a), the first tranchet negative (marked 'Tr.') is left-struck. The tranchet scar on face (b) is right-struck and was made second, judging by the negative bulb present. This was followed by three small removals on the distal end of the second tranchet scar. The distal two of these are hinged, as indicated by the step symbol on the image. In this case, neither of the two tranchet removals was final.

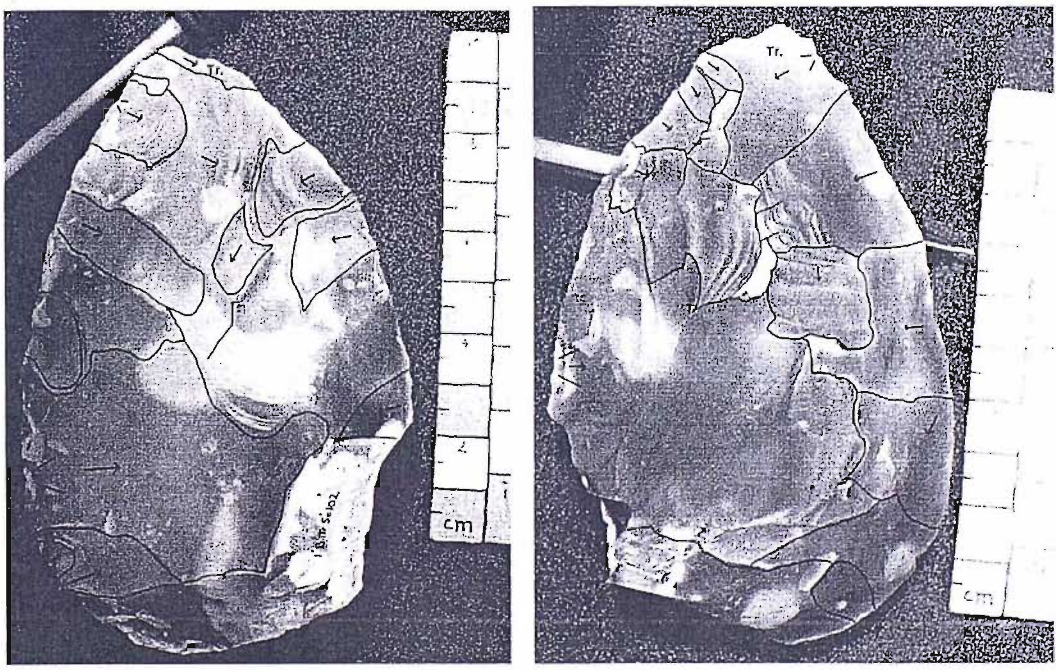


Figure 4.24. Boxgrove biface 2891 [FL.102] with negatives outlined.

4.4. RESULTS

4.4.1. High Lodge

4.4.1.1. Tranchet laterality

Out of 21 handaxes examined, 19 had one or more measurable tranchet scars. Two handaxes were excluded (#3186 and #3222) for the following reasons: the wide scar at the tip of #3222 was judged to be a platform rather than a tranchet; the scar at the tip of one face of #3186 was judged not to be a tranchet. The 19 handaxes with measurable tranchet scars yielded a total of 24 tranchet scars, of which 19 are right-struck and four left-struck (Table 4.3).

L	V	R	total
4	1	19	24
17%	4%	79%	100%

Table 4.3. Laterality of 24 tranchet scars on 19 High Lodge handaxes.

A binomial test on the 23 (either left or right) lateralised scars obtained p = .003 (two-tailed), showing the Right:Left ratio of struck tranchet scars to be statistically different from chance, as did the chi-squared test: $\chi^2(1, N = 23) = 9.783$, p = .002. Therefore it appears that the High Lodge assemblage is significantly biased towards right-struck tranchet negatives despite the small sample size.

When considering only the 13 handaxes with single tranchet scars (the 14th single scar is vertical), the proportion of right-struck scars is still greater than the left-struck (Figure 4.25 and Table 4.4). However, the small number of left-struck negatives precludes any statistical analysis on these sub-groupings.

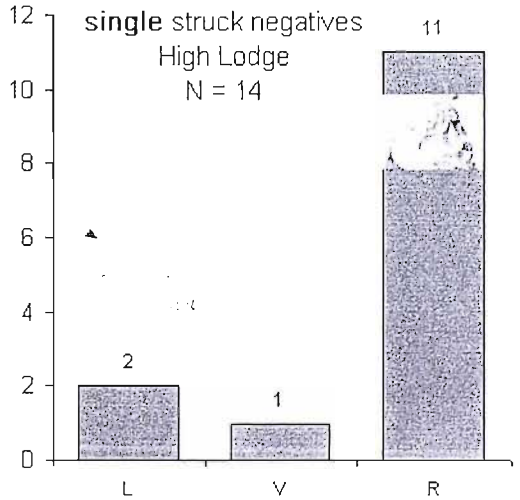


Figure 4.25. Laterality of single tranchet negatives on High Lodge handaxes.

When considering only first removals (in each pair of scars), one is left-struck and four are right-struck. The second removals in each pair also count the same (Table 4.4).

	L	V	R	total
first tranchet negatives	1	0	4	5
second tranchet negatives	1	0	4	5

Table 4.4. Laterality of first and second tranchet negatives on High Lodge.

In summary, the High Lodge assemblage is strongly biased towards right-struck tranchet flakes, whether they are single, first, or second removals.

4.4.1.2. Tranchet removal order

Five of the 19 handaxes have two tranchet scars, as mentioned in the paragraph above. These are always on opposite faces in the High Lodge assemblage. These occur in the following removal orders (combined in Figure 4.26 with single tranchet removals):

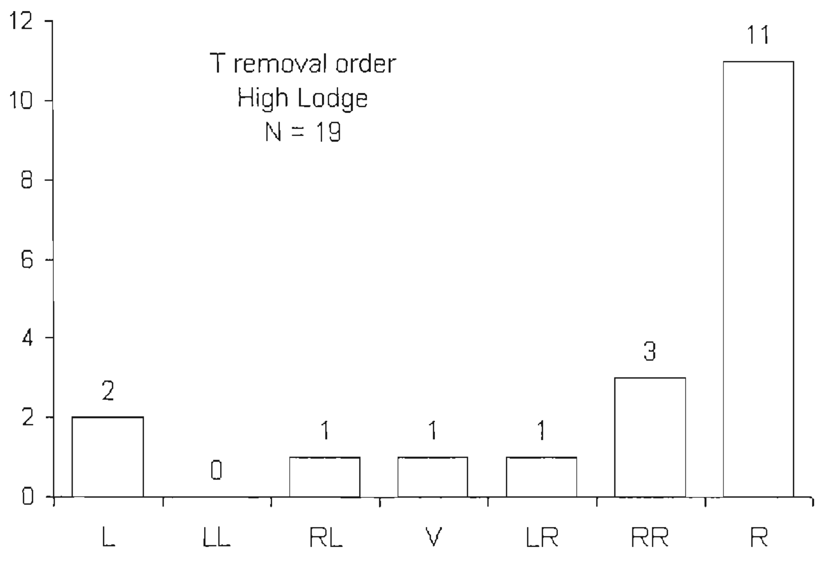


Figure 4.26. Removal orders for tranchet scars on High Lodge handaxes.

It is noteworthy that no LL combinations were found, but three RR combinations did occur in this assemblage. These six tranchet scars most certainly contributed to the high number of pooled right-struck scars and to the high proportion of right-struck scars as first and second in a pair. The LR and RL order were each noted once. The Right-struck bias at High Lodge is also reflected in the removal orders, in which three RR pairs occur but no LL pairs are found.

4.4.1.3. Tranchet scar lateralised percussion traits

The first check was for correlations between the laterality of flaps and hackles on each tranchet scar. Because many negatives had only either flaps or hackles, the scars with both elements represent a subsample of the archaeological sample. In the High Lodge sample, only one tranchet scar yielded both hackles and flaps: #3228-2. This right-struck negative showed a Z hackle and a rightward flap, the expected combinations according to the Boxgrove pattern (below).

The state of preservation of these pieces was generally not fresh enough for such traces to have remained visible; many are patinated, and the raw material appears too coarse in some cases for these features to appear. Furthermore, the small sample size does not give reason to expect many features: even in a fresh assemblage like Boxgrove Q1B, these features do not occur on every negative. 35 % have some features at Boxgrove. This predicts only 8 scars should contain features at High Lodge, whereas the actual number is 11. Eight percent of the Boxgrove assemblage have both hackle and flap features. This same percentage would yield an expected number of 1.92 scars with both features for n=24 scars at High Lodge; the actual number is one.

Crosstabulations between the tranchet scar's laterality and the direction of hackles or flaps show a weak ($p<0.1$) tendency for right-struck scars to contain rightward flaps (Pearson $\chi^2 = 5.000$, df = 2, two-sided p = .082) and Z hackles. In fact, the only tranchet scar to possess both hackles and flaps (#3228-2) has this combination.

However, it must be noted that no left-struck negatives were found to contain any hackles, and only one left-struck negative contained any flaps. The two tables below show that the unexpected pattern is rare: only 1 S hackle out of 7 occurred on a right-struck negative, and only 1 leftward flap occurred on a negative, this being a vertically-struck tranchet scar tending toward the left (# 3226).

flaps * laterality Crosstabulation		negative laterality			Total
		L	R	V	
flaps	l	0	0	1	1
	r	1	3	0	4
Total		1	3	1	5

Table 4.5. Counts of flaps per lateralised negative at High Lodge.

hackles * laterality Crosstabulation		negtiave laterality			Total
		L	R	V	
hackles	S	0	1	0	1
	Z	0	6	0	6
Total		0	7	0	7

Table 4.6. Counts of hackles per lateralised negative at High Lodge.

The High Lodge data show that the pattern of flaps and hackles is expected since they are basic features of flint fracture. Despite the small number of data points for the High Lodge sample, the use of these features to interpret tranchet scars' axes of percussion is thus justified.

4.4.1.4. Tranchet angle

4.4.1.4.1. Angle ranges

The angle of the tranchet negative's long axis relative to horizontal (the line perpendicular to the long axis of the handaxe) was measured, as described in the methodology. Figure 4.27 shows the frequencies of High Lodge tranchet negatives in each ten-degree angle range. These are labelled on the X axis by their midpoint value (i.e. angle range 25-35 is labelled as 30 on the graph).

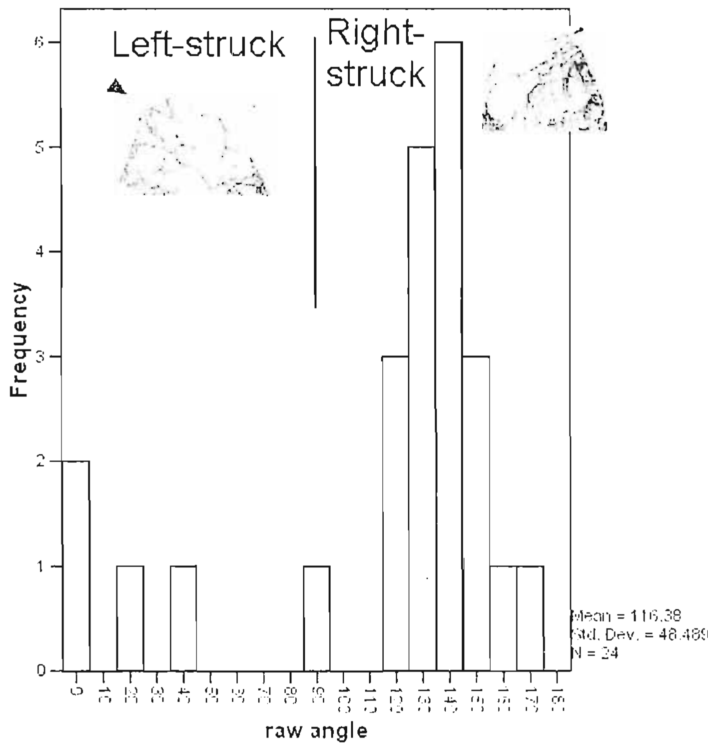


Figure 4.27. Frequencies of High Lodge tranchet negatives in each 10° angle range.

Working with "absolute value" angles allows a better view of the similarities between the angles of right and left negatives. There is a peak at 35°-55° from the horizontal line, showing a preference to strike tranchet flakes around the absolute angle of 45° (Figure 4.28).

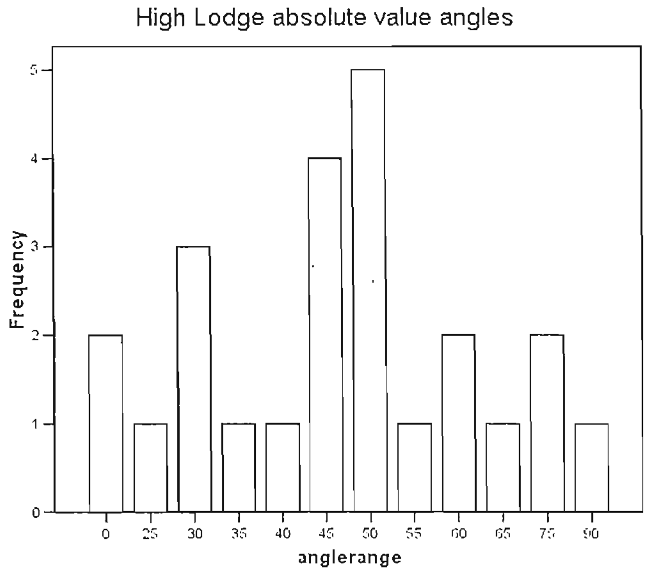


Figure 4.28. Absolute value angle ranges, High Lodge right and left combined.

4.4.1.4.2. L vs. R angles, handaxes pooled

Table 4.7 shows compared Left-struck and Right-struck dispersions and distributions, showing mean and standard deviation, variance, and range. However, there are only 4 cases of left-struck negatives, which prevents any interpretation of patterns in these values.

Statistics		L angle range	R angle range
N	Valid	4	20
	Missing	20	4
Mean		17.50	51.50
Std. Deviation		21.794	15.985
Variance		475.000	255.526
Range		45	60

Table 4.7. Comparison of High Lodge frequencies for left and right angle ranges.

Figure 4.29 displays these distributions.

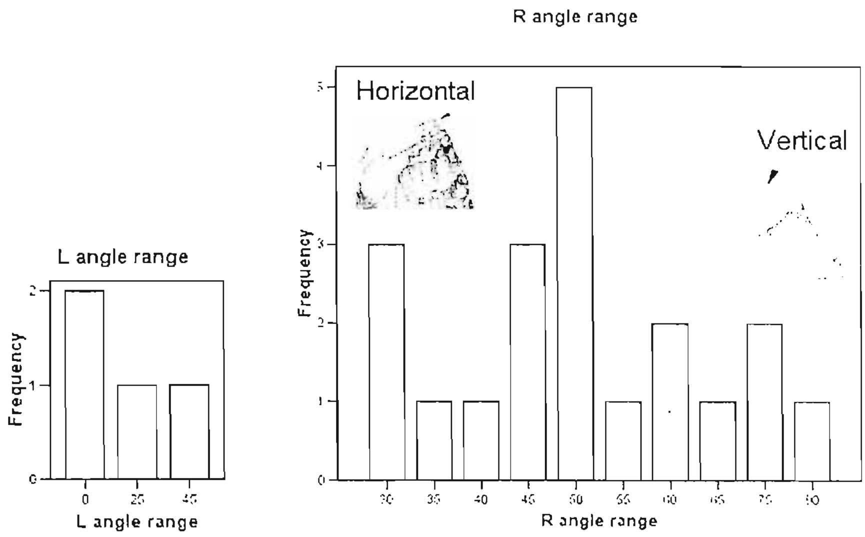


Figure 4.29. High Lodge left and right absolute value angle ranges.

Comparing the angle values, the rightward angles appear to be shifted closer to the vertical than the leftward angles. This finding appears to support the hypothesis set out in the beginning of this chapter, that right-struck tranchet scars have an angle closer to the vertical than left-struck scars. That result appeared when all the scars in each laterality group were pooled. The next question to be addressed is whether these pooled left-struck and right-struck angles have the same pattern as the individual L+R pairs on each handaxe. This can more precisely test the hypothesis, in terms of comparing the different angles that are found on a single handaxe.

4.4.1.4.3. Left vs. right angles on the same handaxe

To compare the left-struck vs. right-struck angles within handaxes, only the handaxes with more than one tranchet removal were analysed. At High Lodge, these consist of five double-tranchet pairs, always on opposing faces. There are one of each RL and LR pairs; no LL pairs, and three RR pairs. It must be stressed that the very small number of left-struck angles (4) calls for caution in interpreting differences between the laterality groups. Therefore the left-struck and right-struck angle data are not analysed separately, but are simply pooled for High Lodge when making comparisons with Boxgrove below.

4.4.1.5. Summary - High Lodge

The assemblage consisted of 19 tranchet handaxes studied from the site, which is roughly contemporary with Boxgrove despite the imprecise stratigraphic provenance of its Old Collection lithics. Twenty-four tranchet negative scars were analysed. A strong bias towards right-struck scars was present (79% of all tranchet scars), on single, first, and second tranchet removals. The order of double removals was also biased to right-struck flakes, yielding 3 RR combinations but no LL pairs. The fracture features on the negatives were poorly preserved, so that either flaps or hackles could be seen on only 5 tranchet scars. Nonetheless, there was a good match between right-struck negatives and rightward flaps and/or Z hackles. The removal angles are closer to the vertical for right-struck flakes. There are not enough left-struck negatives for statistics, but the most vertically-oriented left-struck angles match the most horizontal right-struck angles.

4.4.2. Boxgrove

Fourteen pieces from Q1B and one from GTP17 had been taken away for analysis and thus were not available to study. A sample of tranchet bifaces from Q1A (N=9) and Q2C (N=3) was also studied, in addition to the handaxe from Q2A (# 9700) with its three conjoining tranchet flakes (described by Bergman & Roberts 1988 before the third flake was found). This brought the number of potential Boxgrove tranchet bifaces to 319.

According to the explanation in the methodology, all removals on bases are excluded from this study; the bifaces were re-coded so that the base removals were not counted in the sequence. For example, piece # 31665, which has the RL removal order on the tip plus a rightward removal on the base, was re-coded as RL. Five bifaces with only a single base tranchet were thus excluded from the entire analysis: #10188, #10351, #4193, #4216, and #5561.

There was a total of 461 identifiable tranchet negatives on the tips and bases of the 319 handaxes studied. Following the argument made in the methodology against using base-struck tranchet scars, I excluded the ten base tranchet negatives (counting 4 L-sgl, 1 L-one, 2 R-one, 2 R-3, and 1 V-sgl). These are listed in Table A2.1 in the Appendix 2; they consist of the five handaxes with single scars mentioned in the preceding paragraph, and five scars on handaxes that also have tip removals. It must be stressed that comparisons with the flake assemblage in this respect are impossible, since it is not yet possible to determine which part of the handaxe a tranchet flake was struck from; hence no exclusions were made in the tranchet flakes.

The largest proportion of handaxes (58%, n = 182) had one remaining visible tranchet negative, and others had two (40%, n = 127) or three (2%, n = 5) tranchet scars which were complete enough to be analysed. Eight negatives could not be interpreted. They consist of five handaxes (not included in the counts above) and three "T1" first-tranchets (two are included in the overall counts because they are part of double-tranchet pairs), listed in Table A2.1 in the Appendix 2. Only scar numbers 30405-1 and 7474-1 were included in the laterality counts; all others were excluded from the entire analysis. Excluding the handaxes which only had tranchet negatives on the base, there were 314 handaxes with at least one tranchet scar on the tip, making a total of 451 tranchet negatives.

The total number of flakes analysed was 66. Thirteen flakes located in the tranchet flake drawer were excluded for various reasons, mostly because they could not be oriented (details are in Table A2.2 in Appendix 2). Only one conjoin was found between a subsample of these flakes (only the unbroken and largest ones) and a subsample of the handaxes (drawers 28 to 34). These are flake # 5169 and biface # 30067: their features match, although there is slight distortion preventing an airtight fit, as with the three flakes and handaxe # 9700.

4.4.2.1. Tranchet laterality (H, F)

4.4.2.1.1. Laterality in negatives

As mentioned above in Assemblages, there were 314 handaxes with at least one tranchet scar on the tip, making a total of 451 tranchet negatives. Only two conjoins were studied: the previously-known Q1A biface with its three tranchet flakes and the newly-found pair of flake # 5169 and biface # 30067.

Not counting the five vertical (85° to 96°) removals on tips, the ratio of left to right scars is statistically different from chance (binomial test, two-tailed p = .042); $\chi^2(1, N = 446) = 4.341$, p = .037), shown by the fact that p<.05 in both cases (Clegg 1982:175).

Left-struck = 245 (55 % of 446 non-vertical scars)
Right-struck = 201 (45 % of 446)
Vertically-struck = 5

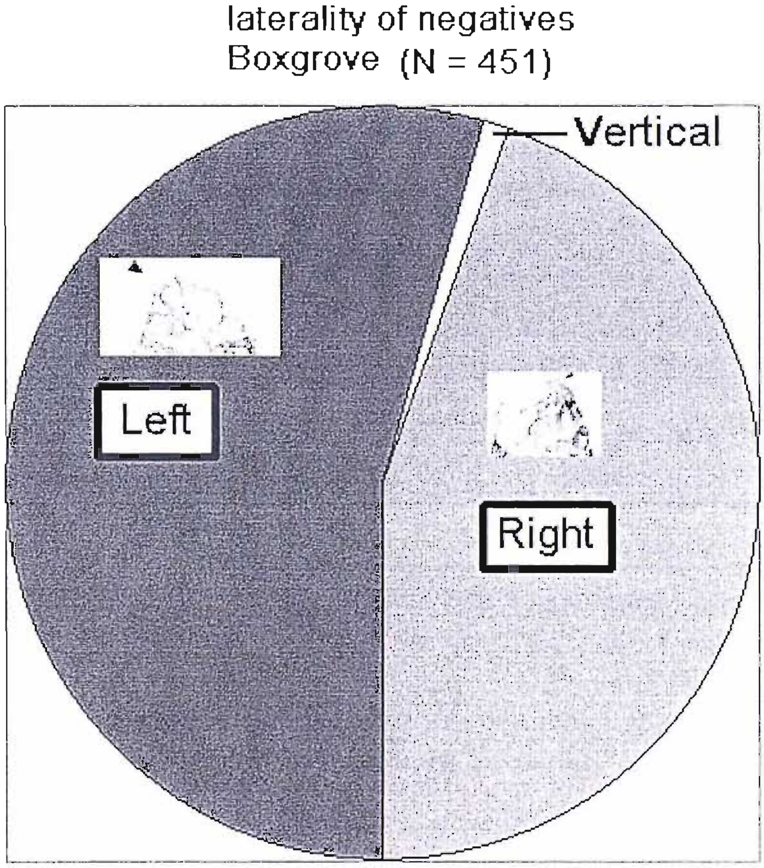


Figure 4.30. Laterality of tranchet scars on 314 Boxgrove handaxes.

4.4.2.1.2. Laterality in flakes

Among the 66 Boxgrove flakes that were counted as tranchet flakes, the numbers of right and left struck flakes are not statistically different from chance according to the binomial test (two-tailed p = .109) and the chi-squared test: $\chi^2(1, N = 66) = 2.970, p = .085$.

The fact that the number of left flakes (40 = 61 %) is nearly double that of right flakes (26 = 39 %) in this sample suggests a tendency toward left-struck tranchet flakes, which could be reflected in the significantly higher proportion of left- than right-struck negatives on the handaxes.

Adding to these figures the previous data from Quarries 2C and 2D, analysed by Wenban-Smith (pers. comm. 2005), the proportions are summarised in the table:

Source	Quarry	Left-struck	Right-struck	Indet.	Total
Wenban-Smith	2C	12	18	0	30
Wenban-Smith	2D	8	5	0	13
Uomini (this study)	1B, 2	40	26	13	79
TOTALS		60	49	13	122
%		49%	40%	11%	100%

Table 4.8. Combined data for Boxgrove tranchet flakes.

The total proportions are not statistically different from chance (two-tailed binomial p = .338; $\chi^2(1, N = 109) = 1.110, p = .292$). The diverse patterns in the pooled data confirm the null hypothesis that left- and right-struck tranchet flakes occur in equal proportions.

4.4.2.1.3. Comparing negatives and flakes - laterality

Returning to the handaxes, we can compare and contrast their tranchet negatives with the tranchet flakes. Taking into account the place of each tranchet negative in sequences of removals on each handaxe, there are single, first, second, and third tranchet removals, in addition to some whose order could not be identified (marked as '-one').

Considering only single removals, the proportion of left and right scars is significantly different from chance and is weakly skewed towards left-struck single tranchet scars (binomial two-tailed p = .234; $\chi^2(1, N=181) = 1.597, p = .206$), as Table 4.9 shows.

Binomial Test		N	Observed Prop.	Test Prop.	Asymp. Sig. (2-tailed)
laterality	L	99	.55	.50	.234[a]
	R	82	.45		
	Total	181	1.00		[a] Based on Z Approximation

Table 4.9. Frequencies of left and right Boxgrove single-struck tranchet scars

The view for first and second tranchets occurring in pairs has an equally consistent tendency towards leftward scars, as the next table and figure show. Table 4.10 lists the numbers of right and left tranchets for each place in a sequence (first, second, or single removals).

L order	n (L)	binom. sig.	n (L+R)	chi-sq. sig.	n (R)	R order		V order	n (V)
L-1	63	.519	118	.461	55	R-1		V-1	3
L-2	67	.275	121	.237	54	R-2			
L-3	4		5		1	R-3			
L-one*	12	.664	21	.513	9	R-one*		V-one*	1
L-single	99	.234	181	.206	82	R-single		V-single	1
Pooled L	245	.042	446	.037	201	Pooled R		pooled V	5
Total L flakes	40	.234	66	.206	26	Total R flakes			

*L-one, R-one, and V-one are scars in pairs or triples whose order could not be ascertained.
Table 4.10. Boxgrove tranchet negatives (451) by place in tranchet removal sequence.

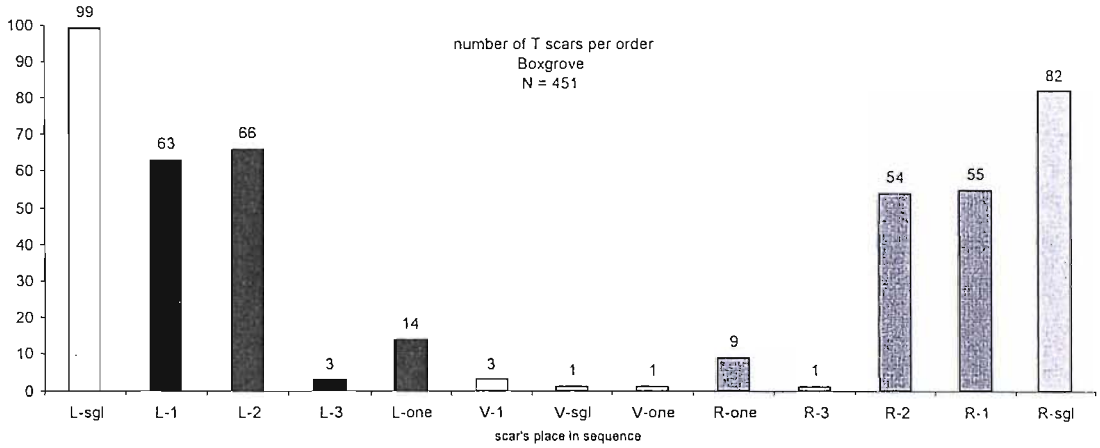


Figure 4.31. Bar chart of Boxgrove tranchet negatives (451) by place in tranchet removal sequence.

As can be seen from Table 4.10 above, in general, there is a weak yet consistent tendency for more left scars overall. Dividing each of the places in a pair of removals into left and right groups enable testing for differences between the groups. The pattern of a leftward preponderance holds for all places, whether the negative is a first removal, a second removal, or a single removal on a given handaxe. Thus, in all cases, there are more left than right tranchet scars. Statistical significance ($p<.05$) is reached in only one case, shown underlined in the table, which is for the pooled left-struck scars. Therefore the combined tranchet negatives show a statistically significant leftward bias.

4.4.2.2. Tranchet removal order (H)

4.4.2.2.1. Schema of double removals

Double-tranchet removals produce a different effect on the handaxe edge depending on whether both are struck from the same direction or not. Two removals which are done in the same direction from the viewpoint of the knapper, each on an opposite face of the biface, are essentially struck in opposing directions from the point of view of the handaxe's tip. These will result in material being removed from both edges of the handaxe. An example is shown below.

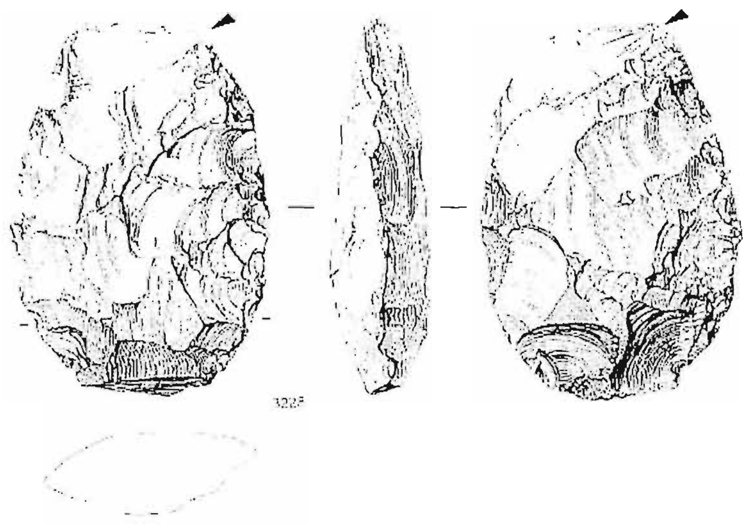


Figure 4.32. Example of double-right tranchet removals. High Lodge #3228. From Ashton *et al* (1992).

In contrast, if the goal is to remove material from the same edge of the tip, then the two removals must be made in opposite directions. These are illustrated in the figure below, which represent views looking onto the tip of the handaxe as if it were standing on its butt, pointing directly to the observer. The arrows show the direction of the tranchet removal, and the solid lines show the resulting sharp edge.

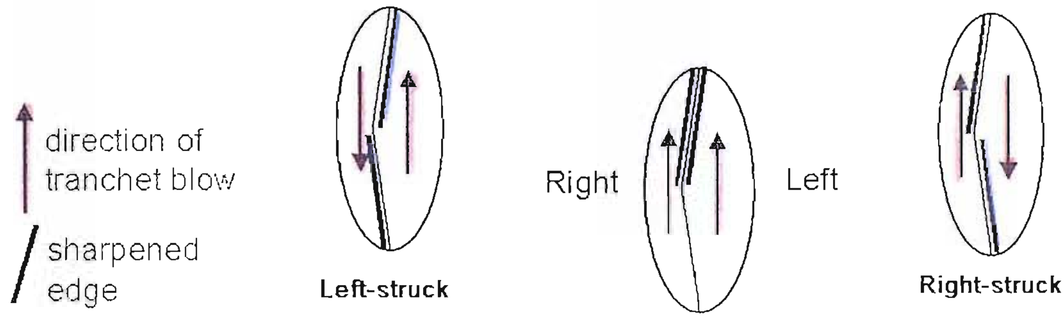


Figure 4.33. Schemas of double tranchet blows, looking onto the tip of the handaxe.

4.4.2.2.2. Orders - general numbers

Because of the relatively high proportion (40%) Boxgrove bifaces with more than one tranchet removal, they deserve closer attention.

Various combinations of left, right, and vertical scars occur, the maximum observed being three on one handaxe. At Boxgrove the doubles take the form of two removals on opposing faces. Only #7744 shows two removals on the same face but none on the other face; these are both right-struck, at 120° and 150° respectively.

In the case of triples, the third removal can be made on the same face as either the first or the second, and the handaxe flip (moving to the other face) can happen in any point of the sequence (see the table below for the details).

In theory there could be any number of tranchet removals on a given handaxe, but only the last few remain visible on the abandoned tool; the handaxes cannot tell us whether there were other tranchet removals during previous stages in the tool's lifetime.

The 314 handaxes bearing tip-struck tranchet scars were classified according to number of visible tranchet negatives left on the tip, as single (N=182), double (N=127), or triple (N=5), shown in Figure 4.34.

4.4.2.2.3. Left vs. right orders

The next step is to group the handaxes by removal order. They were placed on the left or right sides of the chart according to the conceptual counterparts that were considered relevant (double-leftward LL corresponds to double-rightward RR; LRL corresponds to RLR; VL corresponds to VR; full listing in Table 4.11). Their distribution is illustrated in the bar graph. This shows strong mirror symmetry between the left and right distributions of handaxes for each removal order. In fact, Table 4.11 shows that left-struck and right-struck numbers are similar if the orders are compared according to their symmetrical counterparts.

Figure 4.34. Number of handaxes per removal order, Boxgrove.

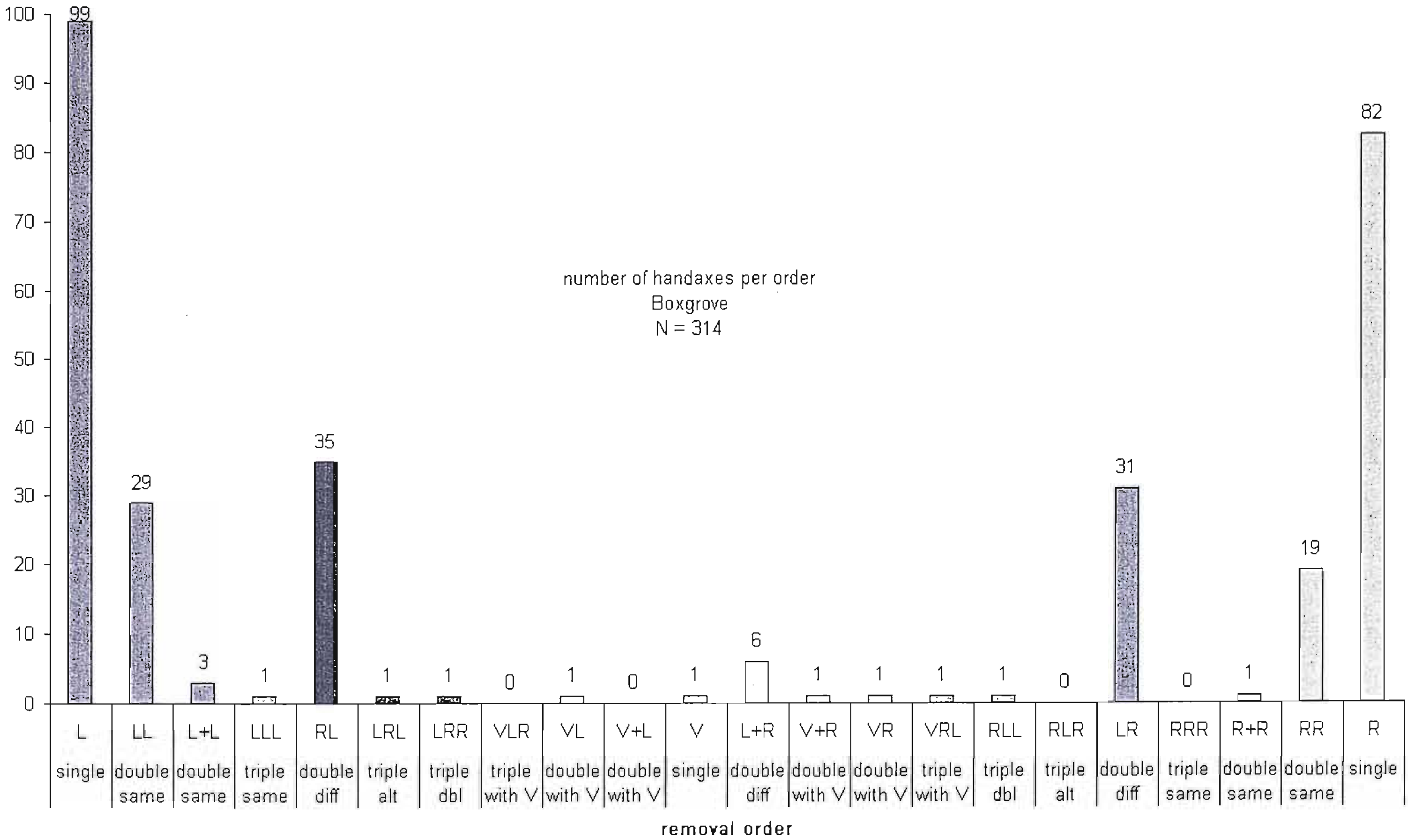


Figure 4.34. Number of handaxes per removal order, Boxgrove.

order	L	R
single	99	82
single vertical (V)	1	
double same (LL / RR)	29	19
triple same (LLL / RRR)	1	0
double different (RL / LR)	35	31
double different-order unknown (L+R)	6	
triple alternating (LRL / RLR)	1	0
triple with double (LRR / RLL)	1	1
triple with vertical (VLR / VRL)	0	1
double with vertical (VL / VR)	1	1
double with vertical, order unknown (V+L / V+R)	0	1

Table 4.11. Compared numbers of left and right handaxes (n=314) per removal order, Boxgrove.

According to Table 4.11, there are 99 single left-struck handaxes for 82 single right-struck handaxes. None have only a single vertical scar. For double removals with the same direction on each face, 29 have the LL order and 19 the RR order. For opposing removals to create a single cutting edge, 31 have the RL order and 35 the LR order; a further six handaxes have one of each right and left scars but their order could not be ascertained. Four bifaces have a vertical removal combined with another (one of each VL and VR, and one uncertain order V+R).

In sum, the existence of the conceptual counterparts of removal orders can be confirmed by the observation of symmetrical proportions in both columns. This is verified by checking that in all rows, the left column has larger numbers (as expected by the overall greater numbers of left-struck than right-struck in the tranchet negatives).

This test clarifies one questionable counterpart pair. At first it was not obvious which removal order the LR and RL pairs correspond to: should they be classified by the direction of their first tranchet removal (i.e. LR placed into the leftward category, and RL placed into the rightward group)? The table shows there are more RL than LR negatives, which suggests that actually RL should be placed into the left-struck category and LR belongs to the right-struck category. This means that the final removal is the one that best classifies the negatives. This would be the most logical prediction, given that in general, most tranchet scars can be considered as final when we find them on handaxes. In other words, we should assume the default position that a single tranchet negative alone on a handaxe could have been the last in a series of tranchet removals that we can no longer see.

4.4.2.2.4. Triple removals

Five handaxes have triple tranchet removals on the tip (Table 4.12):

biface number	triple sequence of tranchets
7590 (RLL)	A first rightward removal at 160°, then two leftwards at 80° and 70°. I failed to record which face these removals were made from.
10775 (LRR)	First a left-struck tranchet at 50°. Then on the opposite face, a right-struck one at 155°. Finally, returning to the first face, a right-struck one at 135-140°, overlaying the proximal part of the first tranchet and removing the bulb of the second tranchet.
5069 (LLL)	This tiny, black, roughly-shaped biface has a horizontal leftward tranchet L1 on one face. This was followed by two others, whose order could not be determined: one was on the same face at 50°, the other on the opposite face at 355 (upward). All were subject to later thinning flakes to remove protruding ridges at their lower margins.
1112 (LRL)	The first two tranchets were removed from the same face of this tiny handaxe, first leftward at 70°, then rightward at 155°. Then a left-struck tranchet was removed from the opposite face at 15°.
FL. 338 (VRL)	First a vertical removal was done. Then on the opposite face, one of each right and left tranchets were made. Their order could not be ascertained.

Table 4.12. Details of Boxgrove bifaces with triple tranchet removals.

Among these five handaxes, three different triple-tranchet sequences are evident. In order to facilitate discussion, they are named by the sequence in which the gestures are executed (the order of Knap and Flip) and by the location of their tranchet removals (Same face or Other face). The flow diagrams illustrate these.

Sequence KFKFK / SOS consists of removing a first (T1) from one face, then flipping the handaxe to the other face to remove a second (T2). It is finally flipped again to return to the first face for a third (T3) removal. This is the case of #10775.

Sequence KKFK / SSO entails making T1 and T2 on the first face, then flipping the handaxe once to remove the T3 on the opposite face. Handaxe #1112 received this sequence.

Sequence KFKK / OSS involves removing T1 on the first face, then flipping the handaxe once and making T2 and T3 on the second face. This is the case for #FL.338.

Because the second and third removals on handaxe #5069 could not be ordered with respect to each other, this piece falls into either the group of SOS (KFKFK) or SSO (KKFK). Handaxe #7590 cannot be assigned to a type since the face on which the removals occurred was not recorded. Nonetheless, for all four triple sequences (except 5069), the order of the first, second, and third tranchet removal is known. On #5069, the first removal is known but the other two are ambiguously ordered.

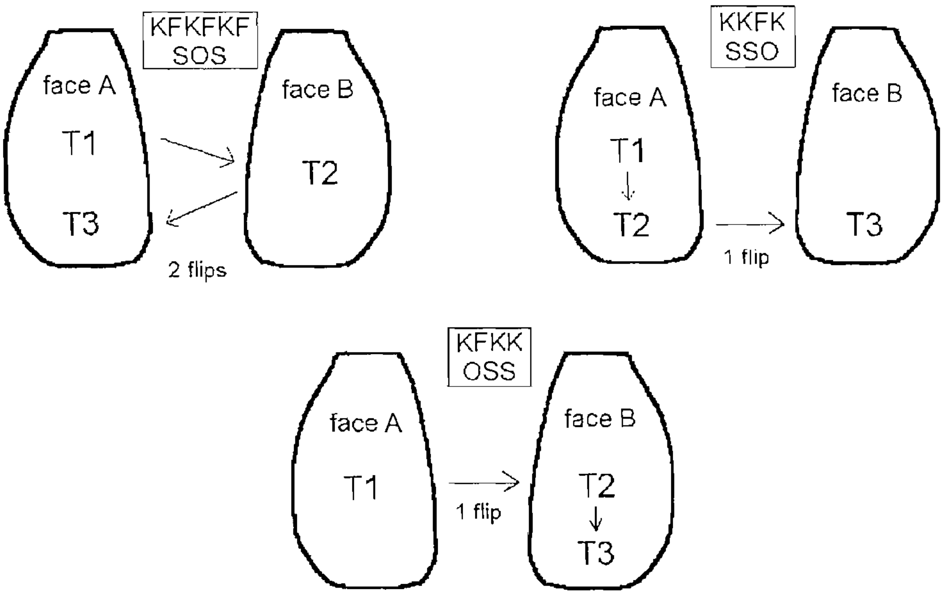


Figure 4.35. Flow diagrams of the various triple-tranchet sequences at Boxgrove (n=5).

Only the first described sequence (KFKFK / SOS) involves two flips, whereas the other two sequences only require one flip of the handaxe. However, these "sequences" can only be considered as such if all three tranchet flakes were knapped at once. This seems highly unlikely, since Pope & Roberts (2005:93) suggest that each tranchet flake was knapped only when the biface needed resharpening. This idea is supported by the fact that much of the previous (not final) tranchet scars has disappeared, possibly from use. Of course, there is no guarantee that each tranchet on a given handaxe was removed by the same individual. Pope & Roberts (2005:93) imply that people transported the handaxes when they were out of range of flint raw material, but the knapping could have been shared in a group.

There is no pattern regarding the laterality of removals in the sequence: left-struck and right-struck tranchets can occur equally on either face, in any order. The double and triple tranchet removals, although too few in number for statistics, follow the pattern of a leftward bias, although this is stronger in the double-same removals (LL vs. RR) than in the double-different removals (RL vs. LR).

4.4.2.3. Tranchet scar lateralised percussion traits (H, F)

4.4.2.3.1. Fracture features on negatives

To check for correlations between scar laterality and the direction of hackles or flaps on all tranchet scars pooled, contingency tables were produced using 451 negatives. However, only a fraction (N=160, 35 %) of these negative scars actually have any flaps or hackles: 291 scars have neither feature; 9 have only hackles; 110 have only flaps; just 41 scars have both hackles and flaps.

	left flaps	right flaps		N flaps total		S hackles	Z hackles		N hackles total
left negative	63	6		69		17	1		18
right negative	5	74		79		3	28		31
vertical negative	3	0		3		1	0		1

Table 4.13. Crosstabulations for left- and right-struck negatives vs. hackles and flaps, Boxgrove.

Bold indicates expected high numbers.

From Table 4.13 it is clear that both hackles and flaps are good predictors of the flake detachment direction. In other words, left-struck removals tend to have L-flaps and/or S-hackles, whereas right-struck removals mainly have R-flaps and/or Z-hackles.

The flaps and hackles were tested for their correlation to each other and to the direction of the tranchet negative. For these statistics, the flaps and hackles were each tested separately against the negative's laterality. This includes all scars which had both hackles and flaps, meaning that 41 of these cases overlap. There were 151 cases with flaps and 50 cases with hackles.

4.4.2.3.1.1. Flaps

According to the uncertainty coefficient (symmetric negative laterality * flaps = .591), knowing the laterality of the negative (right-struck or left-struck) reduces error by 60 % in predicting the laterality of the flaps; error is reduced by 56 % when the roles are reversed. The contingency coefficient (.650) shows there is a high degree of association between the laterality of negatives and flaps because the value is closer to 1 than to 0. The lambda measure of association (symmetric negative laterality * flaps = .825) being very close to 1 reveals that the negatives are very good at predicting the flaps (.845), and flaps are only slightly less good at predicting negatives (.806).

4.4.2.3.1.2. Hackles

The uncertainty coefficient is similar to the one for flaps (symmetric negative laterality *hackles = .571). Knowing the laterality of the hackles reduces error by 60 % in predicting the laterality of the negatives; error is reduced by 55 % when the roles are reversed. The contingency coefficient (.642) shows there is also a similarly high degree of association between the laterality of negatives and hackles. The lambda measure of association (symmetric negative laterality *hackles = .775) being also close to 1 reveals that the negatives are very good at predicting the hackles (.810), and hackles are only slightly less good at predicting negatives (.737).

4.4.2.3.1.3. Co-occurrence of hackles and flaps

In order to check for associations of both hackles and flaps on single tranchet scars (N=41), the following statistics were calculated (flaps*hackles):

The symmetric uncertainty coefficient = .519 means that error is reduced by 51 % when flaps and hackles predict each other. The contingency coefficient = .620 shows a high degree of association between the two variables. The symmetric lambda = .733 means the two features are good at predicting each other.

The next table (4.14) shows that leftward flaps most often occur with S hackles (13 times) and rightward flaps with Z hackles (24 times), whereas the opposite associations only occur rarely (left flap with Z hackle = 2 times; right flap with S hackle = 2 times). It is noteworthy that in the two "unexpected" combinations of R-flap and S-hackle, one of these occurs on a right-struck negative, which is the direction correctly predicted from its flaps' direction. The other unexpected combination occurs on a left-struck negative, which correctly matches its hackles' prediction. The same is true for the two odd combinations of L-flap and Z-hackle: one is found on a left-struck, and the other on a right-struck negative. Therefore all scars have at least ONE fracture feature that agrees with their actual struck direction.

	left flaps	right flaps	
S hackles	13	2	
Z hackles	2	24	

Table 4.14. Crosstabulations for hackles and flaps associated on same negatives, Boxgrove.

There is no negative on which the hackle and flap combination contradicts (i.e. that indicates it was struck in the opposite direction from) the actual struck direction: all the Z+R combinations occur on right-struck scars, and all S+L combinations occur on left-struck scars.

The only exception to this latter observation, #774-1 (contains a "typical" leftward S+L combination although the negative was right-struck), probably results from a coding error: according to my original drawing, there is a single R-flap on the bulb area and a row of L-flaps at the distal end. I apparently counted these latter because they were more numerous, but the existence of the R-flap on the bulb shows that the flake detachment began with the expected rightward direction, and thus I should have coded this negative as R-flap instead.

4.4.2.3.1.4. Distribution of fracture features

The next question about laterality relates to the difference between rght and left negatives in their fracture features: Is there a tendency for either rightward or leftward scars to contain more features? The next two tables (4.15 and 4.16) answer this question by giving the proportions.

	left flaps	right flaps	no flaps	TOTAL
S hackles	12 11:1 (left negative=92%)	2 1:1 (right negative=50%)	6 5:1	20 16:3
Z hackles	2 1:1 (left negative=50%)	24 0:24 (right negative=100%)	3 0:3	29 1:28
no hackles	54 51:3	54 5:49	289 171:118 (left negative=59%)	397 227:170
TOTAL	68 63:5	80 6:74	298 176:122	446

Table 4.15. Frequencies of hackles and flaps, broken down by right or left negative, Boxgrove.

	left negatives	right negatives	binom. sig.	vertical negatives	total L+R+V
any features	74	83	.523	3	160
only one feature	61	56	.712	3	120
only hackles	5	4		0	9
only flaps	56	52	.773	2	110
S hackles only	6 *	1		0	7
Z hackles only	0	3		0	3
L flaps only	51 *	3	<.001 *	2	56
R flaps only	5	49 *	<.001 *	0	54
two features	13	27	.038 *	1	41
S hackles + L flaps	11 *	1		0	12
S hackles + R flaps	1	1		0	2
Z hackles + L flaps	1	1		0	2
Z hackles + R flaps	0	24 *	<.001 *	0	24
no features	171 *	118	.002 *	2	291
					452

Table 4.16. Comparison of left negatives and right negatives, for hackle and flap features, Boxgrove.

Asterisk indicates a significant difference (p<.05).

As the two tables above show, there is no statistically significant difference in the pooled distributions of features between right-struck and left-struck negatives. Both right and left negatives are equally likely to have any kind of features (p=.523), especially if they have just one feature (p=.712). There are roughly equal numbers of right and left negatives that have only hackles or only flaps. Among the 41 scars that have both features, namely hackles and flaps together, there are significantly more (two-tailed binomial p=.038) right-struck negatives. Among scars that have no features, there are significantly more (two-tailed binomial p=.002) left-struck negatives.

The most robust differences (p<.001) appear in the lateralisation of flaps alone, which is expected according to the agreement of features with their struck direction (as discussed in the paragraphs above). Overall, right-struck and left-struck negative scars are equally likely to retain only one percussion feature. Whereas right-struck scars are more likely to retain both hackles and flaps, left-struck scars are more likely to have no visible features. Each group of scars has distinctive hackle and/or flap patterns which can be used to predict the laterality of the negative or vice versa.

4.4.2.3.2. Fracture features on flakes

Out of the 66 flakes, only three did not have any features. Of the remaining 63 flakes that showed some sort of feature, half (34) showed only one feature, this being most often flaps (n = 31 flakes). A large proportion (n = 29 flakes) had both hackle and flap features (Table 4.17). The same table shows that there are in general no significant differences between left-struck and right-struck flakes in terms of their fracture features.

	left flakes	right flakes	binom. sig.	total L+R
features present	38	25	.130	63
only one feature	23	11	.058	34
only hackles	1	2		3
only flaps	22 *	9 *	.029 *	31
two features	15	14	1.000	29
features absent	2	1		3
				66

Table 4.17. Comparison of left and right flakes, for fracture features, Boxgrove. Asterisk indicates a significant difference (p<.05).

Differences between left and right flakes are statistically significant when it comes to the occurrence of flaps alone: left-struck flakes are much more likely to have only flaps (p=.029).

The pattern of associations seen on the negatives (above, table 4.17) is the same on the flakes, as table 4.22 shows: left-struck flakes can be predicted by leftward flaps (either alone or with S hackles), while right-struck flakes can be identified by righward flaps alone or with Z hackles.

	left flaps	right flaps	no flaps	TOTAL
S hackles	10L, 0R	2L, 1R	1L, 1R	13L, 2R
Z hackles	2L, 0R	1L, 13R	0L, 1R	3L, 14R
no hackles	20L, 2R	2L, 7R	2L, 1R	24L, 10R
TOTAL	32L, 2R	5L, 21R	3L, 3R	40L, 26R

Table 4.18. Boxgrove, crosstabulations for left and right flakes within hackles and flaps. Underline indicates expected high proportions.

flake laterality * flake hackles Crosstabulation		flake hackles S	Z	Total
flake laterality	left	13	3	16
	right	2	14	16
Total		15	17	32

Table 4.19. Boxgrove flakes: crosstabulations flake laterality vs. flaps.

Testing flaps against the flake's direction, the symmetric lambda (.714) shows that flaps and flakes are good at predicting each other's laterality. The contingency coefficient (.607) shows a high degree of association between these two variables. Testing hackles against the flake's laterality, the contingency coefficient of .567 indicates good association, and the symmetric lambda (.677) shows good prediction between hackle and flake directions.

The co-occurrence of hackles and flaps on same flakes shows high association and mutual predictability (symmetric lambda .6, contingency coefficient .545). This is true despite the fact that one RZ combination was found on a left-struck flake, indicating the opposing direction to where the flake was actually struck from. Besides this one, there are a few other contradictory full combinations: LZ occurs on 2 left-struck flakes, and RS occurs on two left-struck flakes and one right-struck flake.

4.4.2.3.3. Comparing negatives and flakes - hackles and flaps

Although the left and right proportions for flakes are more divergent than for handaxes, the differences are still not statistically significant, except for flaps alone. Once again, the divergence might be due to the small sample size of the flakes. With continuous variables, the Central Limit Theorem predicts a tendency towards a more even distribution in larger sample sizes. Both right and left flakes are equally likely to have any kind of feature, even if they have just one feature. Among the flakes that have both features, namely hackles and flaps together, there are equal numbers of right and left flakes. Both right and left flakes are found in the categories of having only hackles and having no features. In summary, the use of directional features of flaps and hackles to determine laterality on negatives and flakes is justified by the strong co-occurrence of these features.

4.4.2.4. Tranchet angle (H)

4.4.2.4.1. Angles - overall frequencies

Because precision was judged to be about 10 degrees, by intra-observer reliability (as explained above in the methodology), the angle data are presented here in 10-degree ranges. As for the High Lodge graphs, the angle ranges are labelled on the X axes as their midpoint value (i.e. angle range 25-35 is labelled as 30 on the graph).

There were 449 measurable tranchet negatives out of 451 on the tips of the 314 handaxes. (the direction but not the angle could be ascertained on two right-struck scars, # 30405-1 and # 7474-1, listed in Table 2.1 of Appendix 2)

The "upward" removals are retained as their raw values between 180° and 360°.

Figure 4.36 displays the frequencies of angles per ten-degree range in a bar chart. Figure 4.37 shows the same frequencies in a polar graph (Pérez-Pérez *et al* 1999). There is a clear bimodal distribution, and this is explored in more depth below.

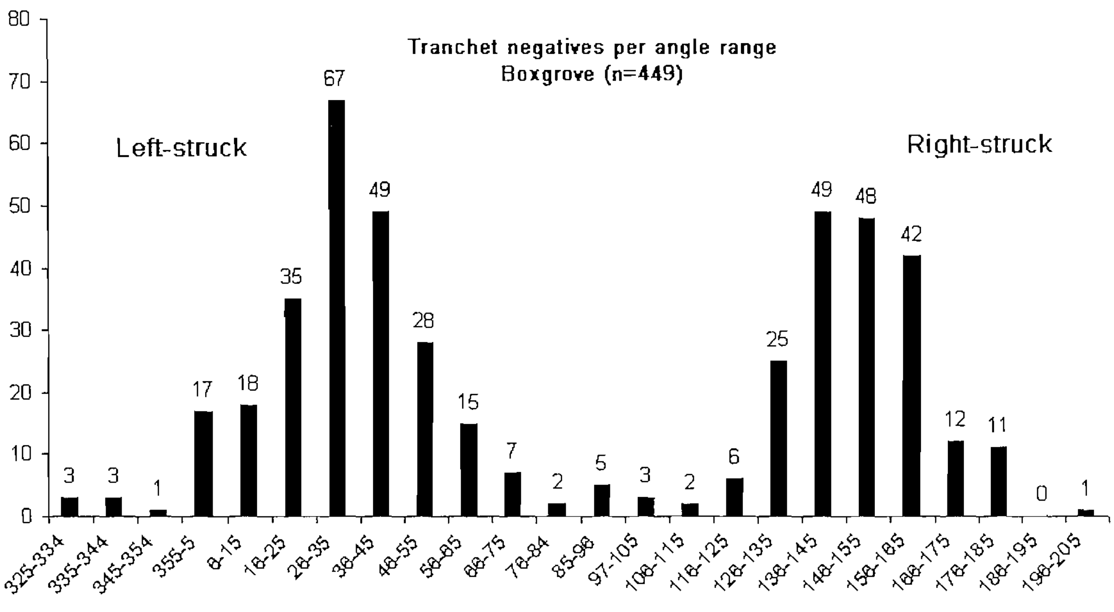


Figure 4.36. Boxgrove angles per ten-degree range.

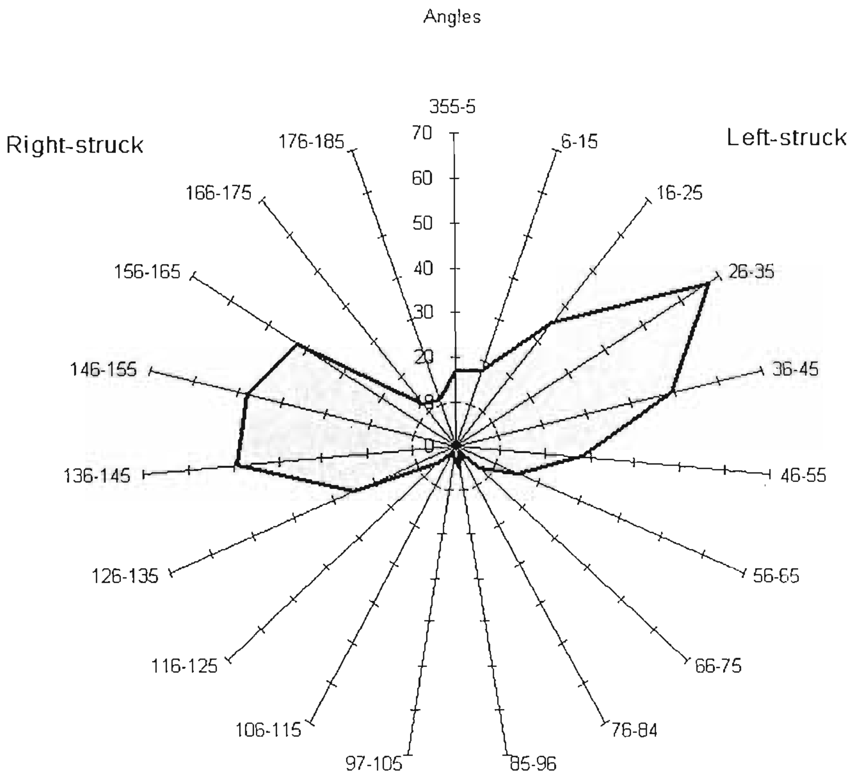


Figure 4.37. Frequency distribution of raw angle values, Boxgrove (N=441).

4.4.2.4.2. Left vs. right angles on all handaxes pooled

In order to compare the overall right and left angles, the raw angle values were re-coded into their "absolute value" equivalents. These are shown for all 449 scars in Figure 4.38.

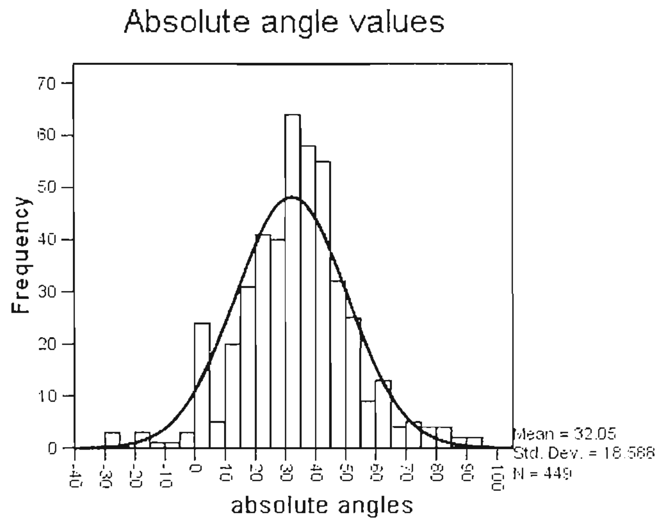


Figure 4.38. Boxgrove angle ranges, absolute value.

The distributions and dispersion data, comparing only the 444 leftward and rightward absolute angles, are summarised in the table.

absolute value angles	left angles	right angles
N	245	199
mean	32	31
S.E. mean	1.2	1.1
median	35	30
variance	373 *	243 *
S.D. variance	19.3	15.6
min	-30 *	-17 *
max	80	80
range	110	97
kurtosis	0.915 *	0.548 *
S.E. kurtosis	0.3	0.3
skewness	-0.436 *	0.135 *
S.E. skewness	0.2	0.2

Table 4.20. Comparison of left and right angle distributions and dispersions, 444 negatives, Boxgrove.

Statistically significant differences ($p<.05$) are marked with an asterisk in table 4.20. A t-test shows that the means are not statistically different: $t(442)=.753$, two-tailed $p=.452$. However, the variances, which are a measure of dispersion around the mean, are statistically different (Levene's test $p=.034$). This can be seen in the box plot (Figure 4.39): there are many more left-struck than right-struck points beyond 0°. While there are similar numbers of points with values greater than 75° on both sides, the greatest difference is the range of the left-struck absolute angles into the negative angles.

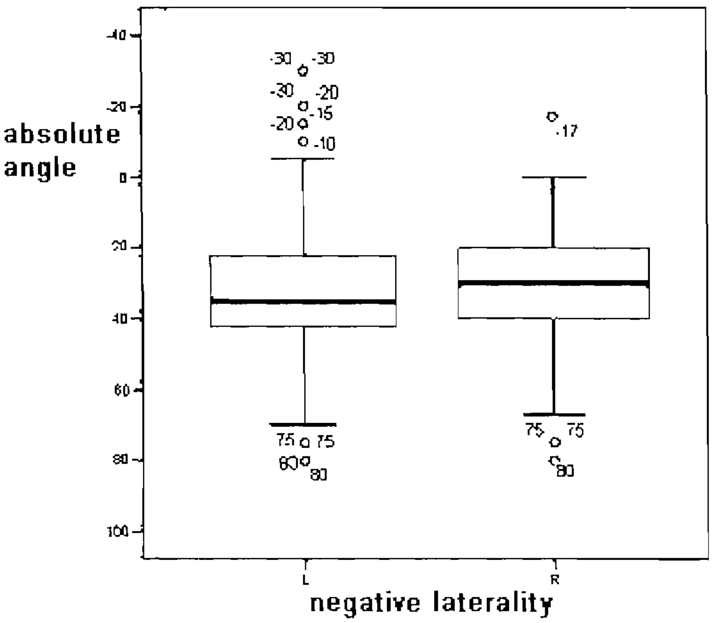


Figure 4.39. Box plot of left vs. right absolute value angles, Boxgrove (n=444).

Despite the different left-struck and right-struck variances, the value of the Mean Difference in the independent samples t-test (1.275) being greater than .05 is not significant. The two bar graphs in Figure 4.40 illustrate these comparisons.

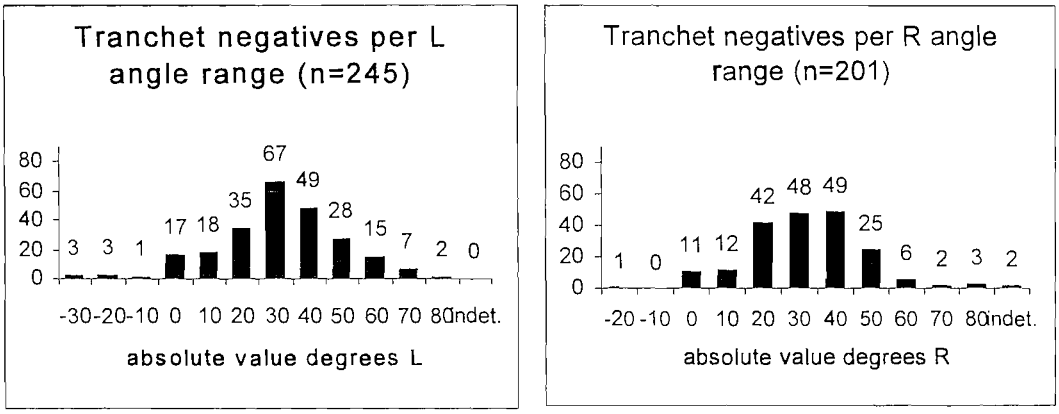


Figure 4.40. Compared numbers of left and right scars per absolute value ten-degree angle range, Boxgrove.

As the two bar graphs in Figure 4.40 show, the values in both laterality categories (left and right angle ranges) are tightly clustered between 20 and 50 degrees away from 0. The absolute value angle distributions are diagrammed in Figure 4.41 to highlight their differences.

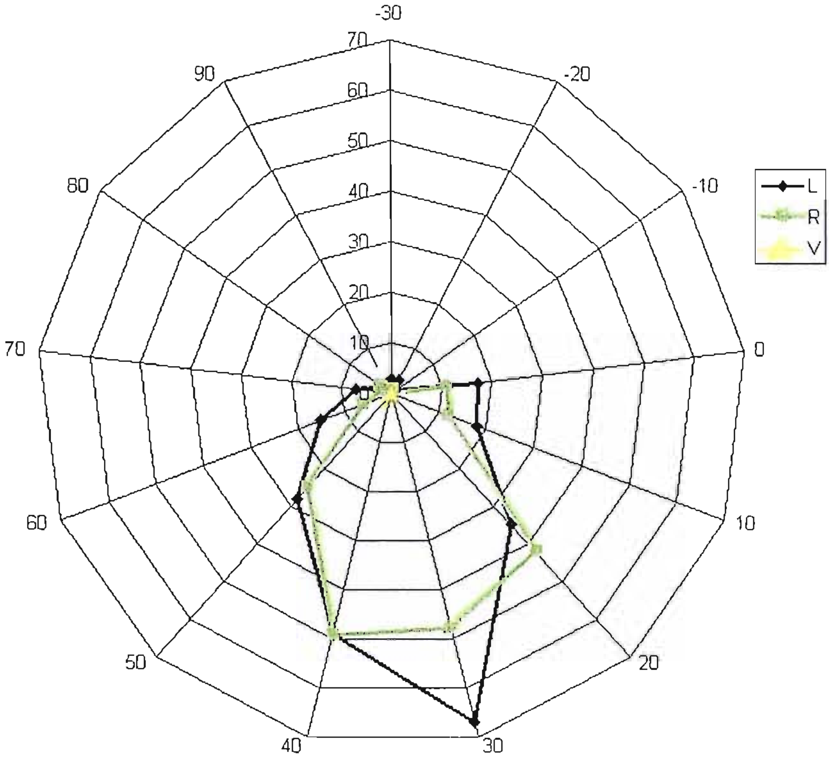


Figure 4.41. Frequency distribution of absolute value angles, Boxgrove (N=444).

Whereas the leftward angles have a clear, sharp peak at 25°-35° (reflected in the high kurtosis value) with a second peak at 35°-45°, the rightward angles peak in a wider range, 25°-45°, that spans both the primary and secondary peaks of the leftward angles. Although the right and left distributions peak in the same general place, namely the range 25-45, the left-struck peak is higher, with a maximum of 116 negatives in this range, whereas the right-struck peak consists of 97 negatives in the same range. Both laterality groups also have a third peak at 15°-25°, which indicates that the removals were preferentially made at angles closer to the horizontal. In summary, the similar peaks on both right and left angles show a preference for knapping a tranchet flake at an absolute value angle of 25-45 degrees away from the horizontal, whether it is struck from the right or the left.

4.4.2.4.3. Left vs. right angles on same handaxe

Only five tranchet triplets were found on handaxes, and one of them (#5069, LLL order) could not be ordered as described above in 4.4.2.2.4.1. The four remaining triplets were plotted according to pairs. Because each handaxe has a different sequence, they cannot be compared.

To better compare and contrast the angles within single handaxes, the triple- and double-tranchet pairs were analysed separately. As described in the Methodology, it was expected that the angles made by the same individual should be similar, and that if the knappers were right-handed, then they should have produced more vertically-oriented right-struck angles. The frequencies of all pairs were discussed above. There are 113 handaxes with double-tranchet pairs, either of the same laterality (LL and RR) or different (RL and LR). In order to check for overall tendencies, all 113 handaxes were plotted by the angle of their first and second removals (Figure 4.42).

The raw-angle scatterplot in Figure 4.42 shows clear groupings for each removal order. The two outliers on the graph are pairs which contain an upward left-struck removal. Each of the four colour clusters represents a different laterality group. The upper left cluster, in dark green, shows the double-different order LR. Because the first tranchet in this pair is left-struck, the angles are below 90° and the second tranchet being right-struck has angles all greater than 90°. Similarly, the double-different order RL is located in the lower right, in dark blue. The double-same pair RR is coloured light green at the upper right. The lower left cluster in light blue shows the double-same order LL. The circles with yellow fill are pairs that begin with a vertical removal (there are no pairs in which the T2 second removal is vertical).

Plotting only the 47 double-same pairs (LL and RR) should reveal any consistently similar angles within handaxes. The graph in Figure 4.43 shows a wide scatter for both groups, which means that two of the same angles on a given handaxe are not necessarily similar.

The next question is: does the same pattern hold for double-different pairs (RL and LR)? In fact, the RL group is shifted closer to the horizontal. This indicates that leftward second removals and rightward first removals are more horizontal than leftward first removals and rightward second removals. Described differently, the second removal in a pair is more likely to be shifted to the horizontal if it is struck leftward, whereas the first removal in a pair is more likely to be horizontally-shifted if it is a right-struck negative.To sum up, the angles of double-tranchet removals follow the pattern of single removals and fail to support the hypothesis about holding positions.

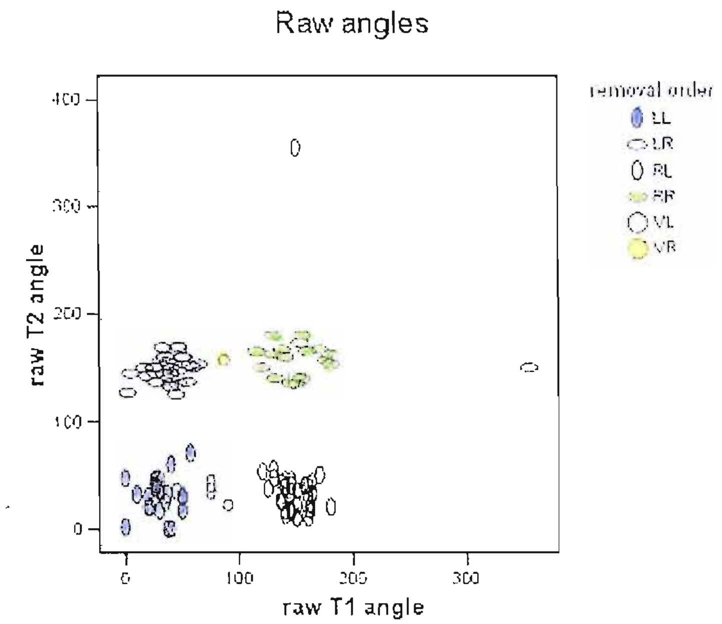


Figure 4.42. Scatterplot of raw angles for first and second paired tranchet removals for Boxgrove.

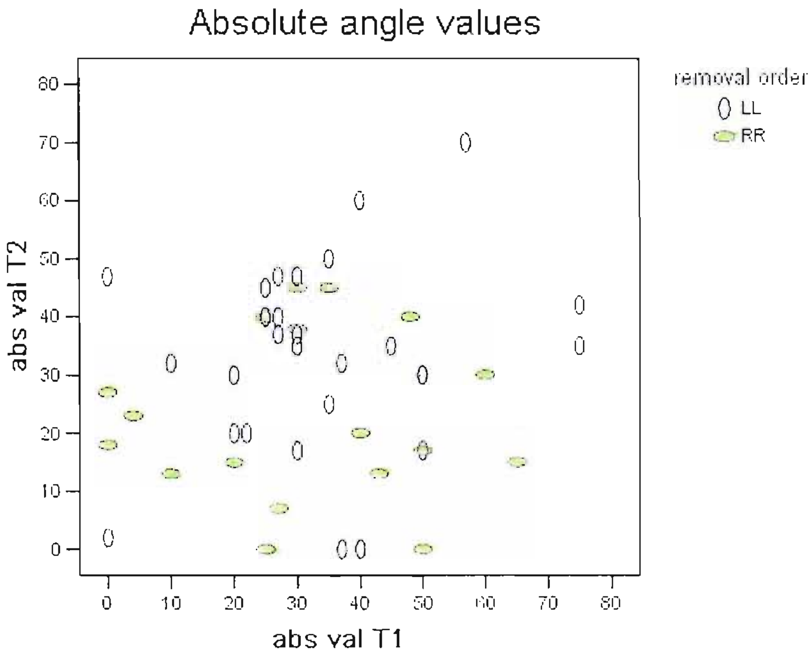


Figure 4.43. Scatterplot of absolute values of first and second tranchets in double-same pairs, Boxgrove.

4.4.2.5. Boxgrove unit layer (H, F)

4.4.2.5.1. Description of units

The LOWER units (3, 3pc, 3c, 4.4u, 4.4us, and below) consist of the Slindon Sands, which were soft, fine-grained marine sands deposited by Marine Cycles 1, 2, and 3. This indicates the beach was completely submerged at this point due to high sea levels, and Britain enjoyed a warm climate. These units were exposed by being later cut into by channel fills (Roberts & Parfitt 1999: 32; Pope 2002: 178).

The MIDDLE units (4/3, 4u/3, 4u, 4, 4a, 4b) consist of the Slindon Silts. These first two (4/3 and 4u/3) refer to the find location of artefacts lying directly on the surface of unit 3 (Pope 2002: 178). The next two (4, 4u) are two major silt bodies. The units 4a, 4b are calcareous and laminated layers which were deposited gently in shallow freshwater, such as a lagoon or intertidal environment (Roberts & Parfitt 1999: 32). At this time, the sea levels were beginning to drop, causing the sea to recede, exposing the beach more often in between tides. Each time the beach was exposed, one layer was created. These provide excellent temporal resolution because a given layer can represent as little as a few hours, and the artefacts in these layers show that people were coming to knap on the beach in these moments. The waterhole with the *in situ* horse butchery site and eight biface manufacturing scatters at GTP17 is contemporary with the surface of unit 4b (Pope & Roberts 2005: 86).

The UPPER units are spring and marsh deposits (4d, 4d1, 5a) and colluvial and soliflucted silts, clays and gravels (8ac, 8a, 6b, 4d2, 4d3) (Pope 2002: 178). Unit 4c is a terrestrial soil horizon which Roberts & Parfitt 1999 (p. 129) considers to be broadly coeval with unit 4d in Quarry 1. The time span of human occupation on unit 4c is estimated to have been between 20 years and 100 years (Roberts & Parfitt 1999: 130). At this point, the sea levels had completely receded leaving the land exposed permanently. Unit 4d is a calcareous spring deposit (Roberts & Parfitt 1999: 32). Unit 5a consists of iron and manganese pans deposited in a terrestrial environment, and mineralised organic material deposited in a fen/alder carr (Roberts & Parfitt 1999: 32). The Fe horizon in unit 5 was deposited in the continuation of the cooling phase that began in the previous levels. Unit 8 is more recent and corresponds to the coldest phase of the climate, comprising very hard chalk and pellet gravel beds that were possibly in a sort of permafrost.

It is important to note that lithics occur in all layers, which indicates the hominins occupied this landscape even during the most harsh and cold climate (Pope 2002). However, the most important layers are the Unit 4 lamina and the Unit 4c intertidal silts, thanks to their excellent preservation and abundance of material.

4.4.2.5.2. Distribution of left and right flakes within units

To check for differences in left to right proportions over time, the handaxe data must be broken down by archaeological layer. The layers containing material studied here are multiple. These were grouped into behaviourally relevant groups of layers, following their place in Roberts & Parfitt (1999: 32), as follows:

LOWER units "3" (marine) = 3, surface of 3, 3c, 4.4u, 4/4u
JUNCTION units "3/4" (between 3 and 4) = 4.3, 3/4, u3/4, 4/3, u4/u3, 4u/3, 4-3c, 4.3c, 4u/4.3m, 4-3m, 4/3m
MIDDLE (ARTEFACT) units "4" (lagoon) = 4, 4*, 4b, 4u
UPPER units "5" (terrestrial) = 4c, 4c?, 4d1, 5a
RECENT units "8" (cliff collapse) = 6b, 8a, 8ac, 8b, 8ac/4

Two flakes (both L) of the 66 had to be excluded because their layer provenance was not indicated. The unit layers for the remaining 64 flakes studied, added to those of the 43 flakes previously studied by Wenban-Smith (pers. comm. 2005, unpub.) are shown in Figure 4.44.

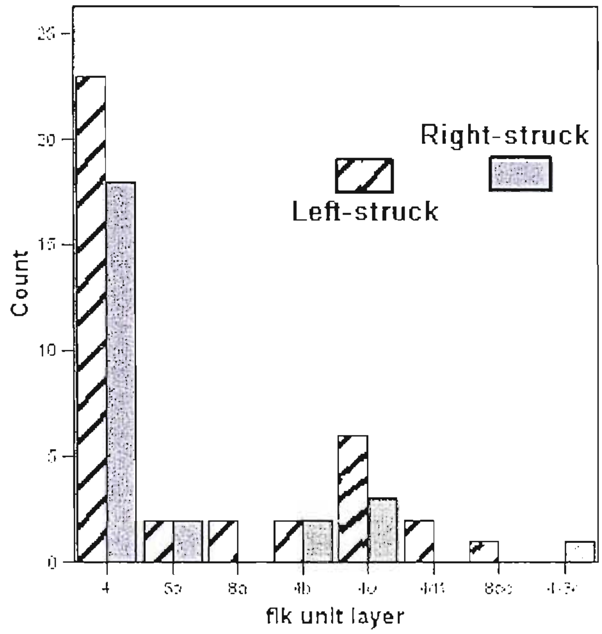


Figure 4.44. Distribution of 64 left and right Boxgrove tranchet flakes within unit layers.

In addition, the proportions of units assigned to left-struck and right-struck flakes are not siginificantly different from 50:50 (p<.05), which implies no change in L:R ratio over time, as the next two tables show.

Layer	age (OIS)	Left	Right	sig.	Total
recent (8a, 8ac)	OIS 12	3	0		3
upper (5a, 4d1)	late 13	4	2		6
middle (4, 4b, 4u)	OIS 13	31	23	.341	54
middle-lower junction (4-3c)	OIS 13	0	1		1
no info		2	0		2
TOTAL FLAKES		40	26	.234	66

Table 4.21. Combined data for Boxgrove left and right tranchet flakes, according to unit layer groups.

Layer	age (OIS)	Left	Right	Total
upper unit 8a	12	2	0	2
upper unit 8ac	12	1	0	1
upper unit 5a	late 13	2	2	4
upper unit 4d1	13	2	0	2
middle unit 4	13	23	18	41
middle unit 4b	13	2	2	4
middle unit 4u	13	6	3	9
middle unit 4-3c	13	0	1	1
Q2C+Q2D, GTP17 unit 4b[8]	13	23	20	43
no info		2	0	2
TOTAL FLAKES		61	46	107

Table 4.22. Details of layer provenance for Boxgrove tranchet flakes (N = 107).

[8] data kindly provided by F. Wenban-Smith. OIS 13, the Cromerian, is a temperate/interglacial stage 524-478 kya. OIS 12, the Anglian/Elsterian, is a cold glacial stage roughly 500-430 kya (Roberts & Parfitt 1999, p.7 table 4; p.30 table 8; p.8 table 5).

4.4.2.5.3. Distribution of right and left handaxes within units

Because 20 handaxes out of the original 314 did not have the unit layer indicated, they had to be excluded. The remaining 295 bifaces were assigned to the following layers (Table 4.23):

Unit layer	Frequency	%
none	20	
Lower 3	49	17
Junction 3/4	50	17
Middle 4	182	61
Upper 5	5	2
Recent 8	9	3
Total	295	100.0

Table 4.23. Details of layer provenances for Boxgrove handaxes, left and right combined (n = 295).

Table 4.24 presents the data for the most numerous removal orders, broken down by unit layer. There are no significant differences between the left and right groups for any layer:

Layer	L	LL	RL	V	L+R	LR	RR	R	other combo	Total	binomial sig.
8	3	1	0	0	0	1	1	3	0	9	
5	1	0	1	0	0	2	0	0	1	5	
4	51	24	21	1	3	16	13	46	7	182	L/R .685, LL/RR .090, RL/LR .511
3/4	17	2	4	0	1	7	4	15	0	50	L/R .860
3	21	4	5	0	2	4	2	11	0	49	L/R .110
TOTAL	93	31	31	1	6	30	20	75	8	295	
no info	3	0	3	0	0	1	0	4	0	11	

Table 4.24. Frequencies of Boxgrove handaxes (n =295) per unit layer, for the most important removal orders.

4.5. Discussion

Comparing and contrasting the two assemblages of High Lodge and Boxgrove is difficult because the nature, quality, and quantity of the data are very different for both sites. Table 4.25 summarises the main findings for each feature, and each is discussed in turn below.

FEATURE	HIGH LODGE HANDAXES	BOXGROVE HANDAXES	BOXGROVE FLAKES
number of artefacts	19	314	66
number of tranchet scars	24	451	---
tranchet laterality	sig. R	sig. L	L = R
tranchet removal order	RR pairs	doubles and triples in all groups	---
tranchet scar percussion traits	R-struck --> R flaps + Z hackles	R-struck --> R flaps + Z hackles; L-struck --> L flaps + S hackles	R-struck --> R flaps + Z hackles; L-struck --> L flaps + S hackles
tranchet angle	R = 35°-67°	L and R prefer absolute angle 25°-45° from horizontal	---
unit layer	---	sig. L; no change over time	L = R; no change over time

Table 4.25. Summary of findings for High Lodge and Boxgrove.

4.5.1. Left versus Right

The 314 Boxgrove handaxes that were found to have one or more tranchet scar on the tip yielded 451 tranchet negatives. There is a statistically significantly higher proportion of left-struck tranchet scars. Furthermore, this is reflected in a slight, persistent tendency toward more overall left-struck negatives in all categories. However, the flakes occur in equivalent proportions. In contrast, the High Lodge handaxes are strongly biased toward right-struck tranchet scars, although the number of cases is much smaller.

The high proportions of right-struck tranchet negatives on the High Lodge handaxes and of left-struck scars on the Boxgrove handaxes prevents ruling out the possibility that cultural constraints were acting upon the knappers at these sites. The differences could indicate a different knapping style. In fact, the experiments suggest that the direction of a tranchet blow depends partly on whether the biface is held freehand or supported against the leg (section 3.3.2.3 of Chapter 3). Specifically, the experimental right-handed knappers tended to favour making a right-struck tranchet when the handaxe was held freehand, whereas the left-struck tranchets were facilitated by supporting the handaxe on either leg. The act of knapping freehand might be more strongly subject to handedness constraints because there are more degrees of freedom to control (cf. Steele *et al* 1995). In contrast, the reduction of degrees of freedom achieved by core-on-leg support might reduce the difficulty of the task, thus placing less pressure on the bimanual system to conform to a pattern of handedness. In this way, right-handers can produce the more 'difficult' left-struck tranchet flakes.

The alternative interpretation of the differences between High Lodge and Boxgrove is that the proportions of right-struck and left-struck tranchet negatives represent individuals of different handedness. However, this rests on the assumption that each handaxe corresponds to a different person. Given the short time scale of the middle (main artefact) units at Boxgrove, 20 to 100 years, it is highly likely that the same hominins visited the landscape repeatedly (Pope 2004). In this case, a restricted number of individuals was responsible for making the handaxes, and the effect of each knapper's hand preference becomes cumulative.

If we accept that the tranchet bifaces are representative of a group or tradition, then the biases in each assemblage must be explained. The biased proportions of tranchet flakes at Boxgrove do not match with the experimental results (section 3.3.3.3 of Chapter 3). The group of unrelated modern-day knappers spontaneously produced equal numbers of left and right tranchet flakes, indicating that there is no biomechanical constraint on tranchet flake production (as Cornford had posited for the La Cotte de St. Brelade sharpening flakes). The experiments did not provide any information on whether modern-day knappers eventually converge on one direction when making repeated tranchet flakes. There could have been a conceptual template for tranchet removals, in which case this would have to be described as a cultural constraint, since biomechanical constraints were ruled out. Cultural constraints operate on individuals by favouring one configuration in the absence of any personal preferences.

Whether the Boxgrove tranchet bifaces were produced by a few individuals or by many groups, their knappers were possibly discriminating between leftward and rightward striking directions, since they produced more leftward removals. However, this could also occur as a result of well-established motor habits. It is possible that the prehistoric knappers tended to consistently make the same laterally-struck tranchets out of habit, just as we do today with many manual activities. In summary, the data show that the Boxgrove knappers preferred to strike tranchet flakes from the left while the High Lodge knappers favoured right-struck removals. Because the knapping of tranchet flakes was not constrained by biomechanics, the only other possible explanations are cultural constraints or motor habits.

4.5.2. Removal orders

Some removal combinations are unseen at High Lodge; the excellent preservation of Boxgrove bifaces allows the observation of a few pieces with triple tranchet removals. It was decided that the RL removal sequence belonged with the leftward removals and vice versa for the LR sequence, suggesting that the final removal in the sequence is the most relevant to classifying multiple-tranchet sequences. From a taphonomic perspective, the final removals in fact correspond to single removals, since both are the last removals to be made before the handaxe was abandoned. However, the analysis left open the question of finality in the tranchet scars. Many were not final, in that they showed further working, in the form of fine retouch to remove the bulb of percussion's concavity and/or removals to eliminate the protruding ridge below the tranchet scar. The experimental tranchet production revealed the necessity of further working in order to straighten (regularise) the edge of the biface and maintain the thinned cross-section at the tip. Therefore the experiments and the artefact observations together do not support the popular notion that tranchet flakes are final removals.

4.5.3. Fracture features

The excellent correlations validate the use of fracture features to determine striking direction. These are useful when the tranchet negative is only partially preserved and the direction cannot be identified from traditional percussion features, for example when its bulb is missing. These features were especially helpful in analysing second-struck tranchet negatives. The experiments confirmed that fracture features located on the fracture surfaces of tranchet flakes and handaxes are correlated, indicating a basic law of fracture for tranchet knapping gestures.

Despite the good feature preservation on the half-million-year-old flint, still only 35% (160) of tranchet negatives from Boxgrove show fracture features. However, the flakes preserve features much better: 63 of 66 have at least hackles or flaps. On both the handaxes and the flakes, these features follow the pattern of leftward flaps + S hackles on left-struck scars and flakes, and rightward flaps + Z hackles on right-struck tranchets. The correlation is so strong that there is no tranchet negative on which the hackle + flap combination contradicts the actual striking direction. There are significantly more right-struck negatives that contain both features, and left-struck flakes are significantly more likely to contain no features.

4.5.4. Angles

The Boxgrove angle results clearly do not support the hypothesis that right-struck angles should be closer to the vertical orientation. The finding at High Lodge of more vertically-oriented rightward tranchet scars does not match the pattern here. On the contrary, the Boxgrove right-struck tranchet angles are shifted towards the horizontal, and have a broader range. The left-struck angles are tightly clustered in the 45° angle range which is more vertical. Despite the appearance of the graphs, the asymmetrical frequencies of right-struck and left-struck scars within each angle range do not reach statistical significance (strongest biases in the 30 angle range: p=.093, and in the 60 range: p=.078).

If the goal of making a tranchet flake was to remove a portion of one handaxe edge, then it is possible the knappers had to use this angle range in order to obtain their ideally-shaped tranchet scar. In other words, the preferred angle range could likely be constrained by the shape of the bifaces themselves. This would dictate that the shape of the tip is created by the handaxe's relative width and length.

However, the presence of tranchet negatives struck from all angle ranges indicates that knappers were *able* to strike different angles of removals. For example, both right-struck and left-struck tranchet scar angles reveal a desire to knap horizontally across the tip, with figures of 11 to 18 removals on each side occurring close to the horizontal mark (-5° to 5°), illustrated in Figure 4.45. Figure 4.38 above illustrates the sub-peak in the 0-5 angle range.

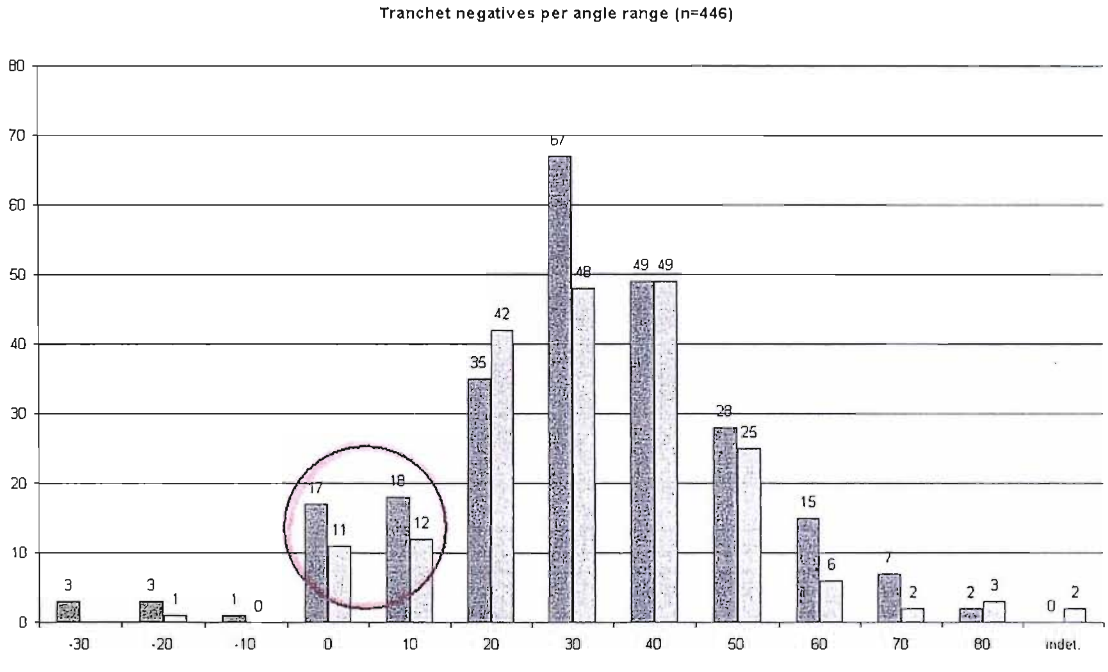


Figure 4.45. Boxgrove, left (blue) and right (green) angle ranges showing secondary preference for the horizontal (circled in red).

However, it appears that High Lodge knappers preferred a tranchet angle closer to the vertical axis of the handaxe, namely between 35° and 67°, whereas Boxgrove knappers preferred to strike slightly closer to the horizontal, at 25° to 45° regardless of left or right direction. This angle range might be the easiest to achieve on the typical Boxgrove biface shape owing to the relative dimensions of its edges, length, and width. The great homogeneity of the Boxgrove bifaces therefore could be either a cause or an effect of this angle range preference.

The pooled angle data fail to support the hypothesis set out above, which was supported by the High Lodge data. This hypothesis predicted that right-struck tranchet angles should be closer to the vertical axis (90°) and the left-struck angles should be closer to the horizontal (0° or 180°), if the knappers were right-handed. The Boxgrove data show instead a more horizontal tendency for right-struck negatives. This pattern is reiterated in the double-tranchet pairs. The left-struck angles, although more numerous, are restricted to a narrower range of angles. In contrast, the right-struck angles have a wider spread, and this in the direction of the horizontal. The differences are not statistically significant (see above), but they deserve an explanation nevertheless.

There are two possible "extreme" scenarios of lithic production which can apply to the interpretation of handedness from these angle results. One scenario is that each handaxe was made by one individual; in other words, all the tranchet scars seen today on a given handaxe were knapped by one person. For example, Boxgrove #30258 and #30259, with their very similar pairs of angles (30°+135° and 27°+130°), were probably made by the same person. In that case, the slight difference between left and right angles could reflect the holding constraints hypothesised above, but this would mean that the vertical tendency of left-struck angles would indicate that most knappers were left-handed. Such a "left-handed knappers" scenario is consistent with the observation that left-struck angles are more tightly constrained within a narrow angle range, indicating greater homogeneity in the knapping gesture (Roux *et al* 1995). However, it is unparsimonious to assume that most people were knapping left-handed in the Lower Palaeolithic and then switched to predominantly right-handed knapping in modern times (Cornford 1986; White 1998).

The second scenario is that the right-struck tranchet flakes were made by right-handed knappers, and the left-handed knappers made left-struck flakes. In that case, a given handaxe could be changing hands each time a tranchet removal was made. This is not at all implausible, given the embedded learning that is found in Mesolithic and Neolithic production (e.g. Pigeot 1990; Högberg 1999) and in modern-day experimental knappers. One example is when learners interrupt their flaking sequence so that a more expert knapper can remove something or correct an error. It is also possible that the knapping situation was analogous to that of miners in Roman times, where left- and right-handers collaborated on the same tasks. The role of left- and right-handers was well-known and managed by Roman mining bosses. The handedness of each miner was kept on written records, so that workers could be selected when one was needed. In the tuff mines of the Pellenz in German Rheinland there were usually three left-handers employed for every two right-handers (3:2), or even a 2:1 ratio (Röder 1957). When digging out the vertical walls of the mines, the right-side walls were straightened by left-handers and vice versa (Bedon 1984:158). In the Gallo-Roman mine at

Saint-Boil (France, first century AD), the rectangular blocks had to be carved out by two miners working together, one of each handedness (Monthel 2002:96). If the Boxgrove knappers were passing around handaxes for tranchet flaking depending on laterality, then the difference in right and left angles could be the result of inherent differences in the holding configurations used by each laterality group of knappers.

Unfortunately, at present we do not know which individuals knapped or used which bifaces at Boxgrove. The two extreme scenarios just discussed give a useful frame for proposing a more realistic scenario, namely a mixed system in which learners were present. These are implied by observations of pieces in the assemblage with stray percussion marks, small sizes, or rough / irregular outlines, profiles, or cross-sections, which are all indicative of less-proficient knapping (Karlin & Julien 1994; Roux *et al* 1995; Winton 2004, 2005; Sternke & Sørensen in press). Some people might have maintained their own handaxes while others might have shared them. Because the palaeohominins were *H. heidelbergensis* and not *H. sapiens*, we cannot attribute social and/or cultural attitudes to the culture surrounding the handaxes: were they shared as functional tools, or were they personal objects that symbolised individuals?

The left-struck and right-struck tranchet negatives were not constrained by holding positions, nor were they subject to cultural constraints. Therefore the data make the robust conclusion that tranchet technology does not provide any information about the handedness of these *H. heidelbergensis* flintknappers. In terms of cultural ideas, the strong symmetry between the distributions and dispersions of left- and right-struck tranchet negatives suggests that the two directions were not perceived as different and therefore were knapped in the same way. In other words, the slight differences in leftward and rightward angles might simply be an effect of normal variation in the knapping gesture. The preference for striking tranchet flakes in the absolute angle range 25°-45° could have been included in the wider learning context, or it could reflect the well-established motor habits of a few proficient individuals.

4.5.5. Unit layer (Boxgrove only)

The excellent preservation context of the Boxgrove lithics allowed easy classification of the data into time spans according to unit layers and spatial location. Analysis of handaxes and flakes by unit layer shows no difference between right-struck and left-struck categories, meaning there is no change in left to right proportions over time. This could indicate that the Boxgrove site was repeatedly visited by knappers of the same group. For example, the short time span of the main artefact layer, of 20 to 100 years, invites the possibility that three generations of hominins used the site. The repeated use of the same landscape (Pope 2002, 2004) would lead to a continuity in tranchet knapping strategies, namely through learning. This idea is discussed in the next and final chapter, with reference to how bimanual skill and language might fit together in a continuity framework.

CHAPTER 5. Synthesis of results and discussion of future directions

I shall now review and synthesise the results of the archaeological tranchet flake analysis and of the experimental replications. This is followed by a wider review of the larger corpus of methods for diagnosing handedness in archaeological and fossil remains, in which I indicate the strengths and weaknesses of the numerous other methods which I have not applied or validated experimentally in the present study. My conclusion is that while the two methods for diagnosing handedness that have been examined exhaustively in this thesis have not been validated, there are many others which appear to hold water. Consequently, this research programme has great potential for continuation and development in parallel avenues. The search for diagnostics of handedness in Lower and Middle Palaeolithic artefacts remains highly relevant, and the need for parallel theoretical exploration of the strength of Common Substrate arguments retains its urgency if archaeologists are to make a valid contribution to language origins research. I therefore conclude by revisiting the Common Substrate arguments discussed in Chapter 1, suggesting a new theoretical perspective that starts with the archaeologically-appropriate Guiard model of bimanual coordination and asks how close an analogy can be found in aspects of language organisation, reflecting an underlying Common Substrate.

5.1. Experimental and archaeological validation of tranchet flake production

The widespread and abundant occurrence of handaxes around the world make them an excellent target for laterality studies. Because they are defined as symmetrical objects, any trace of asymmetry should be evident and unexpected. In the previous chapter a case study of British Lower Palaeolithic handaxes from Boxgrove was examined, using a new methodology, for traces of asymmetry in the tranchet scars and flakes. This study followed the procedure of previously published research, as reviewed in Chapter 2, in which particular methodologies for identifying handedness in lithic production are hypothetically proposed, experimentally tested, and applied to an archaeological collection.

Viewing the results from the tranchet experiments in parallel with the artefact analyses reveals differences in tranchet production techniques and methods. On the level of techniques, some show similarities (such as the use of an antler hammer), but other aspects of technique are not known for Boxgrove (knapping postures and bimanual configurations). The experiments were expected to allow reconstruction of the Lower Palaeolithic configurations for knapping tranchet flakes based on holding constraints. While they did not evidence constraints, they did show that a huge range of variation can exist in holding positions, even among less than ten knappers. These holding positions are idiosyncratic and do not affecting the lateralisation of the knapped product. Aspects of tranchet technique and method that are discussed next in terms of their experimental and archaeological results.

Contrasting the experimental tranchet angles with the Boxgrove angles shows that the peak of preference for Boxgrove knappers (25°-45° absolute value) was closer to the horizontal than for the Lejre experimental knappers (55°-65° absolute value). These are shown in Figures 5.1a and 5.1b.

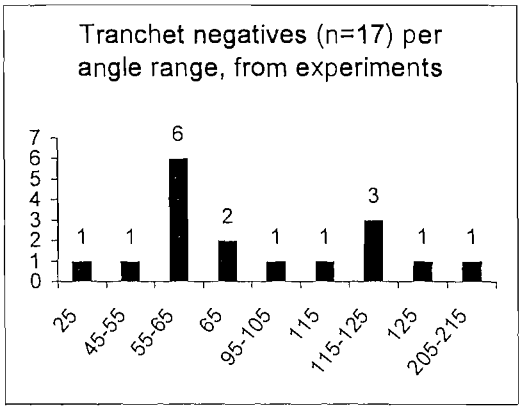


Figure 5.1a. Tranchet scar angle ranges for experimental knappers.

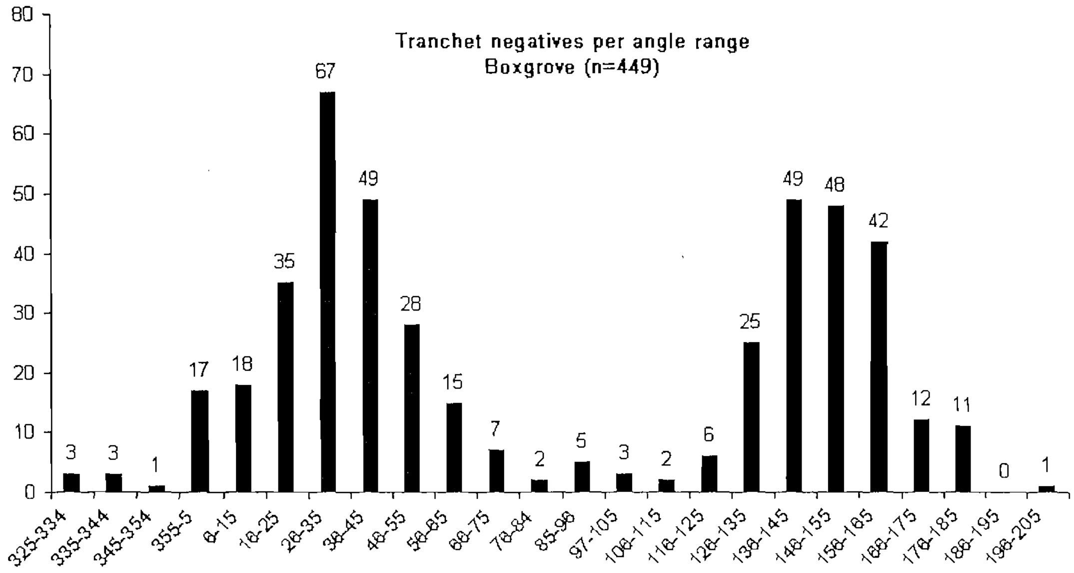


Figure 5.1b. Tranchet scar angle ranges for Boxgrove knappers.

The homogeneity of the Boxgrove angles, as discussed in section 4.5.1 of Chapter 4, could be a by-product the standardised proportions of the handaxe dimensions. A tranchet blow directed along the edge of the handaxe will necessarily follow the angle of the edge relative to the tip shape. The Lejre handaxes appear less constrained in relative tip to edge proportions, since their variability is high and they were less carefully finished than the Boxgrove ones. This indicates that the Lejre knappers paid little attention to finishing the tips. Indeed they had no reason to attend to tip shape, since they did not make the handaxes for use as functional tools. While many of the experimental knappers have used stone tools for butchering or plant processing, none of them had ever experienced using a tranchet-sharpened handaxe. Therefore it is predicted that a practical usage experiment with these bifaces would lead the knappers to produce very specific styles of tranchet removals depending on the task.

The Tranchet experiment brought attention to aspects of the archaeology that were not previously considered, namely the signature of failed attempts. Subjects PW and FS each produced one flake which did not remove the biface edge, and JM made four. Although they were knapped with the intention of making a tranchet blow, such flakes would not be identifiable as tranchet flakes if they were found in isolation. On the handaxes, these would not necessarily be considered tranchet negatives either. For example, the scar from JM's sixth tranchet blow could be suggestive of a tranchet intention due to its length and width, but its distance from the edge suggests it was intended to thin the handaxe face. Another example is JM's third tranchet attempt which broke the handaxe butt. This is found at Boxgrove (personal observation), although rarely (four examples), in the form of broken handaxe tips. The experimental fragment did not show specific fracture features related to the tranchet blow attempt, so it is impossible to know whether the Boxgrove fragments are the result of use breakage or tranchet attempts.

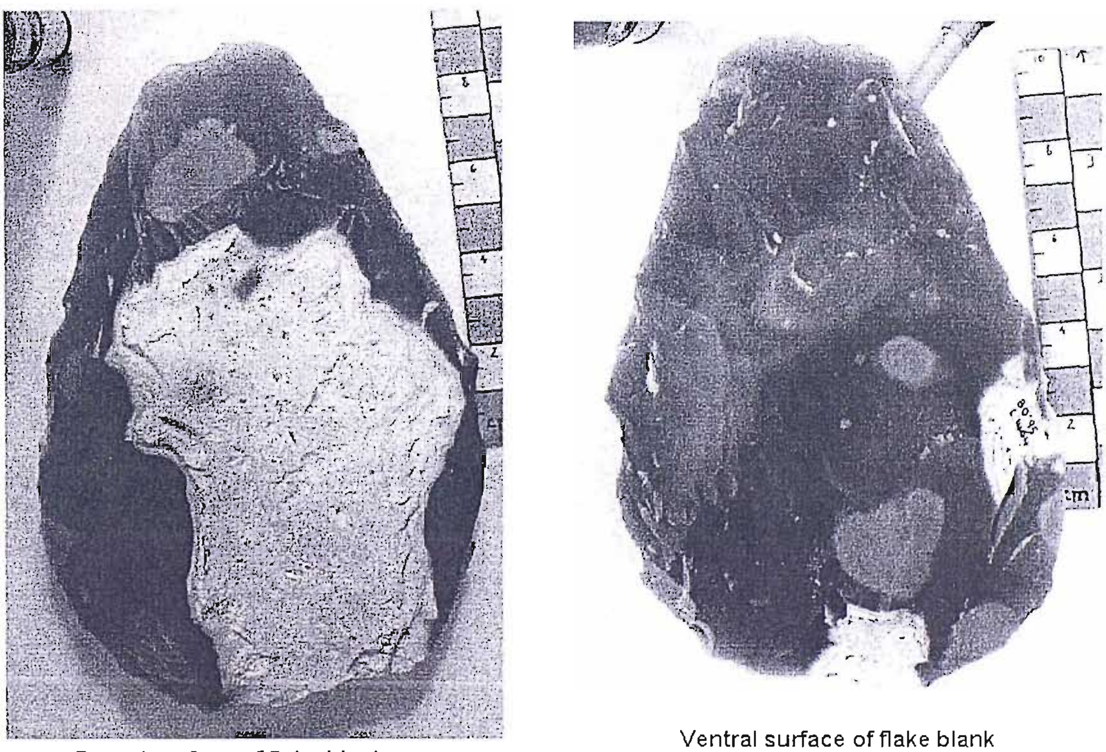
These points also raise the question of intentionality in the negatives: should a tranchet blow be defined by the knapper's intention, or by the knapper's actualisation of the intention? In the Boxgrove assemblage (section 4.2.2.1 of Chapter 4), there are hints that some of the tranchet negatives are the result of an unsuccessful blow. Given that the highly proficient experimental knappers at Lejre still needed some practice to make a successful tranchet flake, it is not surprising to see some errors in their production. If the Boxgrove assemblage was created by knappers of varying proficiency levels, an even higher proportion of errors would be expected to occur. If learners' handaxes were discarded in the same area as the ones made by proficient tranchet knappers, they should be reflected in the assemblage.

In terms of methods, several points are worth mentioning. None of the experimental lithics resembled the archaeological tranchet flakes and negatives seen in the Boxgrove or High Lodge assemblages. For example, all the subjects stopped knapping once they had struck the last tranchet flake on each handaxe. In contrast, the Boxgrove bifaces nearly always incorporated tranchet removals into the middle of the reduction sequences. For example, the tranchet negatives often show retouched bulbs and/or one removal just below the tranchet scar. The experimental tranchet negatives produced large dents where the bulbs were, in addition to large ridges marking the distal edge of the tranchet scar. These would need to be flattened out in order to make a biface of Boxgrove quality. Generally the Boxgrove tranchet scars did not show such prominent ridges or bulb dents; these were either retouched or the tranchets were struck in a way that made them shallow and smooth. The only knapper to approach this ideal was JM with his fourth removal, which made a smooth negative.

The failure of the experimental tranchet flaking to be subjected to constraints on hand-use shows that although Cornford's (1986) original hypothesis was valid for her specific dataset, her methodology is not transferable to tranchet flakes on handaxes. There are several possible reasons for this.

The experimental results make it clear that the tranchet method for British Lower Palaeolithic bifaces is not analogous to the LSF and TSF methods at La Cotte (e.g. Cornford 1986:348). On technological terms, bifaces are generally roughly symmetrical, meaning that both edges have roughly the same thinness and thus have equal potential to withstand a tranchet removal. In contrast, scrapers made on flakes could carry constraints on the removal location of sharpening flakes (J. McNabb, pers. comm. 2005): the proximal end of the flake is thickest due to the bulb, and the distal end, being thinnest, can not always sustain being gripped firmly in the hand.

Even though most Boxgrove bifaces are made on flakes (pers. obs. and Pope 2002), the flake blanks were much larger than the La Cotte scraper blanks. In addition, the large blanks at Boxgrove retain little if any of their original surface, having usually been reduced down to an even thickness all around. Out of the bifaces where some of the original flake blank surface remains (due to minimal flaking or reduction), the tip is not restricted to the flake's distal end; the knappers made the tip on various areas of the flake blank (Figures 5.2 and 5.3).

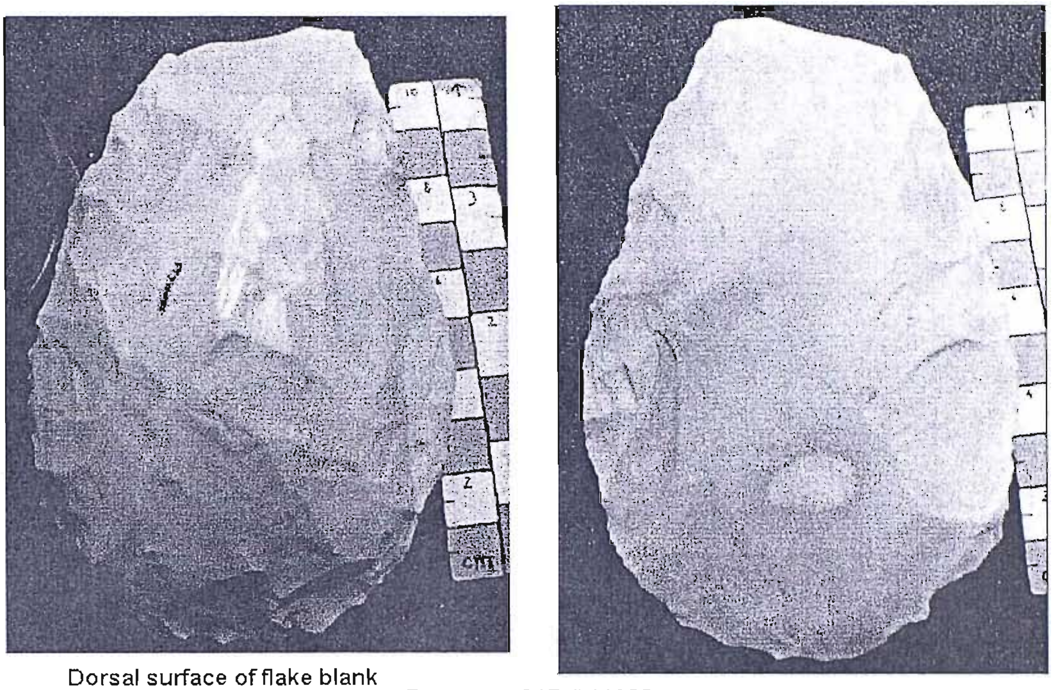


Dorsal surface of flake blank

Ventral surface of flake blank

Boxgrove Q1B # 1464

Figure 5.2. Example of Q1B biface made on a flake (#1464).



Dorsal surface of flake blank

Boxgrove Q1B # 11263

Ventral surface of flake blank

Figure 5.3. Example of Q1B biface made on a flake (#11263).

There are even some examples where a tranchet removal served to thin part of the flake blank's bulb area (personal observation). These show that tranchet blows were not only used to create sharp edges on handaxe tips, but that they also occur in the context of shaping and thinning bifaces.

The thickness constraint of making LSFs on La Cotte flake scrapers is confirmed to some extent by the finding that most LSFs were removed from the distal end of the parent flake tool (Cornford 1986:344 figure 29.12). However, some of the La Cotte LSFs were also removed from the bulbar end of the parent tools, showing it was possible in some cases. Regarding grips, Cornford states that the La Cotte knappers preferred to remove LSFs from the same edge as the gripped edge (*ibid.*:344 and 350); grip manner is based on a replication experiment (*ibid.*:345). That appears to be her only means of estimating grip on these flake tools, but it conforms to the hand holding the core to support the removed flakes (as in the Lejre experiments). Even without knowing the grip area, the La Cotte LSF data clearly show a bias towards striking right-handed flakes from the distal end of the parent tool (*ibid.*:344 figure 29.12). The second largest group is the right-handed LSFs removed from the bulbar end. Because there are a few (<=10) LSFs in all the other categories, a cultural explanation is preferred for this bias rather than any biomechanical constraints relating to handedness.

In contrast, TSFs can only have been struck from the edge opposite the grip (*ibid.*:350 figure 29.18). The fact that over time, TSFs changed shape as the point of percussion was moved from the middle of the butt's area to the left corner of the butt (*ibid.*:349), indicates another process occurring, could also be described as cultural. In the more recent layers, "a more refined technique to create a much smoother, sharper edge was used. The flakes were removed with an obliquely directed blow which leaves its point of impact at the very end or corner of the butt" (Cornford 1986:349). Most of the Boxgrove tranchet flakes were struck in this way, so that the percussion point falls at the end of the old margin (personal observation). Following Cornford, this practice is not interpreted as relating to handedness, but it suggests that the Boxgrove tranchet flakes are analogous to one type of La Cotte flakes (TSFs), at least in terms of one technique (an obliquely-directed blow).

The knappers in the experiment cannot be considered representative of the Boxgrove knappers for three reasons. First, their proficiency levels are not comparable, at least in the production of tranchet flakes. Because none of the knappers (except JM) had seen the Boxgrove material, they did not have a conceptual template to work from. The input which directed them towards the goal of the study was based on a line drawing and the author's explanation of the concept of creating a fresh cutting edge by removing part of both faces along one edge. Second, their modes of subsistence are not equal, which places less pressure on the experimental knappers to produce utilitarian tools. Third, the small sample of experimental knappers resulted in too few tranchet flakes produced for patterns in their production to appear.

Other aspects of Boxgrove tranchet technology were not able to be explored in the experiments. In future experiments it will be important to move closer to the archaeological tranchet productions in order to assess the role of constraints on lateralised features such as making double-tranchet tips (one in each direction or in opposite directions) and different styles of tranchet removals (wide and flat, small and horizontal, twisted edge, etc). Additionally, it would be appropriate to do an experiment to wear down the tranchet-sharpened edges far enough to warrant resharpening (as proposed by Roberts & Parfitt 1999), to get an idea of the tranchet's role within the reduction history and usage life of a handaxe.

In sum, the 100 % preference of subject JM to knap left-struck tranchets shows the role of motor learning in knapping. In sum, the consistent pattern at Boxgrove could be a witness of the well-established motor habits of knappers. The extremely difficult action of knapping tranchet flakes was evidently mastered by the palaeohominins in Britain. According to the model outlined in section 1.2 of Chapter 1, a more stable hand-use pattern is predicted by a more difficult task. This predicted that tranchet flakes should be strongly subjected to consistent motor patterns, and in turn that these would appear in the lateralised features of handaxe manufacture. However, the Boxgrove assemblage cannot yet be decomposed into the productions of individuals. When this becomes possible, it will be vital to test for homogeneity of tranchet flaking within individual knappers at Boxgrove.

The Boxgrove handaxes showed a statistically significant left-struck bias at the level of the assemblage. To explain this bias, biomechanical constraints were ruled out based on the actualistic experiments reported in Chapter 3. These showed that seven modern-day knappers made subtle variations in hand configurations to place the intended point of percussion within the trajectory of the knapping arm, and no evidence of holding restrictions was found for the bifaces. It may be true that there is a constraint to hold the biface with the tip oriented either towards the knapper or to the knapper's right (none of the knappers held the tip pointing away from the body), as hypothesised. But this constraint is clearly wide enough to allow for the production of left- and right-struck tranchet removals. As the bi-directional knappers (EC, FS, MS, NTU) showed, using the same holding position can produce both directions of flakes. The unidirectional knappers (JM, PW, SW) showed that different holding positions can lead to the same direction of removals.

From the empirical work it was concluded that biomechanics does not constrain the production of tranchet flakes, and furthermore that the Lower Palaeolithic knappers at Boxgrove could have exerted cultural constraints on tranchet flake laterality. Therefore, the left-struck flake pattern is consistent with the behavioural interpretations of Boxgrove as a site of repeated occupations by members of the same group (Pope 2004). The time span of maximum 100 years for the main lithic horizon would have entailed several generations from the same family, for whom it is possible that the left-struck direction was simply an idiosyncratic behaviour. The pattern at Boxgrove was interpreted as resulting from the well-established motor habits of the highly proficient knappers who made the handaxes and tranchet flakes. This fits with the definitions given in section 1.2 of Chapter 1 that the bimanually role-differentiated pattern becomes more stabilised the more difficult the task.

5.2. Constraints from difficulty

In this thesis I have investigated archaeological markers of handedness in the stone tool record. My experimental results indicate a need for more research into the biomechanically-constrained aspects of stone knapping, where left- and right-handed configurations should show opposite features. However, it is difficult to identify which features are good candidates. The structured review of skeletal and material culture data in Chapter 2 evidenced a constant and ancient hand-use pattern consistent with a bimanual cooperative model of handedness. This was especially prominent in skilled manipulations. Unfortunately the use of tools in prehistory is strongly tied to skill, simply because of the nature of the tools. None of the data showing evidence for handedness can be considered an unskilled task. They can be classified by difficulty levels according to the number of actions in a sequence and the precision and accuracy required for the elemental actions, as discussed in section 1.2.4 of Chapter 1. The learning time variable is not considered because it is not known for prehistoric artefacts. The ranking is shown in Table 5.1. Precision and accuracy are rated according to the error tolerance, as low, medium, and high. Tasks with high error tolerance, having a wide range of acceptability in the spatial and/or temporal area of execution of the elementary gesture, are rated as requiring less precision and accuracy. The tasks with low error tolerance, meaning that an error can result in a serious destruction of the object being worked on, are rated as highly precise and accurate. The number of actions in a sequence are counted as one, few or many depending on whether the action requires more than one single action. Iterative processes are ones that simply repeat the same action in sequence, with no constraints on ordering the gestures. Sequential processes are ones where each action depends on the result from the previous action(s). The overall difficulty rating is the average of the two factors and is listed as low, medium, or high.

Table 5.1 shows that most of the usage tasks fall into an 'easy' category whereas the production tasks are rated as more difficult. In terms of handedness, the data confirm that task difficulty constrains hand-use patterns in some cases. For example, the teeth striations are ranked as medium difficulty although they are considered use-wear. This ranking may account for the high reliability of this method in determining handedness. One of the other highly-ranked methods, based on the La Cotte data, is also very reliable for hand-use recognition. These would suggest that the lack of reliability of the tranchet knapping found in the present study is anomalous, since it is also a very difficult task. The only production method that is ranked as low difficulty, the cone skew, is a less reliable indicator, which fits with its place in the scale. However, knapping scatters are the only production method to be ranked medium, yet they are highly reliable indicators of handedness. The difference between production and use has implications for the division of labour in social groups, such that the young are more likely to be the users of the tools, and the production of tools is more likely to be done by the more experienced knappers.

Task	Precision and accuracy	Number of actions in sequence	Overall difficulty rating
tranchet blow	high (error can result in handaxe becoming non-functional)	many (preparation included)	high
Long and Transverse Sharpening Flake (LSF, TSF)	high (error can result in scraper becoming non-functional)	many (preparation included)	high
teeth striations	high (error can result in injury to self)	few (hold meat, hold tool, cut meat)	medium
Caddington handaxe	medium (possibility to correct errors, as for a generic handaxe)	many (sequential process as for a generic handaxe)	medium
twisted ovate	medium (possibility to correct errors)	many (sequential process)	medium
single-platform core	medium (possibility to correct errors)	few (iterative process)	medium
bone retoucher use-wear	medium (narrow restriction on angle of stone and retoucher)	few (iterative process)	medium
knapping scatter	low (as for generic knapping)	many (as for generic knapping)	medium
end-scraper use-wear	low (no error; worst result is ineffectiveness of tool)	few (iterative process)	low
sharpening flake use-wear	low (no error; worst result is ineffectiveness of tool)	few (iterative process)	low
Kariandusi, Trent, Furze Platt, Olorgesailie, Somme gravels, Zhoukoudian tools use-wear	low (power grip; no error; worst result is ineffectiveness of tool)	few (iterative process)	low
Clacton biface use-wear	low (rotation motion; no error; worst result is ineffectiveness of tool)	few (iterative process)	low
cone of percussion skew	low (as for basic knapping gesture)	one (not sequential)	low

Table 5.1. Ranking of handedness evidence by task difficulty.

5.3. Validation of methodologies and future archaeological directions

The selected methodologies investigated in the preceding three chapters have been subjected to validation by three means, using actualistic experiments, facts of biomechanics, and ethnographic information. The reliability of these data and methods is summarised in Table 5.2. Among the thirteen methodologies and/or datasets listed in the table, one has been definitively invalidated (tranchet-sharpened handaxes). Regarding the Koobi Fora flakes that are widely cited as the earliest evidence for handedness, the experiments done for this thesis invalidate the methodology (as do Bradley & Sampson 1986; Pobiner 1999), but two published experiments support it (Toth 1985; Ludwig & Harris 1994). Three others remain open questions (Caddington, fit in the hand, cone skew). These would benefit from more experiments and updated lithic analyses.

Nine can be accepted as valid (La Cotte, teeth striations, twisted ovates, bone retouchers, knapping scatters, end-scrapers, use-wear on flakes, Kariandusi, Clacton). However, out of these nine, the robustness of results is highly variable. The La Cotte flakes show unanimously high proportions of right-handed Neanderthal knappers. The small number of flakes showing use-wear confirm this. Additionally, dental striations on Neanderthals are clear and show a group-level preference to right-handed manipulation. Equally positive conclusions can be drawn from twisted ovates, bone retouchers, end-scrapers, and the Kariandusi tools: these artefacts clearly show high proportions of right-handed makers and users in Acheulean and Middle to Upper Palaeolithic industries. In contrast, the dental striations on the Boxgrove teeth only pertain to one individual. Similarly, the knapping scatters only represent an isolated data point, presumably from one single knapper, as does the Clacton biface.

The robust results for Neanderthals are consistent with their skeletal right-arm dominance. The valid data for *H. heidelbergensis* are not inconsistent with an equally marked right-handed pattern in older species, as suggested by the Nariokotome Boy, but there are too few data points directly linked with fossils to conclude on population patterns. Kariandusi is currently the oldest reliable evidence for handedness, at around 1 mya in East Africa. Combined with the Neanderthal evidence, it shows that Acheulean life was conducive to lateralised manual skill. The data for older hominin species were not validated, meaning that handedness can neither be confirmed nor excluded from earlier times.

Methodology / Dataset	Time period / Species	Valid?	Problems
end-scraper use-wear	Upper Palaeolithic	yes	
bone retoucher use-wear	Middle & Upper Palaeolithic	yes	
Long and Transverse Sharpening Flakes (LSF, TSF) / La Cotte	Neanderthal	yes	
sharpening flake use-wear / La Cotte	Neanderthal	yes	too few data points
tranchet blow / Boxgrove	Acheulean, Mousterian / *H. heidelbergensis*	no	failed experimental validation; laterality patterns in the artefacts remain to be explained
knapping scatters / Boxgrove	Acheulean / *H. heidelbergensis* / *H. sapiens sapiens*	yes	
teeth striations / Boxgrove	Neanderthal / *H. heidelbergensis*	yes	
Caddington handaxes	Acheulean	still open	not useable with archaeological flakes unattributed to a particular handaxe; not enough experiments
twisted ovates	Acheulean	yes	no detailed data on the archaeology
Clacton biface use-wear	Acheulean	yes	only one data point
cone of percussion skew / Swanscombe, Purfleet	Acheulean	still open	promising pilot experiment, but poor results when applied to archaeology
Kariandusi bifaces	Acheulean	yes	
Trent, Furze Platt, Olorgesailie, Somme gravels, Zhoukoudian tools hand fit	Oldowan / Acheulean	still open	ways of holding tools not yet established
single-platform cores / Koobi Fora flakes	Oldowan / Acheulean / *Australopithecus habilis* / *Au. rudolfensis* / *Paranthropus boisei*	still open	inconsistent experimental results; not validated in this study; lacks biomechanical basis

Table 5.2. Summary of validity of methodologies and data for handedness.

Future projects might focus on remedying the problems listed in Table 5.2. Many of the proposals have sound bases but are weak on archaeological data. This is true for twisted ovates, for which the published data refer to a 19th-century observation. The use-wear on the La Cotte flakes and on the Clacton biface employ established traceology methods, but they simply suffer from too few data points (one in the case of Clacton).The Kariandusi assemblage could be revisited with a more detailed technological analysis to add to the biomechanics. Further, kinematic methods could be applied to the subjective assessment of hand-held tools in order to obtain objective measurements of tool efficiency for different grip types.

Other data would be improved by additional experiments. For instance, the method devised for Caddington handaxes could be extended with experiments on more subjects beyond the two tested in the publication. The cone of percussion method showed good reliability in the pilot study; it should be expanded using large numbers of subjects, but the measuring method will need to be improved for use with archaeological material. As Chapters 3 and 4 have demonstrated, the methodologies for determining handedness in stone artefacts demand experimental validation. However, it is necessary for experiments to be well-designed and rigorously controlled. Following normal scientific practices, there must be a large enough number of subjects to control for all variables under study; the subjects must be proficient enough to make the objects that are required; the subjects must be naive to the purpose of the experiment; the subjects must produce enough data points for statistical analyses to be done and meaningful. As the tranchet experiment showed, it is very difficult to fulfil all these needs. Therefore large-scale, systematic experimentation must be launched. This can potentially be done at flintknappers' gatherings, where large numbers of naive and proficient subjects are often available and willing.

Given that many methods are novel, and therefore would require further testing to be definitively validated, the most efficient way forward would be to rely on methodologies that are already established. This means that use-wear analysis should be emphasised in future handedness research. As previous research shows, microscopic use-wear and S.E.M. can show valuable information on handedness (Fritz *et al.* 1993; D'Errico 1998, 1992). The level of detail that can be achieved by these methods can inform the questions about hand-holding positions for tools, and the direction of movement when doing a cutting gesture. I would suggest that handedness research should be incorporated into the projects of the archaeological laboratories that have already established facilities. Furthermore, researchers who work with these facilities should be encouraged to include an assessment of handedness in their studies. Knowing which hand to focus on is particularly relevant those who seek to identify, for instance, the traces of hand-held tool-use, the kinematics of tool-use, and the biomechanics of tool production.

The demonstration of right-hand preferences in Acheulean lithic production and use, and the consistent right-bias in Neanderthals, point to early origins for handedness. Since this evidence has been said to lead to language via the common substrate, it is therefore important to explore this possibility. The constraints from Palaeolithic archaeology are now established to relate to the bimanual collaboration model of handedness. Working from this model brings us closer to a Common Substrate that is appropriate for use with the archaeology of human origins.

5.4. The search for the Common Substrate

The approach towards a common substrate for language and handedness arises from the critical review in section 1.3.1 of Chapter 1, which revealed major confusions regarding exact definitions of handedness, language and speech, and the common substrate of the two.

The basis for the language side of the laterality argument is the popular notion that, as a general rule, language functions are processed in the left hemisphere. This idea extends back at least 150 years (see Chapter 1 section 1.1). The idea was mainly supported by extensive aphasia studies showing the relationship between hand preference and unilateral brain lesions causing aphasia (Broca 1861a, 1861b), but originally, in the 1860s, language was not considered to be restricted to one hemisphere as it is now (Zangwill 1960).

As *in vivo* imaging techniques are increasingly available to study the localisation of linguistic and other functions in living, healthy humans and other apes, the notion of hemispheric specialisation for language is being debated again; although broad patterns of unilateral activation can be seen for certain specific functions, there is much interindividual variation (e.g. Tzourio-Mazoyer *et al* 2004). It is certainly not the case that all language functions are restricted to one hemisphere (see Wray 1992 for a review), although there may be different roles for each hemisphere. This is the basis for the bi-hemispheric model of language that is used below as analogy to the bimanual handedness model. A few researchers maintain that the hemispheres are specialised for complementary functions: spatial processing for the right hemisphere and temporal processing for the left hemisphere (e.g. Bradshaw 2001; Aboitiz & García 1997; Hluštík *et al* 2002).

The basis for the handedness side of the laterality argument is that as a behaviour, handedness must stem from some asymmetrical structure in the brain. The functional asymmetry in manipulative ability is argued to be related to structural laterality. As was portrayed in section 1.3.1.1.1 of Chapter 1, function and structure are often confused. After presenting examples from the most common categories of common substrate arguments, the newest and most explicit suggestions for the common substrate were investigated. Current research in this area focusses on genetic mechanisms for cerebral asymmetry affecting motor and linguistic function, functional organisation of motor and language processing as evidenced by aphasias, the role of conceptual processes in linking input with output (or perception with production), the increasing cross-modal connectivity of the parietal association areas and the cerebellum, the connection between tools and language, the role of skill learning in cultural and social primates for individual-level and population-level handedness for knapping gestures, and the possibility that an analytic segmentation substrate in the left hemisphere underlies the learning of language and tool production.

The critical review in section 1.3 of Chapter 1 revealed that proposals for the Common Substrate (CS) often lack explicit characterisation. Furthermore, much attention has been given to speech while neglecting language. The nature of the CS is frequently characterised as structural, whereas here the bimanual roles are considered to be behavioural, i.e. based on function rather than structure. These are reviewed next. The conceptual analogy for language is the analytic / holistic model, defended below. The search for a suitable Common Substrate will incorporate the bimanual model of handedness with the bi-hemispheric model of language. Drawing on the familiar concepts of technique and method, a new common substrate is proposed as an expansion of these ideas. In addition, the new proposal addresses the lack of specification in functional, linguistic characterisation. It is intended to serve the need for a CS which is relevant to Palaeolithic archaeology. This is done by starting with the bimanual model of handedness, since that model was confirmed in Chapter 2 as being appropriate for prehistoric actions.

5.4.1. Support for the bimanual model of handedness

5.4.1.1. The data

The adaptation of Guiard's (1987) model, outlined in section 1.2.2 of Chapter 1, describes handedness as a functional role differentiation of the upper limbs when they act upon a same object. The argument was that each side has a specific, complementary role to play in bimanual manipulations. This is henceforth referred to as Complementary Role Differentiation (CRD). This term was created because there is no agreed terminology. It is called manual role differentiation by Elliott & Connolly (1984) and cooperative bimanual action by Hinckley (1996). Marchant & McGrew (1996:431) specify simultaneous coordinated complementary bimanual actions, whereas Byrne (2005:159) refers to 'co-ordinated manual role differentiation'.

The evidence that is relevant to support this model is the behavioural (observational and experimental) data of skilled hand-use and the functional imaging[9] (brain) studies of manual action in 'normal' and brain damaged people. As argued in section 1.3.1.1.4 of Chapter 1, the nature of the two linked behaviours (handedness and language) must be function. This excludes skeletal (Roy *et al* 1994; Steele & Mays 1995; Steele 2000; Susman 2004) and morphological (e.g. Greig & Wells 2004) asymmetries, even if they are caused by lateralised function. As Chapter 2 revealed, the archaeological data fit the Guiard model in that the high-frequency, manipulative role is played by the right hand and the low-frequency, stabilising posture is done by the left hand. In order to verify that the prehistoric CRD was modern, it must be shown that living humans use the same pattern.

The equal potential of both hemispheres to experience motor and sensory disorders is demonstrated by Stone *et al* (2002). Their meta-review of symptoms for unilateral functional weakness and sensory symptoms reveals that such symptoms are equally likely to occur in either side of the body, and furthermore, they are independent of handedness. The fact that these 'functional' symptoms (symptoms that are medically unexplained by identifiable disease) can affect both sides refutes the notion of 'dominance', and it justifies the premise of the CRD model here.

In a direct application of Guiard's model, Hinckley (1996) found strong support for the roles in bimanual cooperative tasks. He found that people even unconsciously maintained the CRD roles of their hands when they had to reverse roles. Importantly, this effect was only statistically significant for the most difficult version of the task. This further reinforces the

[9] Functional imaging does not show total activation for a given task, but only the additional activation beyond a baseline. The images shown on fMRI or PET, for example, are the result of subtraction (brain doing the target task minus brain doing a control task). Therefore, interpretations of function localisation only refer to the extra processing that occurs for a specific part of a task. Other active areas are cancelled out by the subtraction method.

characterisation of handedness as relating to highly skilled actions, made in section 1.2.3 of Chapter 1.

Stout (*et al* 2000; Stout 2005; Stout & Chaminade 2006) attempted to record direct evidence of each hemisphere's role in stone knapping using PET imaging with six naive and expert knappers. This study found generally bilateral activation relating to the visuomotor nature of the task, although activation was almost always greater in the left hemisphere. Especially prominent was asymmetric ipsilateral activation in the IPS, which is interpreted as reflecting the biased attention to the hammerstone's role as a tool when knapping (Stout 2003:141). Unfortunately, this study has not yet been followed up. The ideal imaging tool (fMRI) cannot be used because knapping in the MRI scanner would create too much motion of the head, causing spatial resolution to be blurred.

The CRD is supported partly by data from ontogeny. Brésard & Bresson (1987) note that babies before 6 months of age appear to have an instinctive CRD in place. When they have to reach for an object that is on a mobile tray, they first place the left hand on the tray to stabilise it, then reach ballistically for the object with the right hand. This behaviour stops at 6 months, with the onset of unimanual reaching. The pattern then fluctuates, and only becomes securely established after several years (Gaillard 1996; Provins 1997b; Corbetta & Thelen 1999).

In an approach which extends the upper limb's laterality to include postural muscles in the trunk and hip, Teyssèdre *et al* (2000) tested eleven right-handed men (tested with the EHI, Edinburgh Handedness Inventory) on a rapid pointing task. The subjects had to sit either on a seat or sit unstably on its edge, requiring the involvement of postural stability musculature. In the unstable condition, the left-handed target task required more postural adjustments to achieve the same level of performance as the right hand. They interpret these findings as meaning that laterality involves not only the upper limbs, but also the trunk and hip.

If this is the case, then the CRD model could apply to the upper half of one side of the body. This is only relevant to certain prehistoric tasks, such as possibly scraping a hide mounted on a rack, or butchering a carcass that has been hung up in a tree. For the kinds of activities that were documented in Chapter 2, like knapping stone or cutting meat in between the teeth, people might have preferred a stable position, just as the ethnographic examples of working posture from Hewes (1957) and Roux *et al* (1995) showed. For delicate tasks such as boring holes and engraving on bone, postural stability is an absolute necessity.

The data from patients with lesions show that the right hemisphere has an important function in spatial awareness and arm movement initiation. Mattingley *et al* (1998) tested three patients with lesions to the Inferior Parietal Lobe (IPL) who displayed symptoms of unilateral neglect (without apraxia or optic ataxia). The IPL patients had slower reaction times than the Inferior Frontal Lobe controls, when reaching to a target on the left. In addition to the established role of the IPL in spatial perception, the authors interpret their results as supporting the view that the IPL is a sensorimotor interface between perception and motor intention. If the right IPL is responsible for both spatial movement and spatial perception in the left visual field, this makes it a good candidate for contributing to the spatial / stabilising role of the right hemisphere, both in perception and production.

Other data from sensorimotor processing show complementary roles for each hemisphere in tactile perception, based on functional MRI (Van Boven *et al* 2005). Twenty subjects (18 self-assessed right-handed, 2 left-handed) had to feel plastic gratings with one index fingertip, and decide if pairs of gratings matched or not, for two tasks. In order to respond while lying in the MRI scanner, the subjects had to flex the right foot for a match and flex the left foot for a mismatch. Only four subjects were tested with both hands, while 8 subjects were tested with either the right or left hand; the two left-handers were only tested on the right hand. One task tested the matching of grating orientation (90° shift), and the other tested grating location (1 mm shift on the fingertip). The study revealed that the discrimination of grating orientation was localised to the left intraparietal sulcus, whereas grating location was processed by the right temporoparietal junction. The CRD model complies with these findings in that location can be seen as an element that requires knowledge of the spatial configurations of objects within a larger context, while orientation can be seen to require a more precise assessment of the properties within an object.

To examine to role of the hemispheres in bimanual motor sequences, de Jong *et al* (1999) recorded activation using PET on 14 adults performing alternating finger movements. To trigger a change in motor programs, an extra movement had to be done on certain cues, randomly placed in the sequence. The authors found that this program change caused activation in the right hemisphere (in the premotor and medial prefrontal areas), and in a small area in the left angular gyrus. Their findings confirm the right hemisphere's role in preparing simple (unskilled) finger movements.

The interactive roles of the two hemispheres in performing finger movements with both hands was studied by Hanna-Pladdy *et al* (2002). Using 13 patients with unilateral Right and 13 patients with Left hemisphere lesions, they tested a variety of finger tasks for different levels of speed, precision, and digit coordination (possibly analogous to the levels of difficulty described in section 1.2.4 of Chapter 1). The subjects and the 86 male controls were screened for right-handedness using an inventory from Briggs & Nebes (1975). Hanna-Pladdy *et al* measured performance (according to speed) on finger tapping, a grooved pegboard, coin rotation, and hand tapping.

In the control subjects, the coin rotation revealed the most difference between hands, with the hand tapping showing the most symmetry between hands. In the left and right hemisphere damaged people, all tasks were better performed by the ipsilesional hand (same side as lesion side). This is expected, since the damage causes loss in the contralesional hand. However, the surprising result was that Right-hemisphere damaged people had greater asymmetry than Left-hemisphere damaged patients. These results indicate that in right-handers, the left hemisphere has control of both hands, whereas the right hemisphere only controls the left hand as previously thought. This would seem to support MacNeilage's (1986, 1992) theory that the left hemisphere controls both frame and contents. The Hanna-Pladdy *et al* (2002) results show that the left hemisphere's 'extra' ipsilateral control is most impaired for the more 'difficult' tasks, i.e. those with the narrowest tolerance for precision, speed, and finger coordination.

In terms of the CRD model, however, the behavioural effects of these control structures lead to unexpected predictions: because the left hand receives commands from both hemispheres, it should benefit from the left hemisphere's superiority in terms of precision, speed, etc. However, the strength of this ipsilateral control may not be comparable to the strength of the contralateral control that the left hemisphere exerts solely on the right hand.

The study by Lausberg *et al* (2003) seems to contradict the above results. With split-brain patients they tested the production of hand gestures to describe scenes. The patients neglected the left personal space when using their right hand to gesture, suggesting that the left hemisphere does not control both halves of space (as proposed above). Rather, the left hemisphere is restricted to processing the right half of personal space. Conversely, the right hemisphere appears to use to the whole personal space, since there was no neglect by the left hand.

This study shows an interesting complement with the Hanna-Pladdy *et al* study. While that team found a more general role for the left hemisphere in controlling both hands, the Lausberg *et al* study found a broader role for the right hemisphere, in using both sides of personal space. However, the Lausberg *et al* results pertain also to hands: the right hemisphere's broad role is evidenced by the better performance of the left hand, which is consistent with the Hanna-Pladdy finding that the left hand is controlled by both hemispheres. Although it is not yet clear what are the relationships between motor control and personal space, the CRD model would predict that the left hemisphere is superior in the fine manual control whereas the right hemisphere is superior for spatial manipulations. These predictions are supported by the data in these two studies.

5.4.1.2. Discussion of the CRD model

There is evidence from a wide range of behavioural, brain damage, and functional imaging studies that supports the Complementary Role Differentiation (CRD) model for handedness. Unfortunately, the most important category of data, ethological observations of people using their hands in real life, is missing. The surprising results found by the survey of Marchant *et al* (1995) shows that such studies are badly needed. The standard measures of 'handedness' (questionnaires, self-report, or writing hand) do not actually measure handedness. Even the experimental studies of hand performance can be criticised for their artificial and induced settings, which might affect the conscious attention of the tasks to be biased to the left hemisphere, just as the linguistic tests do. Despite the lack of naturalistic behavioural data, studies of functional imaging during hand-use are rife. These can be subject to the same constraints of focussing due to their experimental paradigms, but at present it is impossible to record a person's brain activity without their knowledge, unless they are in a coma.

Stout's (Stout *et al* 2000; Stout & Chaminade 2006) imaging studies showed that stone knapping is inherently a visuo-motor task, which was predicted, but he found less activation for mental imagery than expected. Nonetheless, activity was mainly bilateral although biased to the left hemisphere, with an ipsilateral (right-hand) activation attributed to the focus on the hammerstone as a tool. Other studies of muscle activation for postural stability beyond the arms are only partly relevant to handedness, since many prehistoric activities requiring proficient motor control were probably done in a stable sitting position.

Ontogeny tells us that children take many years to stabilise their hand-use patterns into a consistent CRD. This is also the case for non-human apes such as chimpanzees, who develop an idiosyncratic lateralisation, and it confirms that learning and practice are the main drivers of a stable CRD (Provins 1997a, 1997b). Data from brain-damaged people doing skilled and less-skilled gestures show that greater task difficulty induces greater asymmetry in hand proficiency.

The complementary roles of the hands are suggested by functional imaging studies that indicate a right-hemisphere advantage for spatial perception and simple movement, and the processing of personal space and object location. In contrast, studies find a left-hemisphere control of both hands in speed performance and in tactile perception of object orientation.

Taken together, these findings converge on a consistent CRD pattern in which the left hemisphere (right hand) prefers to carry out fast and precise manipulations while the right hemisphere (left hand) is specialised for manipulations that involve processing spatial relations and changing motor programs. These roles conform to the Guiard model in that the right hand performs high-frequency movements and the left hand prefers low-frequency gestures, preferably of a stabilising nature. As the review of archaeological data in Chapter 2 showed, the CRD model was able to successfully account for the patterns seen in the prehistoric artefacts. In the next section, the bi-hemispheric model of language is presented, with particular attention to parallels with the CRD model.

5.4.2. Support for the bi-hemispheric model of language

To match the bilateral model of handedness, a bilateral model of language is needed. The thesis of Wray's (1992) model is that language functions are not restricted to one (i.e. the left) cerebral hemisphere, as much of the literature seems to assume (e.g. some of the commentaries on Corballis 2005). The analytic and holistic components have complementary roles, just as the two hands do. In the case of language perception and production, these two processes can act separately but are usually used together. However, the focus of attention is always a given utterance. As an analogy, the focus of attention in, for example, stone knapping is the moment of impact when the hammer strikes the flint core. In both instances, the person is only attending to one 'thing' at a time. It is important to note that this attention can be conscious or not; this relates to the distinction between two levels of difficulty and the techniques / methods skill levels (cf. Chapter 1 sections 1.2.3 to 1.2.5). The Focusing Hypothesis (Wray 1992) states that the analytic component relies on conscious, attentive processing whereas the holistic component can be under more automatic control. This model is termed here the Analytic/Holistic (AH) model.

The pertinent evidence to support this model is the functional imaging data of non-damaged people doing linguistic tasks and the behavioural (observational and experimental) data from damaged individuals. Because the nature of the linguistic behaviour must be function, data are excluded that relate to the identification of structures such as Broca's area, the planum temporale (Geschwind & Levitsky 1968; Geschwind 1984), and all speech-related areas (Galaburda 1991; Ryding *et al* 1996), in addition to the vast body of fossil and living primate endocast data (Holloway 1981; Holloway & Delacoste-Lareymondie 1982; Falk 1987, 1998; Falk *et al* 2005) and comparative brain anatomy (Semendeferi & Damasio 2000; Semendeferi 2001), even if these structures are the physical location of functions.

Recent data for language lateralisation point to greater heterogeneity among left-handers, for linguistic (analytic) tasks (Szaflarski *et al* 2002). Using fMRI on 50 subjects (with an EHI quotient from -100 to 52), these authors found 8% right-hemisphere activation, 14% symmetric, and 78% left-hemisphere activation for the task. This study indicates that left-handers generally have the same pattern of linguistic function as right-handers, although their manual behaviour differs. However, Jürgens (2005:230) indicates caution by noting that "handedness and language representation are not coupled as tightly as the high percentage of right-handers with left-sided language representation suggests." The AH model that is defended here detaches itself from these problems by representing language equally in both hemispheres, one favouring a holistic mode, the other more analytic.

It seems that the first mention of the terms analytic / holistic for language processing was by Levy (1969). He suggested that the left hemisphere's analytic or 'cognitive' style was exapted by language, thus putting language function into the left hemisphere. The AH model builds on this by accepting the analytic nature of the left hemisphere while also giving equivalent importance to the right hemisphere's holistic functions.

A study of 14 right-handed (by questionnaire) subjects by Ostrosky-Solís *et al* (2004) measured ERP while the subjects listened to a word list that they were asked to memorise. These authors found stronger activation in the left hemisphere, which supports the analytic mode of processing required by explicit verbal memory.

Fabbro (1992) provides evidence for the flexibility of language functions in bilingual people. Although he still adheres to the common view of left-hemisphere language localisation, his data appear to confirm the AH model. He finds support for more symmetrical language processing in some cases. For example, in trained right-handed translators and interpreters, both hemispheres process the first language (L1) during perceptual tasks (dichotic listening) and the second language (L2) during production tasks (verbal-manual interference). Fabbro interprets these and other results as showing more bilateral language processing for bilinguals, as opposed to monolinguals who have left-hemisphere language. It is clear that his tests are all explicitly-linguistic, as Wray (1992) suggests taps on the left hemisphere. Combining Fabbro (1992) with the AH model would in fact lead to the prediction that whereas monolinguals have an analytic left hemisphere, the bilingual translators experience a shift of their analytic capacity to the right hemisphere as well. In this scenario, the knowledge of more than one language causes a distribution of analytic and holistic processing to use both hemispheres equally. What Fabbro's data do not test is whether the holistic functions are shifted to the left hemisphere in these bilinguals.

Further information on this point may come from speech disruptions. Speedie *et al* (1993) reported deficiencies in a bilingual right-hander from a lesion in the right basal ganglia. He was impaired in the holistic elements of language that are commonly accepted as 'automatic' speech: swearing, counting to 20, reciting mealtime blessings, singing familiar songs. The right-hemisphere's role in prosody and intonation, lexical knowledge, syntax, and interpreting the emotional context of discourse is summarised in Obler & Gjerlow (1999). In fact, I would interpret the findings in terms of language rather than only speech. The thesis of the AH model is that holistic utterances, or formulaic language (Wray 2002), form an integral part of our language perception and production. If formulaic utterances are processed holistically, then their localisation to the right hemisphere is supported by the data.

Krach *et al* (2006) find support for the bi-hemispheric model of processing certain kinds of linguistic information. The advantage of their study was that they tested three classes of laterality among their 58 subjects (assessed by the EHI, Edinburgh Handedness Inventory): right-handed, left-handed, and ambidextrous. Interestingly, handedness did not correlate with anything, which argues in favour of the bi-manual model of handedness. They found a right-hemisphere activation for lexical decision. In contrast, the left-hemisphere was most active in mental word generation. These findings imply different linguistic roles for the hemispheres: word generation is highly analytic (hence left hemisphere), whereas fast lexical decision, which requires extracting the word's meaning in an instant too brief for analytic deconstruction, must be processed holistically (hence right hemisphere).

The role of each hemisphere in processing visual stimuli (letter patterns) was studied by Mevorach *et al* (2006). Testing subjects with transcranial magnetic stimulation in the posterior parietal area (PPC), they found that the right PPC is needed to orient attention to salient stimuli, while the left PPC is responsible for orienting attention away from salient stimuli (when these need to be ignored). The Mevorach *et al* findings are partially consistent with the Focussing Hypothesis, since the role of the left hemisphere is to orient attention away from certain stimuli in favour of others. However, the right hemisphere's equally orienting role suggests that the AH model can account for these results.

The perception of emotions in both hemispheres, tested by verbal stimuli, was examined by Smith & Bulman-Fleming (2006). The Waterloo Handedness Questionnaire was used to test for handedness in all 64 subjects. They found the expected pattern of a right-hemisphere advantage for negative emotional stimuli and a bilateral or weak left-hemisphere advantage for positive emotional words that were perceived consciously. When the words are presented briefly enough (17 msec), they are processed unconsciously, which is argued to eliminate the left-hemisphere advantage in analytic word perception (see above paragraph). The strong right-hemisphere efficiency at processing negative emotional stimuli partly supports the holistic role, but more tests are needed to clarify why the positive stimuli are bilaterally processed.

Beyond the large body of data that Wray (1992) invokes to support her Focusing Hypothesis, there is more recent evidence for the AH model of bi-hemispheric language (see Obler & Gjerlow 1999 for a lay summary). The functional imaging data and brain-damage studies confirm the expected left hemisphere's role in explicit language tests such as word generation and error detection. Interestingly, bilingual people seem to have a more bilateral processing for the analytic mode. In intact people and lesion patients, the right hemisphere is active in perceiving and producing 'automatic' or 'formulaic' language elements such as prosody, singing, reciting familiar phrases, and words conveying conscious negative emotion. In addition, fast lexical decision, which requires a holistic mode of processing, also taps on the right hemisphere. All together these results support Wray's (1992) original argument for equally linguistic roles in both hemispheres, where the left hemisphere has an analytic capacity to consciously or attentively reflect on language's constructions, and the right hemisphere operates holistically. In the next section, the AH model is combined with the CRD model in order to propose a Common Substrate that links these two bilateral behaviours, which are unique to humans.

5.4.3. Requirements for the new CS

As detailed in section 1.3.1.1.4 of Chapter 1, based on the gaps in the literature, the new suggestion for the Common Substrate must fulfil several requirements. First, it must be explicitly specified. Second, it must account for the functions of the two linked behaviours, handedness and language. Third, it must invoke a common mechanism of software, as a result of cerebral processes. As reviewed, most of the suggestions are centred on hardware. The hypothesis proposed here outlines a conceptual CS which relates to the Complementary Role Differentiation of the two hands/arms when doing a skilled task, and to the functional lateralisation of language tasks. The above review has focussed on these two elements, in terms of the language abilities and the manual skill that are specific to each cerebral hemisphere. The new CS therefore is characterised in terms of the shared software that is responsible for the functions of handedness and language.

At this point it is important to specify that the proposed CS applies to the interface between perception and production. In terms of language, it is now well-established that fully native linguistic comprehension and performance cannot exist without the interaction of the two (Burling 2000; Studdert-Kennedy 2005). Although many language origins hypotheses neglect one or the other, Burling (2005) appropriately builds a narrative around the relationship of speech and language perception to the production processes. The model of Wray (1992) also includes both, since aphasias can include deficits in both reception and production. With respect to handedness, the perception element of manual skill involves seeing, watching, sensing, and feeling the movements of others and of one's own body parts. In fact, the motor output system (actually called the sensorimotor system) is highly dependent on somatosensory input (Pinel 1997:231-232). The production aspect of manual skill contains of course the movements themselves, but also the conceptual processes that precede the effective motor output, including imagery (Grush 2004), planning, and reflection on the body postures and hand positionings. There may even be a shared conceptual representation of action perception and planning (Prinz 1997).

Therefore it is the junction of perception and production that is relevant to the new CS. Because skill learning depends on an efficient merging of these two modalities (cf. the inversion problem, Studdert-Kennedy 2005; Arbib 2005a), they must both be operational. There is no argument for the primacy of either perception of production. It may be that a categorical perception (of objects, elementary gestures, words, or phonemes) is a necessary ability before one can produce them, but it is also true that baby babbling (either gestural or vocal) seems to precede the infant's perception of categories in the world. In sum, the hypothesised CS remains inclusive of production and perception and their interface in learning processes. What the new hypothesis does not address is the cause or effect of handedness and language, namely the primacy of one over the other.

5.4.4. Putting it all together

Starting with Pinel's (1997:422) simplified textbook chart of hemispheric functional lateralisation, which represents the standard widely-accepted view, we find that the left hemisphere is characterised as superior in controlling movement sequences, verbal memory, reading and writing. The right hemisphere is defined as having a superiority in processing face recognition, music, tactile patterns, and movement in space. The new CS outlined here uses these general concepts to focus on the specific behaviours of language and manual skill.

In fact, Woll & Sieratzki (2005) have already touched on the link that is proposed here. Importantly, they consider language to be "produced by the complementary interaction of both hemispheres" (Sieratzki & Woll 2002:173). While their account centres on the mother-infant interactions that take place during cradling, they seek to explain the human left-cradling preference in terms of the right hemisphere's role in affective processing, including the unique prosody of motherese.Their approach is similar to the one proposed here in that it invokes a duality of processing, holistic vs. sequential. They suggest that the functional specialisation of the left hemisphere includes target-directed behaviour, speech, and sequential processing, while the right hemisphere is specialised for holistic environmental monitoring and spatial processing. The textbook view of right-hemisphere language processing for pragmatics and emotional content (Obler & Gjerlow 1999) supports this proposal. Following Sieratzki & Woll (2002), the present hypothesis extends the spatial processing side to include holistic aspects of language, which include emotion and prosody (as in the textbook view delineated above).

According to the summarised data above, the conceptual role of each hemisphere can be examined. As Figure 5.4 illustrates, the left hemisphere is implicated in all tasks requiring speed and precision, in other words, high-frequency movements, as Guiard (1987) originally proposed. The left hemisphere is also important for manipulative aspects of language and hand skill. These are probably facilitated by a segmenting ability that applies to both domains. The verbal formulation and word generation tasks are typical explicit linguistic tasks that tap on this left-hemisphere segmentation propensity. The capacity to analyse smaller parts of a whole object, both in production and perception, is necessary for executing high-frequency movements. Similarly, language cannot be perceived nor produced unless the speaker-hearer is able to analyse certain segments independently.

On the other side of Figure 5.4, the right hemisphere is clearly responsible for all tasks that have to do with space, whether personal or extra-personal. The formulaic and semantic nature of right-hemisphere language probably relates to an aptitude to perceive and process whole scenes, in which objects occupy a place. When a context must be assessed holistically, such as an environment that must be scanned for dangers (Woll & Sieratzki 2005), the process may be analogous to scanning linguistic input to extract its overall emotional or semantic significance. The common conceptual basis is that the entire context must be perceived and interpreted, without focussing on a single element in that context.

In terms of the CRD model, the coordinated movements of the low-frequency stabilising hand and the high-frequency manipulating hand create actions that can contain both types of elements, slow and fast. This allows several levels of difficulty to be superimposed on the baseline task. Taking stone tool manufacture as an example, the goals and subgoals can be reorganised at will, so that errors can easily be corrected, and innovations can enter the sequence at any point. With an explicit knowledge of each component of the task, the knapper can permit changes to occur in the tool-making process.

Within the AH model, inter-hemispheric coordination results in a rich language capacity that is flexible in terms of its usage, its comprehension, and its resistance to damage. While the holistic hemisphere unconsciously scans the linguistic environment for global information, the analytic half can manipulate or examine particular elements. This layering of attention can tolerate interruptions or disturbances by shifting the attention to the other side.

The effects of lateralised habits favour a consistent bihemispheric pattern, especially with more highly practised actions. The conceptual roles can then be transferred to other modalities, while maintaining the same roles. If the new modality happens to be a sensorimotor one, then the roles will be instantiated in motor learning and skilled manual actions.

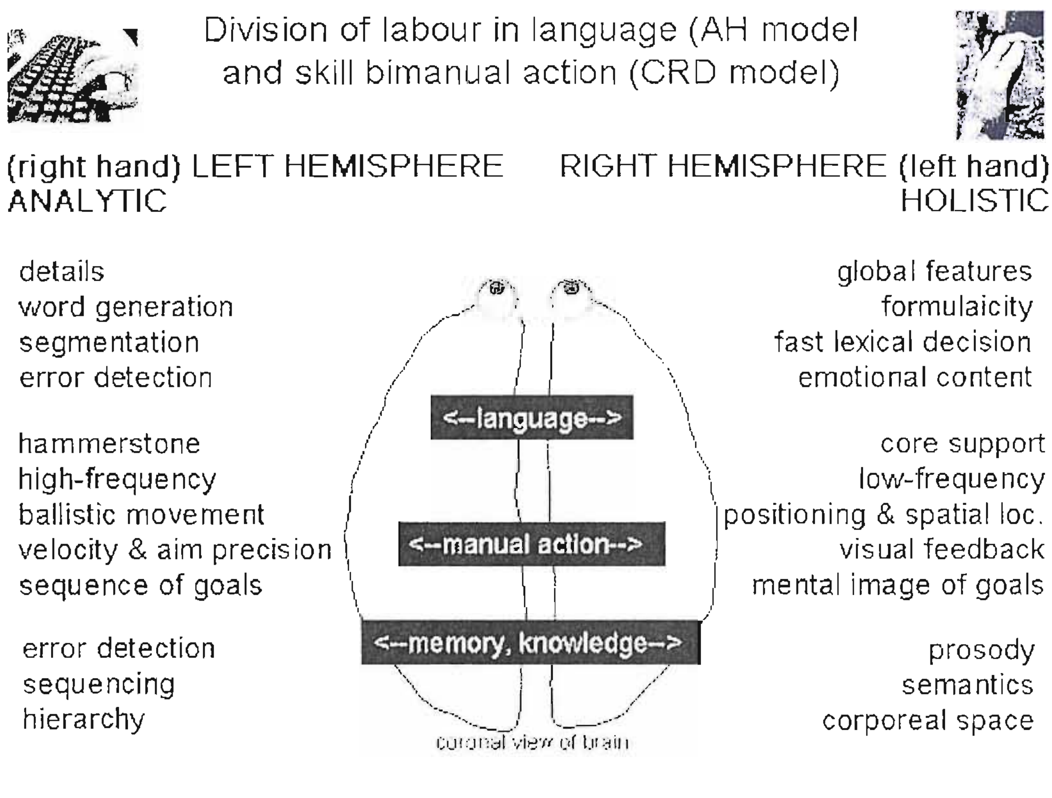


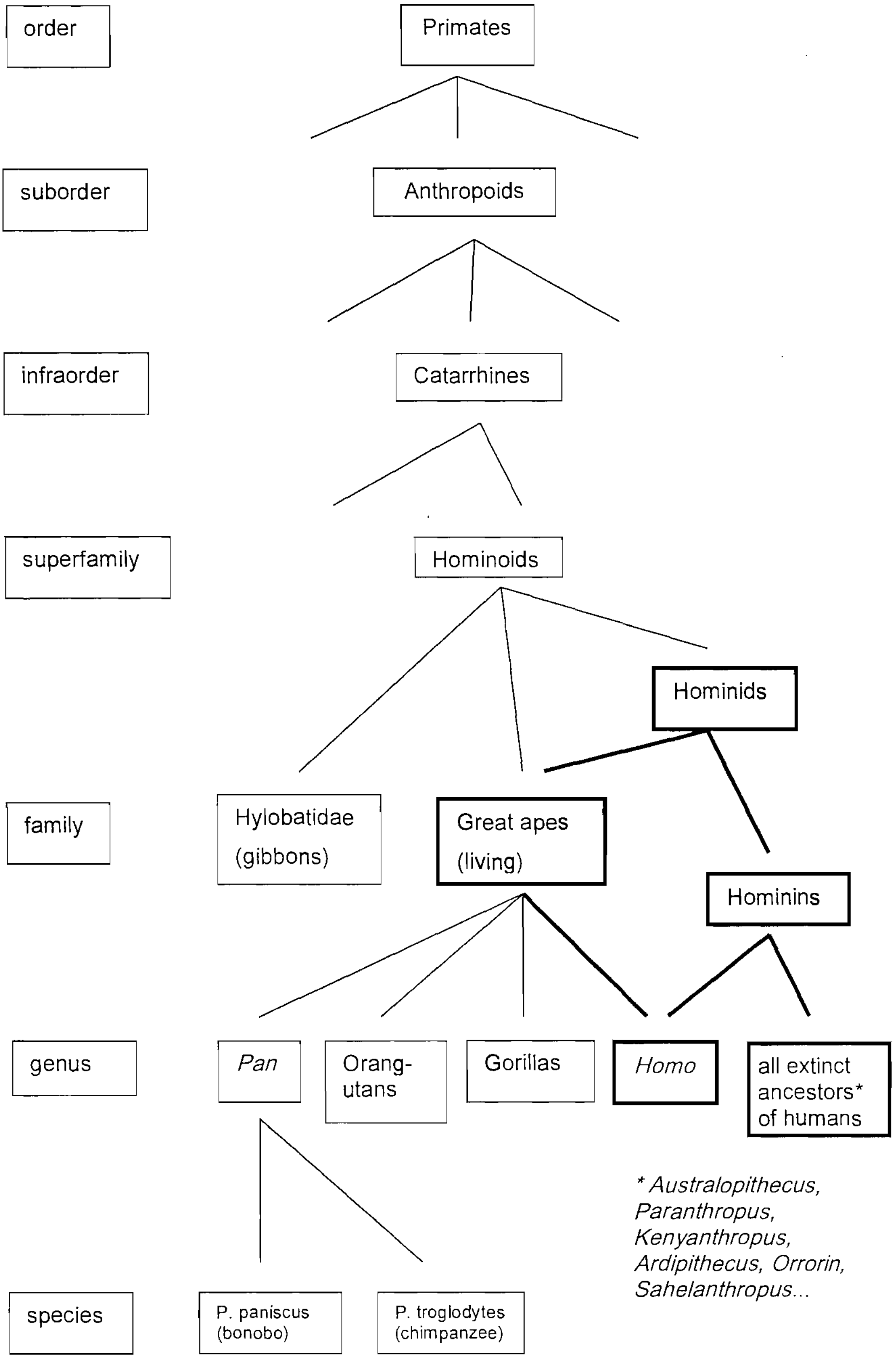
Figure 5.4. Division of labour in the brain: the AH model and the CRD model combined.

5.5. Final conclusion

The experimental work in this thesis (Chapters 3 and 4) did not validate two methods proposed for diagnosing handedness in stone tool production. The tranchet method was definitively invalidated by the experimental programme, although lateralisation patterns in the Boxgrove tranchet-struck handaxes remain to be explained. The single-platform core rotation paradigm was also invalidated by the experiments, but the validity of this methodology must remain open since experiments by other authors give conflicting results. In contrast, the other methods and data synthesised in Table 5.2 have not been invalidated by the present research; many remain open, and all could benefit from further testing using the analytical and experimental means deployed in this thesis. The experimental and analytical validation of methodologies for identifying handedness in lithic artefacts that was presented in this dissertation showed that several other reliable sources of evidence exist. Some assemblages and isolated finds from the Lower and Middle Palaeolithic show robust or anecdotal evidence of a right over left hand preference. The hominin species directly associated with these finds are *Homo heidelbergensis* and Neanderthals; therefore these species can be confirmed as preferentially right-handed on the basis of the valid methods that were reviewed here. Additionally, it can be inferred from methods different to those which were the focus of this thesis that the hominins involved with some Acheulean industries were also predominantly right-handed.

The theoretical analysis of the Common Substrate presented in this thesis has argued that handedness is a scientifically valid framework for future research into Palaeolithic archaeology. This was shown by the successful application of the Complementary Role Differentiation model of hand-use to the artefacts being reviewed. The value of this research, in addition to the establishment of reliable methodologies and robust data for human origins, is to be recognised in its contribution to the extensive debates over language origins. The approach adopted here for the CS is unique in its focus on prehistoric handedness: it begins with a bimanual hand-use model that is the most relevant to archaeology, and works towards a corresponding language model. The novelty in my approach is to start from the handedness side of the argument. Existing approaches to the CS begin with language, and then work towards hand-use. As discussed in Chapter 1, these fail to satisfy the requirements of Palaeolithic archaeology because they assume that language is left-hemisphere dominant, which leads them to assume that handedness only involves the "dominant" hand. If future work by human origins researchers can continue to validate and develop new methodologies for diagnosing handedness in lithic production and use, then the artefact record will reveal its richness by offering hard data to the question of language origins and the emergence of our uniquely human cognitive capacities.

Appendix 1. Primate classification



Appendix 2. Lithics excluded from the analyses

negative number	direction of tranchet	reason angle could not be measured
11263-1	Left	This biface on a yellowish coarse-grained flake has a cleaver tip created by at least one tranchet. The first removal, if it was a tranchet, was mostly deleted by subsequent removals on the same face, and by the second (definite) tranchet T2, struck from the same point on the edge but on the opposite face. Due to the coarse quality of the raw material, and the incompleteness of the potential T1, I counted this handaxe as a single-tranchet piece.
11568	Horizontal	Although this miniature biface has a cleaver tip created by a wide tranchet extending from edge to edge, the only fracture features present on the negative are grooves distributed in two sets of straight lines extending from upper left to lower right of the negative. They do not show the characteristic curved distribution indicating direction. Thus, the direction of the blow was either left-struck or right-struck. On two separate visits, I measured the angle as either 0 or 150, and then 0 or 155; in spite of the second look I am still undecided about the direction of removal.
13453	none	This piece is a small chunk, possibly a very rounded biface tip or base, or a tranchet flake. It is heavily used on both faces.
30405-1	Right	This small handaxe on a flake has a first tranchet T1 so obliterated by subsequent removals that not enough information remains for an angle measure. The handaxe is still counted as a double tranchet although only the second (leftward) T2 angle was measured.
5533	Right	This is a small cortical piece which could be either a tranchet flake or a small bifacially worked piece with a very large tranchet removal. The supposed tranchet removal covers half the surface area but I am uncertain as to this removal's place in the sequence. The area around the bulb has been retouched.
7474-1	Right	The heavily-used tip on this small handaxe was created with two rightward tranchets, but the first was mostly deleted by the second as well as by later removals on the same face and by heavy use-wear on the edge where the bulb should have been. The handaxe is still counted as a double tranchet although only the angle of the second was measured.
FL. 2717	none	The large flat fracture surface running diagonally across the tip was first thought to be a tranchet negative, but on closer inspection in a second visit I decided it was an unmodified part of the original flake blank's ventral face. This area is the most protruding surface on the handaxe's face, with every other part of this face having been removed by flaking. The opposite face was carefully thinned to regularise the profile and outline. It is yet another example of the cleverness of Boxgrove knappers in utilising the existing sharp edges of the flake blanks.
L. 587	unknown	This piece could be a tranchet flake, with a concave bulb negative on the face. It looks like a biface tip due to the careful retouch along one edge and the unmodified edge created by the supposed tranchet removal.

Table A2.1. Details of unmeasured tranchet negatives on Boxgrove handaxes.

flake number	reason excluded
1101	Tiny mesial fragment with shatter break at one end and unidentified truncation at the other end. I could not identify the dorsal and ventral surface, as both appear to have a fracture surface and a portion of margin, although each struck in different directions.
1241	A proximal fragment of what looks like a blade or thinning flake. Distal shatter break. Ventral surface smooth, dorsal surface has three facets all struck from the proximal end, their negative bulb areas retouched on dorsal face.
3975	Tiny triangular fragment (mesial?). Snaps on two of three edges. One surface has two concentric ripples and a tiny segment of possibly opposite margin, other surface has three facets.
4146	Fragment of a patinated huge hinged flake which was retouched along the break. No opposite margin could be found.
4195	Tiny (proximal?) fragment. Face with label on it has fracture surface and three potential margins; other face has fracture surface and two potential margins. Fracture features on both faces give inconsistent direction information.
4267	Tiny distal fragment, proximal thin break (trampled?). Ventral surface has curved hinge termination and possibly a segment of opposite margin on the right; dorsal surface has three facets.
4690	Tiny distal fragment with apparently two ventral surfaces. One is smooth with only ripples, other has ripples plus possibly an opposite margin on the left.
500	Small fragment, unidentified portion. One face has a clear margin of opposite face running along three edges, but the fourth edge is a used/retouched edge and the fracture surface has unclear indications of direction. The other (dorsal?) face has two facets.
5027	A small flake with snaps on two edges. Both faces have ripples indicating a potential fracture surface.
6643	Small fragment with all broken edges. One surface has ripples, other has fracture features with possibly opposite margin on right.
FL. 05	The right half of a siret-fractured flake. Viewing the ventral surface, the proximal edge is covered in cortex, and the right side of the distal part ends in a hinge termination. The left side of the distal part is snapped.The dorsal surface has a fracture surface and a steep margin with many steps (from use?).
FL. 31	A complete, round, patinated flake with entirely cortical dorsal surface. I could not find an opposite margin.
FL. 36	Large, complete long flake. Ventral surface has clear fracture features, bulb, and striking platform. Dorsal surface has a strip of cortex running down the middle from platform to distal end, with an old facet on either side each creating a sharp edge. No evidence of opposite margin.

Table A2.2. Details of Boxgrove tranchet flakes excluded from the analysis.

According to Pope (2002:181), the assemblage should contain more tranchet flakes than the ones found in the museum:

unit layer	Pope thesis	this study
not indicated	--	2
UPPER	--	--
8a	1	2
8ac	2	1
5a	10	4
4d1	4	2
MIDDLE	--	--
4	112	41
4b	--	4
4/3	7	0
4u	50	9
4u/3	3	0
LOWER	--	--
4.4u	4	0
3c	12	1 ?
3	3	0
OTHER*	other=46	43*
GTP17 unit 4b	2	--
Q1A unit 4c	0	--
Q2A unit 4c	3	--
Q2C unit 4c	30	--
Q3D unit 4c	11	--

*Data kindly provided by F. Wenban-Smith (pers. comm. 2005, unpub.)

Table A2.3. Numbers of tranchet flakes reported in Pope (2002) vs. analysed in the present study.
Table after Pope (p.181).

Glossary

- Apes: a short form used here for great apes. The family containing living chimpanzees, humans, gorillas, bonobos, and orang-utans. (Note that in formal classification, apes encompass the gibbons and the great apes.)
- Core: the larger piece of stone from which flakes are removed.
- Cortex (lithics): the outer surface of a flint nodule. When fresh (i.e. from a primary source such as a cliff face or quarry), it consists of white chalk. When it comes from a beach, river, or other secondary source, the chalk has been washed away, leaving the very thin layer of cortical surface on the chalk.
- Cortex (neuroscience): surface of the brain, on which you can see gyri and sulci (the convolutions which leave traces on the endocast). The neocortex refers to the cerebrum - the two hemispheres which are the object of this dissertation. The brain also contains the subcortical structures including the cerebellum, thalamus, hypothalamus and brain stem.
- Flake: a small piece of stone that is detached from a larger piece via conchoidal fracture, either by mechanical means or by knapping.
- Hominids: the great apes and the hominins.
- Hominins: the extinct ancestors of living humans and living humans.
- LCA: Last Common Ancestor. The species from which humans and chimpanzees diverged and each evolved in their separate ways until their present forms.
- LSF: Longitudinal Sharpening Flake. Rejuvenation flake struck from the tip towards the butt of a flake scraper, termed by Cornford (1986).
- LTP: a basic process that is responsible for cognitive development based on environmental input, long-term potentiation refers to the improved efficiency of a synapse caused by repeated stimulation of the neurons connected to it. The effect of LTP is to allow a neuron to fire with lesser amounts of stimulation, which results in the process of learning.
- S.E.M.: Scanning Electron Micrography. A method for microscopically photographing flat surfaces, it is widely used in traceology studies for determining traces of use on stone tools.
- TSF: Transverse Sharpening Flake. Rejuvenation flake struck from the edge of the tip towards the other edge of a flake scraper, termed by Cornford (1986).

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