

M.Sc. Dissertation

Lithic indicators of handedness:  
assessment of methodologies and the evolution  
of laterality in hominids

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## **1. Introduction**

### **1.1 Aims of the study**

Humans are unique in the animal kingdom in that they are strongly biased towards a right manual preference. 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. Because manual specialisation is related to hemispheric specialisation of the brain, the evolution of human cognition can be studied through handedness. In particular, the thorny issue of the timing and processes of the emergence of language is relevant to brain lateralisation. Insufficiencies in the fossil record can be complemented with information from the archaeological record, which is often plentiful in areas where the fossil record is sparse. Several techniques for inferring handedness from lithic evidence have been proposed. However, these methods have not been applied systematically to archaeological samples. Two archaeological collections from the British Lower Palaeolithic were analysed in order to assess the feasibility of using these methods to study large flake collections, and what they reveal about the handedness of the hominids who made these artefacts.

### **1.2 Structure of the paper**

In the first two sections, various aspects of handedness are considered. The ways in which handedness is assessed in humans and primates are discussed, and some of their inconveniences are pointed out. The different dimensions of lateral preference are also presented to demonstrate how primates and humans differ. Some features of the fossil and archaeological records are examined in order to show ways in which handedness can be assessed in past populations, and theories that draw on this evidence are presented. Hypotheses about the

genetic mechanisms for the acquisition and transmission of handedness are described.

Next the physical context of handedness is explored, beginning with anatomical asymmetries. The brain is then studied with respect to asymmetries in morphology and function. The evolution of the brain is reviewed based on fossil evidence, and the lateralisation of the human brain is discussed in terms of two types of functions that are unique to humans: language and stone tool making. A possible link between the two activities, sequential processing, is explored. Finally, some of the theories that have been suggested about the evolution of language are examined.

In the Lithics section, it is contended that archaeology can contribute much to the question of handedness evolution. Some basic notions of flint knapping and a brief timeline of lithic industries are presented. It is argued that primate models are only partially suitable for modelling the tool behaviours of early hominids, notably in the cultures of modern chimpanzees. Then the methods used in the experimental part of the study are described, along with the assumptions behind them. The section is concluded by a discussion of the hypotheses tested in this study.

### **1.3 Terms used**

In this paper, the term 'handedness' will refer to the population-wide tendency of humans to consider the right hand dominant or stronger than the left hand. This manifests itself as a bias in the modern population towards preferentially using the right hand or arm for unimanual and bimanual tasks. Unimanual tasks make use of only one hand, while bimanual tasks require coordinated actions of the two hands. In terms of bias, the dominant hand is preferred for unimanual activities, and in bimanual tasks it is the hand performing the more manipulatively complex action or the action requiring more precision and fine motor skill.

But although people talk about handedness and most consider themselves either right- or left-handed, the concept requires a clear and objective definition before it can be used to test hypotheses for the study of human evolution.

## **2. Handedness**

### **2.1 Defining 'handedness'**

Is the very notion of handedness something that has been imposed upon us culturally and linguistically? When asked whether they consider themselves right- or left-handed, many people respond according to the hand they use to write. Very few tasks require the consistent use of only one hand (cf. Wilczak, 1998), and the most strongly unimanual tasks include writing, drawing, and painting: namely, all activities that involve applying a marking implement to some sort of surface. Because language-related tasks are processed differently from other manual tasks, it is possible that using writing implements is processed similarly to other language tasks, and therefore can show the strong lateralisation that appears in humans. From 60 to 70 % of left-handers are left-lateralised for speech, which is also the norm for right-handers: at least 91 % of right-hand writers are left-brained speakers (Annett, 1985). It may also be argued that the extremely long learning period required for these highly skilled activities is facilitated by consistency in hand use. The social value of hand writing can place pressure on each young individual to develop his or her own style, or handwritten identity. The potential skill of the non-dominant hand will then be abandoned in favour of developing proficiency as quickly and as efficiently as possible in the dominant hand.

### **2.2 Task-specificity**

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 it will be shown 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 primate studies, there is considered to be a bias if one hand is used significantly more than half the time. Accordingly, the use of one hand is considered to be *consistent* if it occurs significantly more than the random figure expected if there were no bias, namely 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. There is evidence that the task type influences the degree of hand preference in individuals or populations (Mitra et al., 1997; Steenhuis & Bryden, 1989). 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).

Lateral bias in hand use may thus be characterised 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 (manual specialisation)
3. a population bias which depends on the task (task specialisation)
4. a population bias which is consistent across tasks (handedness)

The lack of a bias can be expressed in two different ways. In these cases the distribution of right and left hand use is expected to be around 50 %. Individuals

may use either hand randomly regardless of the task (ambidexterity), or they may show manual specialisation but the number of right-preferent and left-preferent individuals is roughly equal in the population (no handedness).

In order to account for the apparent task-specificity of degrees of bias in some primates, workers have suggested classifying unimanual tasks into low-level (familiar) and high-level (complex) categories (Fagot & Vauclair, 1991). 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.

There appear to be differing degrees of bias in humans as well. Steenhuis & Bryden (1989) argue for a distinction based on sequencing complexity. Bimanual tasks often involve executing a sequence of motor behaviours, for example in inserting a pin into a hole, whereas unimanual activities, such as picking up a pin, are simple in terms of sequence processing. Human left- and right-handed subjects show more lateral preferences for sequencing tasks than for simple tasks (Steenhuis & Bryden, 1989). Therefore when measuring handedness in humans, the effects of task type and uni- or bimanuality must be taken into consideration.

### **2.3 Assessment in humans**

The most obvious way to measure handedness in humans is to simply ask people how they classify themselves. However, consistency tests have revealed that people's responses do not always match their behaviour (Annett, 1985). It is not clear whether humans' bias in use arises from a perception of handedness, or causes it. Measures of preference distributions in a population typically display a J-shaped curve, with most people strongly right-preferent, about 10 to 12 % strongly left-preferent, and very few weakly preferent or ambidextrous (Annett 1985; Corballis, 1997). In contrast, measures of relative proficiency

show a normal distribution (bell curve). Tested with tasks such as moving pegs, filling dots, or tapping, most people perform equally well with both hands and numbers decrease in both directions towards increasing differences between the hands (Corballis, 1997). The distinction between reported preference and actual performance will be important to maintain, as methods of assessing handedness in humans and apes differ widely. Methods for measuring lateral bias will be discussed below, as well as some of the problems encountered in comparing humans to other primates.

The methods for assessing hand preference are varied: they include experimental manipulation tasks (such as reaching for food), which are used with infants and primates, to observations of primate behaviour, to self-report questionnaires for adult humans. These usually contain questions about habits like opening a bottle, sweeping the floor, picking up a coin, or holding a tennis racket. One commonly used questionnaire is the Edinburgh Handedness Inventory (EHI). Subjects rate their handedness preference for ten activities, as normal or strong preferences. Table 2.3.a shows the EHI as it is presented to subjects.

Table 2.3.a The Edinburgh Handedness Inventory. From Corballis, 1991 (p. 83).

One way of analysing responses to questionnaires is with the lattice method (Doyen et al., 2001). Lattice analysis reveals information about the structure of handedness, namely that it is multidimensional. Doyen et al. (2001) found that the unimanual and bimanual dimensions affected the responses of right- and left-handers. Furthermore, left-handers had more distinct patterns of handedness, while right-handers were globally more homogeneous in their reported behaviour.

Questionnaires can be criticised because of their element of subjectivity. Many people are not aware of which hand they use to perform certain tasks, which is why testing procedures often provide objects like balls, paper clips, and broomsticks to aid the subjects' self-assessment. Unfortunately, handedness questionnaires have mostly been standardised on North American or British populations, often on undergraduate students. For this reason, questionnaires lack cross-cultural applicability. Since activities like holding a tennis racket, opening a beer can, or combing hair are not common to all cultures, the questionnaires that currently exist cannot be used to study the universality of human handedness.

In order to make handedness assessment more culturally universal and less language-dependent, some methods test hand proficiency differences on the types of motor tasks mentioned above. However, as stated earlier, handedness does not show the same patterns when assessed by preference or performance measures.

The mismatch between reported hand preference and tested hand skill can be reconciled by a model which assumes that hand preference for a given task increases exponentially with hand proficiency. Relative proficiency is expressed as the difference in proficiency between the hands, and it is shown that hand preference can be accurately predicted for each relative proficiency level on the basis of five different tasks (Bishop, 1989). If hand preference is determined by

proficiency differences, then the environmental factors which cause the proficiency differences must be considered.

Comparison studies can confirm the association between hand skill and hand preference. The EHI, which tests hand preference, was compared to a new computerised method of assessing handedness based on motor performance (Henkel et al., 2001). The test involves quickly drawing circles between 12 mm-spaced guidelines on a digitising graphic tablet. The tablet measures the differences in performance of the hands using several kinematic parameters. This method assessed handedness as well as the EHI, and also distinguished between left-handers who had been forced to become right-handed in childhood and those who had not switched hands (Henkel et al., 2001).

Although it seems that neither motor performance nor personal preference can give an accurate measure of overall 'handedness', many different studies have converged on very similar figures and distributions of handedness.

Frequencies of between 80 and 90 percent right-handers have been reported for the large Anglo-Saxon populations that have been assessed with questionnaires. Ellis et al. (1988) found 83 % of self-reported right-handers in one British town of normal people using the EHI, and a population of Swedish university students were found to be consistently right-handed at 90 % and left-handed at 9 % for seven unimanual activities (Levander & Schalling, 1988).

The apparent universality of human handedness comes from suggestions of constant proportions of right- and left-handers across time and across continents. Although the methods described above have mostly been applied to Western populations, other assessment techniques provide information about non-Western and past handedness prevalences.

## 2.4 Universality of handedness

Many cultures certainly possess the notion of a preferred hand. Islamic societies, for example, consider the left hand unclean. In these societies, the right hand should be used to perform all actions considered "clean" (for example, for eating, shaking hands, and paying money). Since these beliefs exist in countries as far apart as Morocco and Malaysia, they probably arose in the customs imposed by the religion before it began to spread from its homeland. Strong beliefs about handedness have also existed in Western cultures until recently (the last few decades of the 20<sup>th</sup> century). In Britain and America, for example, left-handed children were forced to write with their right hand in school.

A preference for right-handedness has been documented from at least 3000 BC. A survey of 1180 works of art from all continents spanning the last 5000 years has revealed that right-handedness is depicted at an average frequency of 92.6 % (Porac & Coren, 1981). The frequencies in this study range from 88 % for works of art from the Americas, to 96 % for Middle Eastern pieces. Additionally, Egyptian tomb engravings frequently depict people writing with their right hand (Corballis, 1991). Even older evidence comes from Palaeolithic cave art. Hand silhouettes usually depict a hand with the thumb on the right, suggesting that the left hand was placed against the wall and the silhouette drawn with the right hand (Pobiner, 1999). It is possible that sprayed-paint hand outlines could have been made by placing the right hand against the wall with the palm upwards. However, modern artists and children usually produce such silhouettes with the palm down (against the surface). To place the back of one's hand against a wall not only is counterintuitive, but requires unusual manual dexterity to place the wrist and thumb at the proper angles for the hand outline to appear normal. The few hand silhouettes that do have a thumb on the left could mean that the artist either painted someone else's hand, or held the painting implement in his/her mouth. Furthermore, there are suggestions that most handprints (made in mud or clay) are of the right hand (Pobiner, 1999).

Studies that have measured handedness in modern people include data from the United Kingdom, North America (including Alaska and Hawaii), Australia, Sweden, Greece, Hong Kong, Taiwan, Japan, Rarotonga, the Solomon Islands, Sierra Leone, and the Congo. The frequencies obtained in these studies range from 86 % to 99.5 %. All of these studies were published between 1957 and 1979; apparently no recent data have been published other than on North American or European Caucasian populations. For this reason there is no justification to claim that human handedness is universal. Nonetheless, the documented cases do show enough significantly high frequencies of right-handedness to argue for a unique behaviour in human evolution.

### **3. Laterality in other species**

#### **3.1 Non-primates**

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. Honey bees have been extensively studied by linguists for their symbolic communication system (cf. Nieh, 1998; Pennisi, 2001; Donovan, 2000; Kak, 1991; Kirchner & Towne, 1994). Although this "bee dance" is performed by honey bees, it is interesting to study other bees as well. 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. The possibility of a "nonadaptive behavioural persistence" is invoked, which has been used to explain lateral biases seen in mice, capuchin monkeys, and humans (Kells & Goulson, 2001).

### **3.2 Primates**

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 manual specialisation. 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, 1991). From a recent meta-analysis of studies, McGrew & Marchant (1997) conclude that primates are individually lateralised but not at the population level. Preferences for the right or left hand are divided at 50 % within the populations studied. There is also evidence that the unnatural conditions of captivity induce stronger lateralisation in chimpanzees.

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 switching 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). This process is probably also responsible for the resulting differences in skill between the two arms of tennis and badminton players. In any case, these chimpanzees did not display handedness at the population level, but only at the individual level, and only for the bimanual task of nut-cracking. Similarly, another study of wild chimpanzees (McGrew & Marchant, 1992) showed that nearly all individuals were consistent in their manual specialisation for termite fishing (see Appendix 4, photograph 1). Individuals consistently used one hand or the other, and a small leftward tendency at the population level was observed.

Manual specialisation was also found in wild langurs (Mittra et al., 1997). There were 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. Langurs often have to steady themselves while reaching for food if they are standing on branches high up in the trees.

Captive male chimpanzees were observed to throw objects with the right hand significantly more than with the left hand (Hopkins et al., 1993). Moreover, they all used the same technique: by stepping forward with the left foot to place their weight on it and throw with the right arm. The right bias was, however, dependent on the chimpanzees' bipedal posture at the time of throwing. A review of the literature suggests that pongids (chimpanzees but not monkeys) show a right-handed bias for reaching, but only when they are bipedal (Hopkins et al., 1993). Appendix 4 shows examples of hand use in three wild species.

It is accepted that free-ranging primates can be individually lateralised but not at the population level. However, when they are induced to stand bipedally in artificial conditions which do not occur in the wild, chimpanzee groups tend to be right-handed. McGrew & Marchant's (1997) meta-analysis supports the dichotomy of Fagot & Vauclair (1991) in that simple, well-practiced tasks are symmetrical. Asymmetry is most strongly evident in novel, complex tasks.

The studies mentioned above appear to converge on one conclusion: the type of task seems to greatly influence the degree of lateralisation; hence, tool-use and throwing are biased at the population level but food picking and carrying are not. There is also some evidence from monkeys of task specialisation: certain manipulation tasks are executed with the right hand and other tasks, such as throwing, with the left hand, by a majority of individuals in the population. For example, Westergaard & Suomi (1996) demonstrated that the use of stone tools

by capuchin monkeys created a right bias. In their experiment, capuchins were artificially induced to strike stones to produce sharp edges and use them to cut open a container to obtain food. The result was a right-handed bias at the population level when only unimanual actions were counted.

### **3.2.1 Marchant & McGrew's (1996) study**

Despite the many examples of positive evidence for manual specialisation or task specialisation in primates, some authors argue that manual specialisation occurs in non-humans only in a few anomalous individuals. In an observational study of 42 wild chimpanzees over four months, Marchant & McGrew (1996) measured hand use for many different lateral actions involving not only the upper limbs, but also the legs and full body. The actions monitored are presented in Table 3.2.2.a below. The observational setting (a national park) was meant to represent the chimpanzees' natural environment of evolutionary adaptiveness, and only spontaneous activities were recorded. When all tasks were pooled, only five individuals were consistent right-handers, four were left-handers, and 29 were ambidextrous. A criticism of this study will be presented below.

Despite the apparent lack of manual specialisation in these chimpanzees, one interesting observation was noted. It was very rare for one hand to be idle while the other was being used for any of the observed activities: the "other" hand was idle less than 6 % of the time for nearly all tasks. The only exception was grooming, in which idleness of the non-grooming hand accounted for 58 % of all idle-hand moments. The other hand was often engaged in postural support, holding a food item, or carrying an infant. In contrast to wild chimpanzees, captive animals spend much less time in arboreal postures. Marchant & McGrew (1996) suggest that terrestriality favours lateralisation because both hands are free, or that life in captivity gives the apes more occasions to have idle hands, thus enhancing lateralisation. However, it is not clear that lateralisation is greater in captive chimpanzees than in the wild. Most of the published studies on

primate lateralisation resemble each other, and the Marchant & McGrew study exemplifies the current research that is being done in this field. To illustrate some of the problems with primate observational research on laterality, this particular study will be discussed. There are several ways in which the Marchant & McGrew study could be complemented by additional data in order to determine which features of chimpanzee and human lateral behaviour are shared and which are unique.

### **3.2.2 Criticism of the study**

One of the problems with using comparative studies to infer causes for the evolution of handedness in humans is that the elements under comparison are often very different. The evidence given for handedness in humans is based on self-report questionnaires of hand preference, while the evidence for lateral bias in primates is from external observations of hand use. Furthermore, the activities that are compared are not the same, for three reasons.

Firstly, all of the 43 limb movements monitored in this study are commonly performed by humans.

Table 3.2.2.a overleaf lists the categories of movements that were recorded.

No studies are known which have published data on hand use for these same activities by humans. It would be interesting to carry out similar observations in pre-school classrooms to assess hand preference in human children. Such settings are probably the best candidates for providing a maximum number of these limb movements in a natural, spontaneous human environment, because of the high behavioural freedom of individuals and the extremely socially interactive context. Considering that 12 of these 43 actions require the presence of another chimp, and several more can be directed to another chimp or to an inanimate object, their social and communicative functions should be considered.

Table 3.2.2.a Lateral limb movements recorded in wild chimpanzees. From Marchant & McGrew, 1996 (p.430).

Actions which require social interaction are: Arm-wrestle, back-reach, beg, embrace, fend, groom, offer, pat, reach, slap, threat, touch. Other actions have optional social interaction, for example Cradle, hold, pull, throw.

Secondly, there is a discrepancy between natural and artificial settings for data collection. The chimp data comprises spontaneous actions, whereas the human data comes from self-observation. In psychology this distinction is made in the form of implicit and explicit knowledge. In order to make the types of data collection more similar, either the chimpanzee methods must be applied to humans, or vice versa. It would not be appropriate to create a questionnaire to assess human hand use for these tasks, because the handedness figures calculated for chimpanzees depend on frequencies of use rather than on a single, binary answer of preference. Convincing people to monitor their own hand use over a period of several months for all 43 activities would not only be difficult, but would also bias the results (due to self-awareness and expectation effects). Conversely, if we were to try to make a chimpanzee study resemble the format of assessing handedness in humans, we would have to rate each individual chimp on a binary measure of hand preference for each type of task. This rating could be based on several months of observation, as in this study. Indeed, it is clear that several individuals show manual specialisation, but there is no indication in the results as to the existence of task-specific hand preferences.

Thirdly, the pooling of data used in the analysis causes an appearance of no laterality. This is because many of the movements recorded would not be expected to show task specialisation. The effects of lateralised movements could have been obscured by the effects of the symmetrical movements. A further analysis should be conducted to examine possible effects of task type on the degree of lateralisation. If it is shown that humans are not right-biased for some types of movements, then it is irrelevant to use these tasks to claim lack of handedness in primates.

The distinction between complex and simple tasks, which was described earlier, might also illuminate some of these results. Marchant & McGrew (1996) propose that lateralisation can only be evidenced in bimanual tasks such as in food processing and grooming. However, this seems obvious, because these are

precisely the kinds of tasks that show the strongest lateralisation in humans (Annett, 1985).

## **4. Handedness in past humans**

### **4.1 Fossil record**

It is obvious that none of the methods used to determine hand preference in living humans or other primates can be applied to fossil hominids. Various aspects of the fossil and archaeological records have been studied with the goal of determining handedness in past populations. Some features of hominid hand anatomy show adaptations to varying degrees of manipulative skills. For example, modern human hand anatomy possesses several specialisations for fine manipulation abilities. Steele (1998) argues that these derived features "characterise our tool-dependent adaptive niche" (p.1211). If hand morphology has been driven by such specialisations, then tool production and use must have been a very important aspect of hominids' environment -- important enough to cause morphological change through natural selection. This means that the increased manipulation skills obtained with the new hand anatomy conferred enough of an advantage on their bearers to make them more reproductively successful. Such powerful selective pressures could certainly have driven changes in brain structure, as well.

The changes in skeletal and muscular anatomy that are present in modern humans probably began sometime during the period that australopithecines were in existence. Bilsborough (1992) provides a description of the different species in hominid evolution for readers not familiar with the main concepts. Marzke (1997) has designated eight features of modern humans which facilitate precision pinching and precision wrist orientation, grips that are unique to humans and are thought to be essential to habitual tool making. Some of these features are present in *Australopithecus afarensis* and in Olduvai hominids, but are less clear in South African specimens. The lack of some of these features in some

individuals could be due to a lack of their necessity for making Oldowan tools. As Westergaard & Suomi (1997) note, capuchins (*Cebus apella*) use two different power grips and three precision grips. They argue that the precision grip provided by the placement of the thumb in humans is not necessary for making the simplest stone tools, and that thumb opposition emerged later than the earliest hominid technology. But the single feature of opposing thumbs must not be used to explain all tool behaviour. Marzke (1997) points out that tool-making adaptations in fossil hominids must be inferred from a set of features rather than one, and she shows how fossils can be associated with the different stages of tool behaviour. Westergaard & Suomi (1996) conclude that hominids had a predisposition to right-handedness which was pressured to become frequent because of the manual skills that hominids were developing in their lifestyle that increasingly depended on tools.

From aspects of the fossil record, inferences about the timing of handedness evolution can be made. Hopkins et al. (1993) suggest that hemispheric specialisation existed before hominids became bipedal, and that a selective advantage for tool use, throwing, or communication could have come from this preexisting brain lateralisation. Considering that bipedal posture does appear to enhance manual specialisation in chimpanzees, as discussed above, human handedness could simply be an extension of this specialisation due to humans' extreme reliance on tools and complex and fine manipulative manual activities.

MacNeilage et al. (1987) also argue for a preexisting manual specialisation in hominid ancestors, and propose that feeding was specialised to the left hand because of a right hemisphere advantage for visually-guided movement, while manipulation was specialised to the right hand.

## 4.2 Archaeological record

Additional evidence of lateral bias in past populations comes from the use and production of stone tools. Wear patterns on handaxes can show the direction of movement used (i.e. for cutting or slicing wood or flesh). Clues about handedness from the production of stone tools, which form the basis of the methods used in the experimental section of this research, will be detailed in the Lithics section below (8).

There are suggestions that Neandertals were right-handed, based on their use of their teeth as tools. Fox & Frayer (1997) examined the front teeth of the Krapina Neandertal specimens, which display unusual scratches on the central area of the labial surface. The angle of these striations relative to the mesiodistal buccal plane was measured with image analysis software. Although a high proportion of the scratches were categorised as vertical, the diagonal scratches suggested that six of the individuals were right-handed and one was left-handed. Their data combined with other Neandertal data implies that left-handedness occurred at about 10 % in these populations. Fox & Frayer (1997) also argue that these hominids had enough manipulative precision to avoid mangling their lips and gums while using sharp tools to cut objects that they held between their teeth.

While there is no reason to assume that Neandertals did not have as precise manipulative skills as other hominids, it is not clear whether their handedness can be inferred from their teeth striations. Bax & Ungar (1999) refute this hypothesis based on a study of four modern populations which commonly perform the processing activities that are hypothesised for Neandertals. They found that wear patterns in these modern humans are mostly non-diagonal, so they conclude that no inference is possible about handedness in Neandertals. Furthermore, no significant variation was observed between the groups although they had very varied diets. From these results it is concluded that neither diet nor food processing behaviour can be revealed by teeth scratches.

## **5. Genetic determinants of handedness**

### **5.1 Mechanisms of growth and inheritance**

Hand preference appears in infancy, suggesting that it is genetically predetermined. However, no gene for handedness has yet been identified (Van Agtmael et al., 2001). The mechanisms for physical asymmetry in vertebrate development are still poorly understood; it is possible that the asymmetrical placement of internal organs originates in early embryonic development. Cooke (1999) proposes that chemical signals, in the form of gradients of concentrations, cause the asymmetries after the emergence of the axial midline structure. They are argued to be universal in vertebrates because cells align themselves to the counter-clockwise beating direction of epithelial cilia (Cooke, 1999).

Genetics certainly affect handedness in some way, because handedness does show non-mendelian patterns of inheritance (Van Agtmael et al., 2001). Heterozygosity for dominant and recessive genes is an important factor in the expression of handedness, as left-handed children can be born from two right-handed parents, and two left-handed parents can produce right-handed children. In addition, there also appear to be some developmental and environmental influences, because twins do not necessarily have the same lateral preference. One suggestion is that the position of the fetus allows freer movement of the right arm, thus predisposing the infant to a right-arm bias. Alternatively, hormones could influence handedness. Orlebeke et al. (1996) studied 1700 twin pairs and their parents and found that left-handed fathers contributed to their sons' left-handedness, while left-handed mothers contributed to both sons and daughters in terms of left-handedness. They suggest that prenatal male hormones play a role in left-handedness (Orlebeke et al., 1996). This could explain the mechanism of right-handedness in human ontogeny, but it does not account for the original selective pressure in hominid phylogeny. Other authors suggest that hand preference is a result of random processes favouring one arm over the other in childhood, or that cultural pressures cause people to conform in

handedness (such as in Islamic cultures). But in this case, it remains to be explained why other primates do not experience such pressures, even though they are highly social (although not as cultural). Sugiyama et al. (1993) found that handedness is not hereditary in wild chimpanzees, suggesting that learning rather than genetics is responsible for hand preference in this species. Human handedness is probably a combination of genetic (inherited) factors and environmental (culture and learning) influences.

## **5.2 Mechanisms of evolution: the Right-Shift theory**

At present there is no genetic theory to satisfactorily explain the evolution of handedness. Annett's (1985) Right-Shift (RS) theory states that the distribution of handers is shifted to the right of the curve for other animals. The curves are bell-shaped in both cases, but in humans the peak is centered around strong right-handedness. The RS theory incorporates the persistence of the existing proportion of left-handers (about 12% worldwide) to claim that the selection was for a balanced polymorphism between a dominant Right allele and a recessive Left allele. Annett & Manning (1989) argue that right-handedness occurs via a decrease in the skill of the left hand, rather than an increase of right-hand skill. They suggest that heterozygotes have greater fitness because certain skills are decreased due to the hemispheric specialisation related to strong handedness.

Nonetheless, there remains to be shown what pressures in hominid evolution could have been strong enough to create and maintain the current R:L ratio of 88:12. Despite genetic theories accounting for handedness, it will be necessary to explain the selection towards left-hemisphere language in humans (~ 70 % of left-handers), since hemispheric specialisation for language cannot be argued to be culturally defined or influenced. The lateralised functions of language, in the context of hemispheric specialisation in general, will be discussed in the next section.

## **6. Morphological asymmetry**

In addition to the behavioural asymmetry of a strong right-handed bias at the population level, humans are asymmetrical in other ways. There is evidence that skeletal size and shape differences, especially in the upper limbs, occur to measurable degrees in right- and left-handers. Apes appear to show no such skeletal asymmetry. The human brain is also morphologically asymmetrical. The relationship of morphology to its functional asymmetry is unclear, but many functions appear to be processed in only one hemisphere. In particular, most linguistic tasks are controlled mainly by the left hemisphere. The patterns of activation are very homogeneous between subjects, although some left-handers differ. Brain morphology in apes supports claims of continuity from humans' ancestors to the present (Steele, 2000b; Semendeferi et al., 1997). The main question is therefore whether studying the morphology and function of the brain can yield any evidence about handedness, to complement the evidence from skeletal asymmetries.

### **6.1 Environmental determinants of skeletal asymmetry**

There is evidence that different patterns of use during a person's life create morphological asymmetries in the upper limb bones. There are two types of asymmetry which can be ascertained from skeletal remains and are relevant to handedness. Fluctuating asymmetry (FA) denotes asymmetry that can favour either side of the body, while asymmetry is directional (DA) if it is consistently right- or left-biased (Albert & Greene, 1999).

Overall differential development in the two sides of the skeleton can reveal how much environmental stress was present during the growth of the individual. The limb bones of teenage Nubians from cemetery samples of 550 to 1450 AD show more bilateral FA in epiphyseal union in the individuals who were more environmentally stressed from differing periods of Christianity (Albert & Greene, 1999).

Although it is interesting to be able to measure stressing factors in the fossil record, Albert & Greene (1999) argue that non-stressed skeletons do not display statistically significant asymmetry in development, and therefore studies must be restricted to highly stressed populations.

The skeletal remains of modern humans of known handedness demonstrate that DA can be measurable in certain populations. Bilateral asymmetry in the hands, arms, and shoulders have all been used to confirm patterns of handedness. The second metacarpal in particular shows bilateral differences due to environmental factors. The second metacarpal of the dominant hand, assessed by self-report, tends to be longer and have greater bone area than that of the nondominant hand, although there is no cortical thickening (Roy et al., 1994). Males generally have larger second metacarpals than females, and the proportion of individuals with a larger left than right second metacarpal in a cemetery sample from the 1800s was found to be about 14 to 25 % (Lazenby, 1998). Because these figures match the proportion of left-handers in similar populations, this author concludes that the size differences are due to handedness. Furthermore, the cross-section of the midshaft in this bone was found to be noncircular in some cases, suggesting that the hands were differentially subjected to strong grasping or manipulating forces (Lazenby, 1998). This is especially interesting for the production of stone tools because of the second metacarpal's major role in power and precision grips (Scheuer et al., 2000), which are both necessary for habitual tool-making (Marzke, 1997). Two of the muscles most used in Oldowan core reduction (i.e. tool making) are in the thumb and forefinger, which implies that these bones would have experienced the most stress and therefore the effects should be most visible in the fossil record (Marzke et al., 1998).

Humeri and clavicles also show patterns of asymmetrical loading. Medieval skeletons have similar proportions of humerus length asymmetries to more recent samples (Steele & Mays, 1995), but differential mechanical loading appears to affect only the tubercular region of the proximal humerus as

measured by outline analysis (Tanaka, 1999). Heavier loading on the right clavicle and its ligaments is evident at the population level (Mays et al., 1999). This study found that the right clavicle in a medieval sample was generally more robust, shorter, and showed less lateral curvature than the left. Furthermore, juveniles were more symmetrical than adults, supporting the hypothesis that DA is the result of inhibited skeletal growth on the dominant side (Mays et al., 1999).

Bilateral asymmetry is not restricted to the effects of biomechanical loading patterns in childhood. An Upper Palaeolithic male skeleton shows that the upper limbs can become extremely asymmetrical as a result of loading patterns that begin in adulthood, even if there is no apparent pathology in the weaker limb (Churchill & Formicola, 1997).

According to Wilczak (1998), asymmetry might not be due to biomechanical loading factors. The muscle insertion sites of long bones in native continental US and Alaskan specimens, ranging from protohistoric to modern samples, show a right bias in all populations of 50 to 85 %. Despite the find that sexual dimorphism is greater in colder climates, it is argued that handedness does not play a role in asymmetry. It was found that long bone length differences appear in childhood, increasing to adulthood. Wilczak (1998) argues that, because handedness is more important for fine motor tasks than for muscularity, asymmetry reflects the many activities involving strength which make use of both arms in different roles. Muscle insertion size tends to be more symmetrical, suggesting that loading stress actually reduces the effects of developmental tendencies to a larger right arm. This is because "there are few tasks which impose stress exclusively on one side of the skeleton" (Wilczak, 1998; p.322). Furthermore, there is evidence that 20 years of tool-making creates greater muscle development in the left hand of a right-handed knapper (Marzke et al., 1998). Therefore muscle development is not entirely reliable for measuring asymmetry related to tool production and use.

## **6.2 Cerebral asymmetry**

### **6.2.1 Brain shape**

The human brain has a distinctive pattern of morphological asymmetry, which can be studied in hominids through endocasts of fossil skulls. In modern humans, the right frontal lobe and the left occipital lobe tend to protrude; these are called petalias. However, the brain's imprint on the interior of the skull is often too poorly preserved in fossils or too unclear to be measured. From the hominid fossils that have clear endocrania, it is evident that the right frontal and left occipital petalias are present from australopithecines onwards (Holloway, 1981). Although petalias can occur in other primate skulls (Steele, 2000a), only apes show the human combination (Pilcher et al, 2001). Modern sulcal patterns are present in *Homo* and *Australopithecus africanus* (Falk, 1987; Falk et al., 2000). Endocasts can not only provide information about the shape of the brain that once occupied a fossil skull, they can also serve to estimate brain size. This is useful for justifying taxonomic classifications of specimens or arguing one's case for changing an attribution (cf. Blumenberg, 1985; Grine et al., 1996; Antón, 1999; White & Falk, 1999). Cranial capacity has, in general, increased in the hominid lineage (Beals, 1984), although in *Homo erectus*, cranial capacity increased at varying rates in different regional subsamples (Leigh, 1992). The variation observed in populations has increased to the present, as evidenced by the cranial capacity range of a large sample of Middle Pleistocene humans (Lorenzo et al., 1998).

### **6.2.2 Brain size**

There are a number of methods for estimating cranial capacity. The differences in estimates from cranial capacity, brain weight and brain volume are often ignored (Smith et al., 1995). Some of the earliest measurements were made simply by filling the skull with seeds or sand. The most common technique involves creating a plaster endocast and measuring its volume. A cured latex

shell or flexible rubber peel is made inside the skull, then it is removed and a solid plaster endocast is made which can then be placed in water to obtain its volume (Holloway, 1981; Falk & Kasinga, 1983). More modern methods make use of scanning technology and are entirely non-invasive, which means that extremely fragile and incomplete specimens can be studied. For example, Conroy et al. (2000) used CT scans and mirror imaging to produce 3D reconstructions of a skull and a virtual endocast. In addition, sculpted 3D reconstructions can be made using other specimens to complete missing parts (Köhler et al., 2001).

### **6.2.3 Evolution of brain size and shape**

Although it is not certain how cranial capacity and intelligence are related, the types of abilities that characterise human cognition are probably linked to increased processing power in certain areas of the brain. Increased speed or efficiency of signal transmission can be gained in several ways: more gray matter (neurons) can contribute to faster-spreading signals; areas of the brain can become specialised for particular functions, reducing the travelling distance of signals; or dendritic connections can increase in number. Specialisation of functions causes reorganisation of brain structure, especially in terms of hemispheric specialisation (Falk, 1987). Some workers suggest that the modern organisation of the brain appeared with *Homo* (Tobias, 1987), while others argue for more ancient origins of increased brain size (Elton et al., 2001).

When average figures of cranial capacity are calculated for each hominid species, there is an increase in brain size over time. However, the rate of increase is not constant. The appearance of *Homo sapiens* is accompanied by an apparently faster increasing brain size, which is accentuated by the decrease in body size of modern humans (Kappelman, 1996). Because the size of the brain is determined by the size of the body (McCarthy, 2001), and could also be related to neonate size (Lynch et al., 1983), relative brain size should be used to

assess changes in the hominid lineage (Ruff et al., 1997). This is also important for claims about the sizes of various parts of the brain relative to the total brain size. For example, it has been found that the relative size of the frontal lobes in humans is not larger than expected for primates (Semendeferi et al., 1997). The temporal lobes and insula are slightly larger than expected, whereas the cerebellum is relatively smaller than expected for apes (Semendeferi & Damasio, 2000).

## **7. Functional asymmetry**

### **7.1 Hemispheric specialisation of motor and linguistic skills**

Imaging techniques allow the active brain to be studied in humans. In particular, the functions of the two hemispheres can be examined for various tasks, and differences between right- and left-handers can be revealed. The patterns of activation for motor movements differ between right- and left-handers, as a recent fMRI study by Solodkin et al. (2001) demonstrates. Subjects were grouped by handedness as assessed by the EHI. Simple finger movements created similar bilateral activation in both groups of subjects, whereas sequential movements activated small, lateralised areas in right-handers and larger, more bilateral areas in left-handers. The areas activated were M1 (primary motor), S1 (primary sensorimotor), the premotor cortex, SMA (supplementary motor area), and the cerebellum. SMA was not expected to be active because a metronome timed the finger movements; it is suggested that SMA activation is due to the preparation and sequencing needed to perform the task. Solodkin et al. (2001) conclude that functional lateralisation is thus correlated with hand dominance: left-handers seem less strongly lateralised than right-handers, implying that their bilateral brain activation reflects their bilaterality.

If right-handers are more strongly lateralised than left-handers, this might be the result of selective pressures due to habitual tool-making. Right-handers could have had an advantage in learning to produce tools, to use them, or in general intelligence. The review of the literature which follows suggests that if

transmission of lithic production was an important feature in hominid evolution, then right-handedness could have become predominant in the groups that relied on tools for survival.

The role of the SMA, M1, and cerebellum in speech production matches that of finger movements. Dogil et al. (2001) note that these areas are activated for planning and executing simple articulatory movements. Therefore it seems reasonable to posit a connection between the cerebral circuits involved in language and tool use.

## **7.2 Cognitive aspects of tool skills**

The vertical transmission of flint knapping skills in hominids most likely occurred by active teaching, probably from the onset of the Oldowan. Since chimpanzee mothers do passively teach and have been observed to actively teach tool-using skills such as nut-cracking to juveniles (Boesch, 1993), it is reasonable to infer that australopithecines and *Homo* did teach as well. If the transmission of tool-making skills in early hominids was nonverbal, then observation would have been the means of learning skills. Michel & Harkins (1985) demonstrated that, in humans, learning to tie knots by pure observation is greatly facilitated if the teacher has the same handedness as the learner. Learning to produce tools, then, could have been an important factor in the evolution of human handedness.

An important component of learning to knap is the control of motor movements (Roux et al., 1995). This suggests that increased fine motor abilities could have greatly improved knapping behaviour in hominids, providing a selective advantage for better-skilled individuals.

Right- and left-handers also differ in their ability to remember crescent moon orientation, as suggested by Martin & Jones (1997). These authors propose that some sort of motor imagery, for example in the form of visuo-spatial sketchpads

for working memory, is responsible for the differences between right- and left-handers. Orientation memory is relevant to early stone tool production because working memory is vital in the process of flint knapping, and learning to hold the core and hammer at the proper angles is essential to successful flaking (Whittaker, 1994). Therefore learning flint knapping is reliant on orientation memory. This type of memory is used in modern times for linguistic tasks like reading the letters **b d** and **p q**. Because these tasks are dependent on handedness (Martin & Jones, 1997), it is possible that orientation memory related to stone tools was as well.

The visuo-spatial sketchpad hypothesis is also supported by Findlay et al. (1994). They found that subjects held an image of tactually-presented shapes in working memory in order to use them to solve tasks. Furthermore, response times were shorter when the shapes had been learned tactually with the right hand (i.e. the left hemisphere) rather than the left hand. This left-hemisphere advantage for image generation based on tactual stimuli means that right-hand dominance in manipulation of stone tools would have been more successful than left-hand dominance.

It is likely that word processing occurs in the dominant hemisphere because information which is received by the nondominant side is lost due to an inability to obtain processing capacity from the dominant hemisphere (Olk & Hartje, 2001). If it applies to tasks other than word processing, this intrahemispheric competition could serve to enhance a preference for the dominant hand, namely in flint knapping. Also evident, however, is that the ipsilateral hemisphere plays an important role in motor sequence learning. Unimanual movements are planned in part by the ipsilateral M1, and they are learned by ipsilateral sensorimotor areas as well as contralateral ones (Hazeltine, 2001).

Further evidence relating to flint knapping is that the left hemisphere specialises in temporal processing of movement (i.e. the right hand is faster at executing

movements) and the right hemisphere regulates spatial configurations (i.e. the left hand is better at learning spatial configurations) (Bradshaw, 2001). If this sort of hemispheric specialisation were present in hominids before they became habitual tool-makers, then each hand already had its role predetermined when flint knapping became common as a survival tool. The right hand would naturally have been used to hold the hammerstone, which requires fast and precise movements, while the left hand would have held the core, owing to the necessity of properly positioning -- and maintaining -- the core to receive hammerstone blows.

### **7.3 Common substrates of tools and language: sequential processing**

Despite the fact that 91 % of right-handers and 70 % of left-handers develop language deficits with left-hemisphere damage (Annett, 1985), there is no clear refutation of equipotentiality of the two hemispheres to process language. Bishop (1988) argues that the right hemisphere can also develop language functions after unilateral brain lesions to the left. Nonetheless, language still preferentially develops in the left hemisphere. The ability of the brain to transfer certain functions to different areas is simply a result of its great plasticity and should not be confused with specialisation.

There is evidence that manipulative skills and language processing are controlled by the same areas of the brain. Namely, constraints in Broca's area apply to both linguistic processing and to movement execution during flint knapping (Steele et al., 1995). Broca's area in primates and human infants is hypothesised to serve similar functions regarding the sequential organising of tools and grammatical elements (Greenfield, 1991). But Broca's area is not the only structure implicated in motor and linguistic behaviours. The basal ganglia also participate in the learning of sequences such as grooming and syntax (Fuentes, 2001).

The planum temporale, which is implicated in the comprehension of speech, shows lateralisation patterns unique to humans. Buxhoeveden & Casanova (2000) found that the spacing between cell columns in this area was significantly increased in the human left hemisphere. Additionally, this effect is correlated with brain size and might be related to the tendency in humans for larger left planum temporalae (Buxhoeveden & Casanova, 2000). This structure's evolution with its role in language processing can therefore contribute to the emergence of language capabilities.

#### **7.4 Language evolution**

Theories about the origins of speech and language are extremely varied, and only some of them will be discussed here. Suggestions range from the emergence of speech through choral singing as a cohesive social function (Richman, 1993), to a link with schizophrenia resulting from a genetic change for differential hemispheric development (Crow, 1996; 1997a; Horrobin, 1996). Two camps postulate different dates for the emergence of language; they fall on either side of the postulated Middle to Upper Palaeolithic "transition" which is marked by the appearance in the archaeological record of cave art, body painting, jewelry and ornaments, and other modern behaviours that characterise *H. sapiens sapiens*. However, there is not enough evidence to prove the occurrence of a "cultural revolution" at this late stage (McBrearty & Brooks, 2000). Therefore this discussion will focus on arguments supporting early dates for the emergence of cognitive capabilities relevant to language, which can be tested using the entire archaeological record beginning from the appearance of the very first Oldowan stone specimens.

Hypotheses about the evolution of language capacities, considered below, include those linked to complexity in material cultures (Belfer-Cohen & Goren-Inbar, 1994; Santangelo, 1999; Susman, 1991), grooming (Aiello & Dunbar,

1993) and social group-living (Savage-Rumbaugh & Rumbaugh, 1993), negative consequences of bipedalism (Vishnyatsky, 1999), or subsistence activities (Otte, 1999).

Belfer-Cohen & Goren-Inbar (1994) argue that the lithic assemblages created by *H. erectus* groups in the Levant imply as much sophistication in intellect as modern humans. Santangelo (1999) suggests that *Australopithecus* enjoyed a selective advantage with the production of chopping tools, an advantage which triggered the increase in brain size with the transition to *Homo*. Evaluation of the fossil and archaeological records in East and South Africa imply that *Paranthropus robustus* and *Homo habilis* were accomplished tool makers, and that these robust australopithecines possibly used the tools to process plant foods (Susman, 1991).

The pressures of living in large social groups have also been invoked as possible influences on language emergence. Savage-Rumbaugh & Rumbaugh (1993) argue that the cognitive abilities for symbolic representation and communicative intent are common to humans and chimpanzees, and that language arose to improve efficiency in social interactions involving sharing food and hunting. These complex social interactions are postulated to appear with the earliest *Homo* because of increased group sizes, which led to increased brain size (Aiello & Dunbar, 1993).

It is also possible that the transition to bipedalism placed australopithecines at such a disadvantage in terms of land predators that compensation strategies, namely in the form of culture, quickly prevailed (Vishnyatsky, 1999). In any case, the inhabitants of Pleistocene Europe until the lower Palaeolithic lived successfully and comfortably for long enough to become entirely adapted to many of the different environments which existed then (Otte, 1999).

The above hypotheses suggest that language could have emerged when brain size increased, because of the role of cognition in social structure. Increasing social complexity in hominid groups probably selected for larger brains and motivated the development of language abilities. The next section will detail aspects of stone tools that are relevant to the evolution of cognitive capacities in hominids.

## **8. Lithics**

### **8.1 Contribution to the study of handedness**

It is essential to incorporate archaeological considerations into any sort of study on hominid behaviour. There are so few clues in the fossil record as to past behaviour that it is useful to turn to the archaeological record to complement information and test hypotheses. The advantage of archaeological evidence over fossil evidence in inferring behaviour comes from the distinction between two kinds of past behaviour:

1. behaviour that causes morphological change (e.g. bipedalism, brachiation, mastication, moving to cold habitats)
2. behaviour that may not have any effect on morphology (e.g. decorating objects, scavenging, carving wood, flaking stone).

Setting aside the apparent adaptations of the brain and hands to habitual tool use after a million years (cf. Marzke, 1997), the effects of adopting a new style of flint knapping, such as occurred in the transition from Oldowan to Acheulean technologies, do not appear in the fossil record. The only way that changes in mentality can be documented is through the objects that hominids produced. Up to 400 kya, this means exclusively stone and bone objects. The carved hunting spears from Schöningen (Thieme, 1997) prove that the use of wooden tools was common by 400 kya, and many more wooden artefacts are preserved from the

Neolithic onwards. However, it is evident that modern humans were right-handed by this time, so the later periods will not be considered here.

Another advantage of lithic assemblages is that they are the only direct evidence of behaviours as they occurred in "real time" -- meaning that the effects of behaviours such as in 2. (above) appear immediately. In contrast, the behaviours listed under 1. do not show effects until hundreds of thousands of years later. Making a chopper can be achieved in a few minutes, whereas morphological and environmental change take a long time. Inferring behavioural changes from fossils requires projecting hypothetical behaviours back in time to estimate when the ancestors of a particular individual began the behaviour. For example, it is not known how dependent Lucy (*A. afarensis*) was on bipedalism, because her upper body was still arboreally-adapted and her hips and lower limbs were not as idealised for walking as in modern humans (cf. Berge, 1994; Crompton et al., 1998; McHenry & Berger, 1998; Stern & Susman, 1983). On the other hand, a handaxe and a skeleton which are found together can be assumed to have been laid down within a span of a few decades to a few thousand years at most (excluding the possibility of redeposition due to geologic processes), depending on the quality of stratigraphy and dating techniques. Through archaeology, therefore, we can associate fossils with the very tools that their contemporaries made, in order to connect specific behaviours to individuals or species.

The contribution of archaeology to the questions of cognitive evolution is in revealing the behaviour of early hominids. Although we cannot always identify which hominids were the makers of a given set of tools (such as some of the artefacts that are transitional between Oldowan and Acheulean, which are temporally associated with both australopithecines and *Homo erectus* or *H. habilis*), it is accepted that the artefacts were produced by hominids rather than other apes.

A variety of analyses can be carried out on lithic assemblages, including experimental knapping, replication studies, and raw material sourcing (see Odell, 2000 for a good review of the different techniques). Before studies concerning the recognition of handedness in the archaeological record are presented, some basic concepts of flint knapping will be described. Following this introduction to lithics, some published primate models of early hominid tool behaviour will be introduced, along with a discussion of their validity for human evolution. Then the methods used to assess handedness from Lower Palaeolithic flakes in the experimental part of this study will be described, followed by the hypotheses under scrutiny.

## **8.2 Dynamics of flint knapping**

Most of the remains of man-made artefacts consist of stone tools, cores, and flakes. For periods prior to about 400 kya, stone and bone are the only elements present in the archaeological record. Flaked bone is present from at least 1.7 mya. Because studies have focused primarily on stone tools (Ono, 1998), flaked bone tools will not be considered here.

Knapping stone can occur by direct or indirect percussion, or by applying pressure. Direct percussion can be done with hard hammers (other stones) or soft hammers (antlers, bone, wood, etc.). Indirect percussion (use of an intermediate tool between the hammer and core) is only attested from the Mesolithic onward, and pressure flaking from the Upper Palaeolithic, so these techniques are not relevant to this study. Similarly, soft-hammer percussion appears in the record from 700 kya (Inizan et al., 1995) and therefore will not be included either. The only method that remains constantly in use from the first Oldowan tools is hard-hammer percussion, and thus the focus here will be on this method.

Hard-hammer percussion involves striking a stone, called the **core**, with a hammerstone. The **flakes** that come off the core when it is struck are either discarded or used. The flakes are sometimes treated as cores and reshaped, as in the Levallois method; if they are too small they are discarded. The original core is often covered in **cortex**, which is the outer layer of the stone, and can be identified by its rough, weathered texture and light colour. Flint is found in the form of nodules, rounded lumps of chalk which, when broken open, expose the glossy black flint inside.

Flakes are struck off successively, using a flat surface such as the scar of a preceding flake as the **striking platform**. The angle of the blow must be between 45 and 90 degrees to the platform in order to produce a correct flake (Whittaker, 1994). The resulting flake has a **bulb** and **cone of percussion**, with ripples radiating outward from the direction the blow came from. Figures 8.2.a and 8.2.b illustrate the different parts of the typical flake.

Figure 8.2.a Flake attributes. From Whittaker, 1994 (p. 17).

Figure 8.2.b Flake attributes. From Inizan et al., 1995 (p. 33).

### **8.3 Timeline of lithic industries**

A brief timeline of the main lithic industries that are relevant to this study is presented below. The Oldowan industry designates the first human-made stone tools to appear in the archaeological record. It is succeeded by the Acheulean around 1.7 mya, which gradually develops into various Mousterian industries in Europe and Asia (paralleled by MSA industries in Africa). A host of industries then flourish around the world from the Upper Palaeolithic onwards, and many cultures use flaked stone tools today. Table 8.3.a overleaf summarises the main industries in Africa and Eurasia. Figure 8.3.b overleaf shows geographical distributions of sites around the world.

Table 8.3.a Timeline of artefact industries. From Klein, 1989 (p. 112).

Figure 8.3.b Geographical distribution of lithic sites. From Klein, 1989 (p. 205).

The earliest known lithic artefacts date from 2.5-2.3 mya and come from several areas of Africa. The oldest tools are currently from Gona, Ethiopia and are dated at between 2.6 and 2.5 mya (Semaw et al., 1997). In Kenya, the Turkana basin has yielded the Lokalalei artefacts, which are dated at 2.34 mya; more than 60 refits have been achieved from these remains (Roche et al., 1999). Some later pre-Acheulean tools include ones from Malawi, dated at 3-1.6 mya but resembling ESA flaking techniques of 2-1.6 mya (Kaufulu & Stern, 1987). In South Africa there are Oldowan technologies present at 2-1.7 mya (Kuman & Clarke, 2000). Unifacial choppers from Dmanisi, Georgia also represent Oldowan technologies from 1.7 mya, suggesting that they were made by hominids present in the first wave of dispersal from Africa (Gabunia et al., 2000). In the Middle Awash valley, Ethiopia, there is an apparent persistence of Oldowan assemblages until about 0.6 mya (Clark et al., 1994), but the transition to Acheulean elsewhere generally occurs between 1.7 and 1.5 mya.

Oldowan artefacts are distinguished from the first Acheulean ones by their apparent simplicity of production, namely in lack of core preparation. See Figure 8.3a overleaf for an illustration. In fact, tools show increasing understanding of fracture mechanics throughout the Oldowan (Kibunjia, 1994), and the transition is marked by the appearance of symmetry around the long axis of the tools (Gowlett, 1986) and the use of stone cache strategies (Kimura, 1999). Acheulean handaxes are characterised by their symmetrical appearance (see Figure 8.3b overleaf for an example) and bifacial flaking. Dominguez-Rodrigo et al. (2001) argue that 1.5 my-old handaxes from Tanzania were used for woodworking, possibly for making hunting spears. Acheulean artefacts are found from 1.7-1.6 mya to about 100 kya in Europe or 200 kya in Africa (Klein, 1989) and are found in Morocco (Raynal et al., 2001), Israel (Saragusti & Goren-Inbar, 2001), South Africa (Kuman & Clarke, 2000), and throughout Europe.

Figure 8.3.a Oldowan chopper.

Figure 8.3.b Acheulean handaxe.

#### **8.4 Validity of using primate models for early hominid tool behaviour**

Models of the behaviour of Oldowan tool-makers have drawn from primate studies because of the possibility that these hominids were not very cognitively different from modern chimpanzees (Wynn & McGrew, 1989). However, even if modern chimpanzees can be considered a "reasonable behavioural analog" to the tool use and intelligence of pre-Oldowan hominids (Toth, 1993), Oldowan hominids' behaviour was innovative in two ways. Firstly, they transported tools for much longer distances than has ever been observed in living primates, and secondly, they were able to outcompete large carnivores to obtain food.

Although the communicative behaviour of some New World monkeys has parallels in human speech and language (Snowdon, 1989), there is no reason to consider modern primates as suitable models for Plio-pleistocene hominid intellect and behaviour. By the time of the existence of australopithecines and early *Homo*, hominids' anatomy and ecological niche were very different from those of their ancestors. Jalles-Filho et al. (2001) disagree with the use of capuchins to model early hominid tool behaviour. They argue that since these monkeys are unable to transport tools, they differ qualitatively in their mental representations of tools compared to early hominids. Indeed, there is evidence that capuchins have less human-like cognitive capacities in other domains compared to apes (Visalberghi, 1993).

If lithic manuports are considered a defining characteristic of early tool behaviour in humans (Potts, 1991) then the lack of tool- or food- transporting behaviour in other species precludes their use as analogs to hominids. Nonetheless, some aspects of ape tool behaviour are very similar to those of humans. Chimpanzees in particular seem to use tools in unique ways most resembling human behaviour (McGrew, 1993). Namely, the transmission of nut-cracking follows the same functions as human teaching (Boesch, 1993). It is concluded that chimpanzee

mothers show humanlike abilities to care about their child's learning process, predict the child's actions with respect to correct actions, and influence the child's performance. Other aspects of culture that chimpanzees share with humans are the social learning mechanisms that allow transmission (vertical and horizontal) of cultures (Boesch & Tomasello, 1998).

Direct evidence of the stone tool-making skills of a modern chimpanzee shows that there are several qualitative differences with the behaviour of early hominids. Schick et al. (1999) have taught an adult, linguistically-trained male chimpanzee (Kanzi) to produce flakes for three years. As stated above, the angle of the blow must come at less than 90 degrees to the platform in order to produce a flake; Kanzi uses average angles of 89.7 degrees, whereas humans produce average angles of 80 degrees (Schick et al., 1999). Furthermore, this study found that Kanzi's preferred technique is to throw the hammerstone against the core, raising the possibility that early hominids used this technique before their manual dexterity allowed them to use hand-held cores and hammers.

## **8.5 Inferring handedness from the lithic record**

### **8.5.1 Clues from tool use and production**

From the preceding discussions of primate 'handedness', early hominid tool behaviours, and the connection between language and hemispheric specialisation, it follows that it will be interesting to determine when, how, and why this unique feature of modern humans arose. At present, two categories of hypotheses are competing: those which argue that the appearance of Acheulean technologies marks the beginning of modern human cognitive capacities, and those which postulate an earlier origin of modern mental abilities. This debate can benefit from knowing when the right-handed bias in humans appeared at the population level. If it is accepted that language capacities emerged with the brain reorganisation event that was responsible for creating the population right bias,

then the time at which this right bias appeared is the *latest* possible date for the origins of language.

Considerations of handedness based on archaeological evidence have until recently been subjective, such as the impression that a handaxe fits better in the right or left hand. A similar but more rigorous approach has been proposed by Phillipson (1997). This study examined edge damage on East African Acheulean handaxes dated to around 1 mya. It was found that the patterns of wear from use are consistent with left-handed holding (based on comfort related to asymmetrical front and back faces) at 11 %. Another analysis of wear patterns suggests that hafted axes and adzes become damaged on one side depending on the handedness of their user (Spenneman, 1987).

Two methods have been proposed for assessing handedness from the archaeological flake record, i.e. by determining in which hand the knapper held the core. The earlier method, which is named the cortex method and will here be abbreviated Ctx (Toth, 1985), involves simply looking at whether the remaining cortex is on the left or right side of the flake, if it is viewed dorsally with the platform facing upwards. The most recent method, the cone of percussion method abbreviated CP (Rugg & Mullane, 2001), requires assessing the angle of the cone of percussion (right- or left-pointing) relative to the platform.

### **8.5.2 Assumptions behind the methods**

Each of the methods proposed is based on a set of assumptions about knapping processes. None of these assumptions have been tested experimentally, and this study was carried out with complete awareness of these unverified principles. As one of the goals of the present research was to test the feasibility of using the Ctx and CP methods on very large archaeological samples, this aspect of the methods was examined.

The Ctx method is based on the premise that the muscles of the wrist holding the core are more adept at making the hand turn anti-clockwise during flaking. Ctx also assumes that flakes are removed serially using the same part of the core as the platform without changing wrist rotation direction. These two assumptions taken together imply that for right-handed knappers, cortex will remain on the right side of most flakes (a scar from the preceding flake occupying the left side).

The assumption behind the CP method relates to knapping skill. Because motor movements are imperfectly aimed (stemming from constraints of human motor and perceptual systems), the hammerstone blow will not always strike the platform perpendicularly to the ground. The premise that the blow will more likely be aimed away from the knapper's body is then evidenced as a higher proportion of right-skewed flakes from right-handed knappers and vice versa.

## **8.6 Hypotheses for the present study**

Based on the available evidence from different fields, a time period can be proposed for the emergence of laterality. Results from the primate observations and the brain studies support the hypothesis of an incipient lateral bias in hominids which was subject to selective pressures when tool use became habitual. The most important transition in anatomy and behaviour appears to occur around the transition from Oldowan to Acheulean industries, or from *Australopithecus* to *Homo*.

The specimens studied for this research are from large flake collections from the British Lower Palaeolithic (Purfleet and Swanscombe), and therefore served to test whether the hominids from this time period already had the lateral bias that we do. The Ctx and CP methods were applied on these flakes with the goal of testing the following questions and hypotheses:

1. how useable the methods are for an untrained experimenter;
2. whether the archaeological samples yield similar ratios to the published ratios;
3. whether the two methods yield the same results;
4. left-handers produce more unassignable flakes.

Several important predictions can be made regarding these four points.

Firstly, the useability of the methods is essential if further studies are to be carried out. The inexperienced experimenter serves as a test to determine how long it takes to learn the methods. It is also important to note any difficulties the experimenter has with the methods in order to suggest improvements.

Secondly, the archaeological samples should match or exceed those of Toth (1985) in the ratios, if the Ctx method is applied properly. Because the collections here are more recent than those of Koobi Fora, it would be expected that a higher R:L ratio would be present.

Thirdly, the methods' accuracy can be inferred based upon the percentage agreement on flake assignments. The proportion of flakes that are assigned to the same category (right, left, or unassignable) by both methods indicates how well they agree.

Fourthly, the proportion of flakes which are assigned differently by each method can be further separated: a flake can be assigned R in one case and L in the other, or a flake that is assignable by one method can be unassignable by the other. This can be used to test hypothesis 4: it would be predicted that L flakes (assigned by Ctx) would more often be unassignable by CP.

In the next section, the results from Purfleet and Swanscombe will be presented, followed by a discussion of conclusions reached and suggestions for further research.

## **9. Materials and methods**

### **9.1 Archaeological sample**

Specimens from two sites of the Lower Palaeolithic in Britain were analysed: Purfleet and Swanscombe. The two sites are separated by what is now the Thames (cf. Figure 9.1.a).

Figure 9.1.a Map showing the geographical location of Purfleet and Swanscombe. From Conway et al., 1996 (p. 2).

Purfleet is located at Thurrock in Essex, and flint artefacts were discovered in 1961. It is one of the major sites of East Anglia (Wymer, 1985). The collection studied comes from Site A in Botany Pit, which was excavated by Snelling. The industry is categorised as Proto-Levallois, and is dated to 300-200 kya (Bates et al., 1998). The artefacts are characterised by crude Levallois working and very few modifications (Wymer, 1985). In total 326 flakes from Botany Pit, ranging from small to large in size, were studied.

The site of Swanscombe, which lies in Kent, comprises several excavations. The flakes studied from this collection are chalk flint artefacts from Barnfield Pit, notably the Lower Loams (LL) and Lower Gravels (LG). The LL specimens come from Trench B3, knapping floor complexes 19, 20, 21, and 22, and were uncovered during the 1968-72 Waechter excavations. The same excavations yielded the LG flakes for this study in Trench A, 3.80-4.20m below the ground. Some flakes used in this study were uncovered in Base LG number 4, and also from Trench A2, Spits 5 and 6 from the 1970 excavations, 3.97-4.47m below the surface. These samples are all dated to about 400 kya and are attributed to the Clactonian industry (Ashton & McNabb, 1996). These flakes are mostly medium-sized, with some small flakes and a number of partially refitted cores. In total 338 Swanscombe flakes were analysed. Included were refits comprising up to four pieces. There were also some natural (non-human-made) flakes and many knapping chips, which were ignored for the present study.

## **9.2 Laterality analysis**

The flakes were studied by the author over a period of one week from 30 July to 3 August 2001. They were examined in the laboratory where they are stored, with a table lamp and sunlight providing lighting, and viewed against a white or dark blue background. The experimenter systematically studied the flakes in the order in which they were arranged in their storage boxes. Each box contained from 6 to 46 objects, depending on their size, and were not ordered in any way

on the shelves. Nor were the flakes in each box ordered except for the refit pieces, which were either glued together or had indications of how they fit together (by numbers and letters).

The Ctx method and the CP method were applied one after the other, either per group of boxes (two to four at a time), per box, or per flake. The order in which they were applied was varied to avoid judgment bias and balance their effect among the different sites and different sized flakes. The experimenter did not analyse flakes for more than 3 1/2 hours at a time, to ensure that eye strain would not affect judgment by the CP method.

It had been planned to perform reliability tests on random samples with a few days' spacing, to test for intra-observer error. However, for this study it was decided to forego the reliability tests in the interest of obtaining a maximum sample size. Consistency of judgement was found to be excellent in the few flakes which were re-examined, and large numbers of flakes were deemed to be more important to the present study than observer consistency.

## **10. Results**

### **10.1 Methods' applicability**

#### **10.1.1 Requirements for flake attributes**

To apply the cortex (Ctx) method, one views the flake from the dorsal side with the striking platform facing upwards. If there is any cortex remaining on the flake, its laterality is inspected. Cortex can be located on one part of the flake's dorsal side (see Figure 10.1.1.a below) or spread on an area. Cortex on the right side is assigned right-oriented, and cortex on the left side is classified as left-oriented.

Figure 10.1.1.a Examples of left and right cortex flakes. From Ashton et al., 1992 (plate 29).

Typical non-lateral (unassignable) cortex distributions are upper, lower, central, U-shaped, upside-down U-shaped, entirely corticated, and bilateral (see Figure 10.1.1b below). A detailed breakdown of the occurrences of each is given in Appendix 1a.

Figure 10.1.1.b Non-lateral cortex patterns: lower, central, U-shaped, entirely corticated. From Ashton et al., 1992 (plate 27, plate 22, p. 155, plate 25).

To apply the cone of percussion (CP) method, the flake is viewed ventrally with the platform facing upwards. The cone of percussion is examined to determine its angle relative to the platform. If the cone is skewed to one side rather than being perpendicular to the platform, then it is classified as either right- or left-oriented. Figure 10.1.1.c shows examples of flakes with visible cones.

Figure 10.1.1.c Examples of lateral flakes for CP analysis: right-oriented, left-oriented, left-oriented, right-oriented. From Ashton et al., 1992 (plate 15; p. 184; plate 23) and Ashton, 1996 (p. 216).

Each method places different requirements on flake morphology in order for it to be applied.

For a flake to be assignable under Ctx, it must, firstly, possess cortex, and secondly, be orientable according to a platform. As described above, there are many possible patterns of cortex distribution, and only two of these patterns (right side and left side of the dorsal surface) yield assignable specimens. Although this method is entirely objective owing to the binary nature of the judgement, it is often the case that cortex is not simply lateralised. Other complications come from the inability to identify a platform or the cortex itself. A flake may be unassignable for other reasons as well, namely due to unidentifiability of the platform, dorsal side, or cortex.

To be an assignable flake under CP, it must have, firstly, an undamaged cone of percussion, secondly, an undamaged platform, and thirdly, a flat platform by which to judge the angle of the cone. Often the bulb of percussion is damaged or the cone is missing, resulting in the flake being unassignable. Furthermore, the striking platform is not always flat; it can have a convex or concave shape, or be damaged on one side of the bulb of percussion. In this case the experimenter must extrapolate the angle of the platform from its remnants. It can also occur that there is a well-defined bulb of percussion, but the cone is worn or broken off.

Figure 10.1.1.d overleaf gives examples of assignable and unassignable flakes for CP.

It is evident from the above that the only requirement both methods have in common is that a flake must possess an intact platform. Because the two methods use different features of the flake, they can complement each other. Flakes that have a damaged cone can be assigned with Cx, and flakes with no cortex can be assigned with CP. Providing there are intact platforms, the Cx and CP methods can be used together to assign a maximum number of flakes.

Figure 10.1.1.d Examples of flakes that are difficult to assign with CP: no platform; rounded platform; uneven platform and damaged cone; platform on an edge. From Ashton et al., 1992 (plate 14; plate 40; plate 24; plate 4).

### **10.1.2 Useability of methods by untrained experimenters**

Both methods are simple to learn for completely untrained observers; once a few flakes have been studied, analysis proceeds quickly and efficiently. It is recommended that observers be given explanations by someone who has applied the methods before. For the Ctx method, cortex can be hard to identify, as sometimes only a small patch of apparent cortex is evident and might actually be weathered flint. The most difficult aspect of judging flakes with the CP method is in assessing the angle of the cone. This is often a very subjective assessment because the angle is relative to the platform's surface. The platform can be perceived differently depending on how the flake is held, what colour or texture the viewing background consists of, what angle the light source is coming from, and what is decided to be the actual striking platform. Because there is often a small flat part of platform directly above the cone, surrounded by different angles of platform, sometimes on different sides, it is necessary for the experimenter to decide which part of the entire platform would have been the target of the blow that detached the flake. For this judgement, a knowledge of flint knapping is beneficial and an untrained experimenter can only decide which part of the platform looks the flattest. It was found that holding a straight pencil along the top of the platform greatly aids this decision.

Both methods require an ability to identify the striking platform and dorsal surface of the flake. The easiest way to orient the flake is first to identify a bulb or cone of percussion. The flake is then held with the cone pointing upwards and facing the experimenter for the CP method, facing away from the experimenter for the Ctx method. Cones of percussion are usually quite obvious on a flake's surface, as the bulb stands out convexly and the accompanying conchoidal ripples are quite clear.

## 10.2 Laterality ratios

Before the results of the present study are analysed, the results of published studies will be presented for each method in turn. The distributions of right- and left-oriented flakes found in the Purfleet and Swanscombe collections will be examined, with particular attention to unassignability reasons and possible grouping factors. Then the Ctx and CP methods will be compared against each other with the aim of estimating their agreement. Finally, some general comments about the feasibility of using the methods to assess handedness in large archaeological samples will conclude the Results section. Appendix 3 lists the raw information recorded for all 647 flakes.

### 10.2.1 Cortex analysis

#### 10.2.1.1 Comparison to published ratios

The original study by Toth (1985) included experimental core replication and two archaeological samples of Oldowan and Acheulean flakes. The results are presented in Table 10.2.1.1.a below. A right to left (R:L) ratio of 57:43 was found for the Oldowan samples, and 61:39 was found in the Acheulean flakes. The experimental flint knapping, performed by an experienced right-hander (Toth himself), produced a ratio of 56:44.

Site	Industry, Date	Number assignable	L	R
Koobi Fora, Kenya	Oldowan, 1.9-1.4 mya	303	130	173
Ambrona, Spain	Acheulean, 0.4-0.3 mya	79	31	48
experimental core replication	right-handed, 1982-85	386 of 1569 (24.6 %)	169	217

Table 10.2.1.1.a Numbers of right and left flakes obtained by Toth (1985).

Toth did not state the total numbers of flakes studied in his archaeological samples. This raises the possibility that he could have simply analysed flakes at random until the desired ratios were obtained. However, nothing can be concluded about his methods without further proof.

In reply to Toth, Patterson & Sollberger (1986) performed an experimental study and found a ratio of 47:53 for a right-handed knapper and 56:44 for a left-hander. Their results are summarised in Table 10.2.1.1.b.

Site	Industry, Date	Number assignable	L	R
experimental knapping	right-handed, 1986	60 of 132 (45.5 %)	32	28
experimental knapping	left-handed, 1986	18 of 35 (51.4 %)	8	10

Table 10.2.1.1.b Numbers of right and left flakes obtained by Patterson & Sollberger (1986).

A larger-scale study by Pobiner (1999) on experimental knapping found an overall ratio similar to Toth's, although individuals differed in their production of right and left flakes. Seven right-handers produced a total of 284 flakes, resulting in a 60:40 ratio (cf. Table 10.2.1.1.c).

Site	Industry, Date	Number assignable	L	R
experimental knapping	right-handed, 1999	96 of 284 (33.8 %)	38	58

Table 10.2.1.1.c Numbers of right and left flakes obtained by Pobiner (1999).

The present study examined a total of 647 flakes.

The results for the Purfleet and Swanscombe flakes are presented below in Table 10.2.1.1.d. Because the ratios do not differ significantly between collections, the results are pooled to obtain the overall ratio of about 50:50.

Site	Industry, Date	Number assignable	L	R
Purfleet, GB	Proto-Levallois, 300-200 kya	163 of 326 (50 %)	80	83
Swanscombe, GB	Clactonian, 400 kya	156 of 321 (48.6 %)	79	77
Purfleet + Swanscombe	-----	319 of 647 (49.3 %)	159	160

Table 10.2.1.1.d Separate and combined numbers of right and left flakes obtained in the present study by Ctx.

As Table 10.2.1.1d shows, Purfleet yielded 49.1 % left-oriented flakes and 50.9 % right-oriented flakes. Swanscombe yielded 50.6 % L flakes and 49.4 % R

flakes. Combining the results gives a total of 49.8 % L flakes and 50.2 % R flakes for both collections.

### 10.2.1.2 Analysis of knapping scatters

Rugg & Mullane (2001) suggested analysing ratios for knapping scatters separately in order to control for the effects of individual knapping style. The Swanscombe samples were therefore classified by knapping complex, and ratios are presented in table 10.2.1.2.a. Appendix 2a lists the numbers of flakes assigned to R and L categories. The ratios are presented graphically in Figure 10.2.1.2.b below.

<u>trench/complex</u>	<u>ratio R:L (%)</u>	<u>significant R bias</u>
A	80:20	*
(A2/base	0:0)	
(A2/spit 6	100:0	*)
A2/s6/4.47m	67:33	*
A2/3.97m	32:68	L
A2/top	83:17	*
A2	67:33	*
A3	33:67	L
A4/base	49:51	
A4/3.65m	63:37	*
A4/3.55m	50:50	
A4	57:43	
(B3	100:0	*)
B3/19	50:50	
B3/20	33:67	L
B3/21-22	31:69	L

Table 10.2.1.2.a Ctx ratios for each Swanscombe trench, ordered from most superficial to deepest layers. Parentheses indicate complexes with less than one flake in both R and L categories.

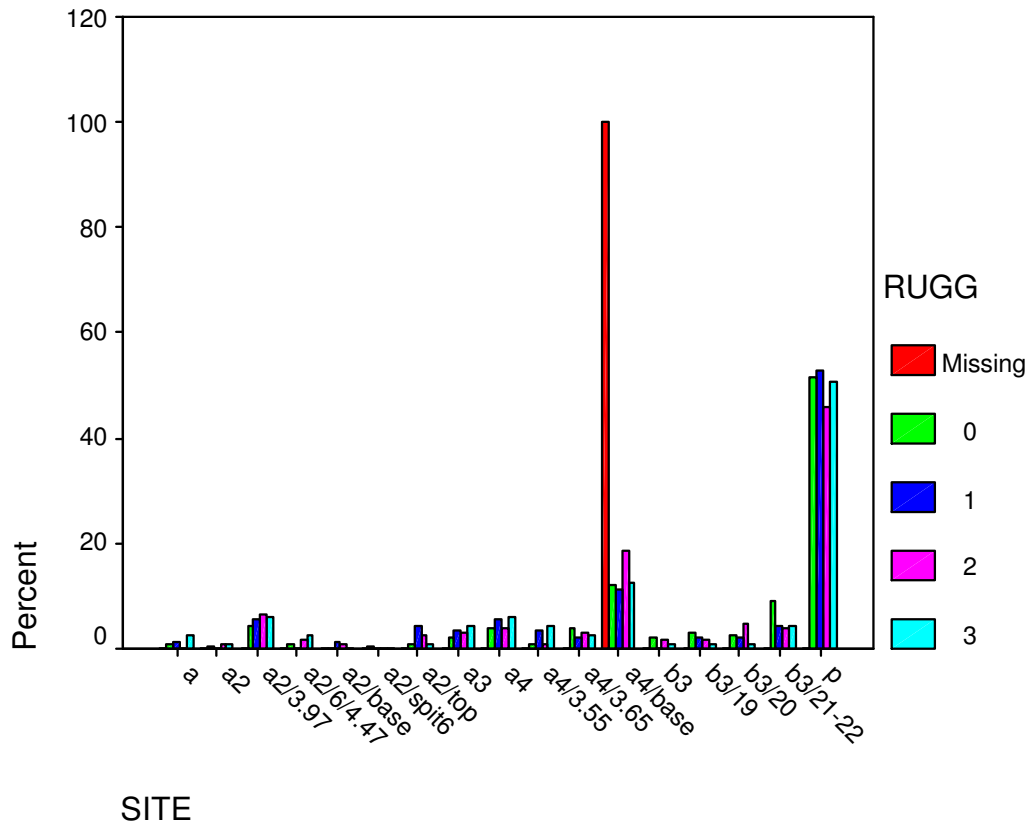


Figure 10.2.1.2.b Proportions of R and L flakes assigned by CP, categorised by knapping complex. 0 = unassignable; 1 = L; 2 = R; 3 = S.

There is a significant R bias in five of the 16 Swanscombe sites, representing 18 of 156 assignable flakes. A significant L bias is found in four sites. Following Rugg & Mullane (2001), if we use the knapping complex rather than the flake as the unit of study, then we obtain overall figures of 46.5 % L flakes and 53.5 % R flakes (excluding sample sizes less than or equal to 1). It should be noted that although there are complexes which produce up to 83 % R flakes, none of the L-biased complexes produce more than roughly 2/3 L flakes. Therefore it appears that in the Swanscombe collections, right bias is stronger than left bias.

### 10.2.1.3 Unassignability of flakes

Toth obtained 1183 unassignable flakes of 1569 total (75.4 %) in the experimental knapping samples. Patterson & Sollberger obtained 89 unassignable flakes of 167 total produced (53.3 %). Of these 89 flakes, 52 were entirely corticated (58.4 %) and 37 had central cortex (41.6 %). Pobiner found that 109 of 188 unassignable flakes had no cortex (58 %), and 79 had non-lateral cortex (42 %).

In the present study, half the flakes were unassignable by Ctx. Of 647 flakes, 328 were unassignable (50.69 %) because of the following reasons:

- 165 were non-corticated (50.3 %)
- 87 had non-lateral cortex (consisting of 8 bilateral, 52 lower, 18 upper, and 9 U-shaped, central, or other patterns) (26.5 %)
- 42 were entirely corticated (12.8 %)
- 34 had unidentifiable attributes (10 platform, 19 dorsal surface, or 5 cortex) (10.4 %).

A detailed breakdown of the occurrence of each type of specimen is given in Appendix 1a. The proportions confirm the published findings of at least 50 % unassignability, although proportions of non-corticated, non-lateral, and entirely corticated flakes differ. This is not surprising, as the method of knapping is the main determinant of the types of flakes produced.

## 10.2.2 Cone of percussion analysis

### 10.2.2.1 Comparison to published ratios

Rugg & Mullane (2001) obtained, from experimental flake production by eight subjects (four left-handers and four right-handers), an overall R:L ratio of 75:25. Table 10.2.2.1.a summarises their findings.

Site	Industry, Date	Number assignable	L	R
experimental knapping	R and L handed, 1999	75 of 299 (25.1 %)	19	56

Table 10.2.2.1.a Numbers of right and left flakes obtained by Rugg & Mullane (2001).

In the present study, 33 % of flakes could be assigned to R or L. The remaining flakes were either judged to be straight, or were unassignable.

Once again, the Swanscombe and Purfleet results were pooled (see Table 10.2.2.1.b).

Site	Industry, Date	Number assignable	L	R
Purfleet, GB	Proto-Levallois, 300-200 kya	164 of 326 (%)	47 (45.2 %)	57 (54.8 %)
Swanscombe, GB	Clactonian, 400 kya	167 of 319 (%)	42 (38.5 %)	67 (61.5 %)
Purfleet + Swanscombe	-----	331 of 645 (%)	89 (42 %)	124 (58 %)

Table 10.2.2.1.b Separate and combined numbers of right and left flakes obtained in the present study by CP.

Of the 645 specimens (2 had no data because they were unintentionally omitted), 331 could be assigned with CP either as R, L, or straight (S). 118 of these were S (35.65 %), 124 were R (37.46 %), and 89 were L (26.88 %). This means that 213 flakes were assigned to a lateral category, with a R:L ratio of 58:42.

### 10.2.2.2 Analysis of knapping scatters

A breakdown of ratios by knapping floor for the Swanscombe flakes is presented below in table 10.2.2.2.a. Appendix 2b lists the numbers of flakes assigned to R, L, and Straight categories. The ratios are presented in graphical format in Figure 10.2.2.2.b below.

trench/complex	ratio R:L (%)	significant R bias
A	0:100	L
A2/base	50:50	
A2/spit 6	0:0	
(A2/s6/4.47m	100:0	*)
A2/3.97m	62:38	*
A2/top	43:57	L
A2	100:0	*
A3	57:43	*
A4/base	70:30	*
A4/3.65m	67:33	*
A4/3.55m	25:75	L
A4	50:50	
(B3	100:0	*)
B3/19	50:50	
B3/20	75:25	*
B3/21-22	56:44	*

Table 10.2.2.2.a CP ratios for each Swanscombe trench, ordered from most superficial to deepest layers. Parentheses indicate complexes with less than one flake in both R and L categories.

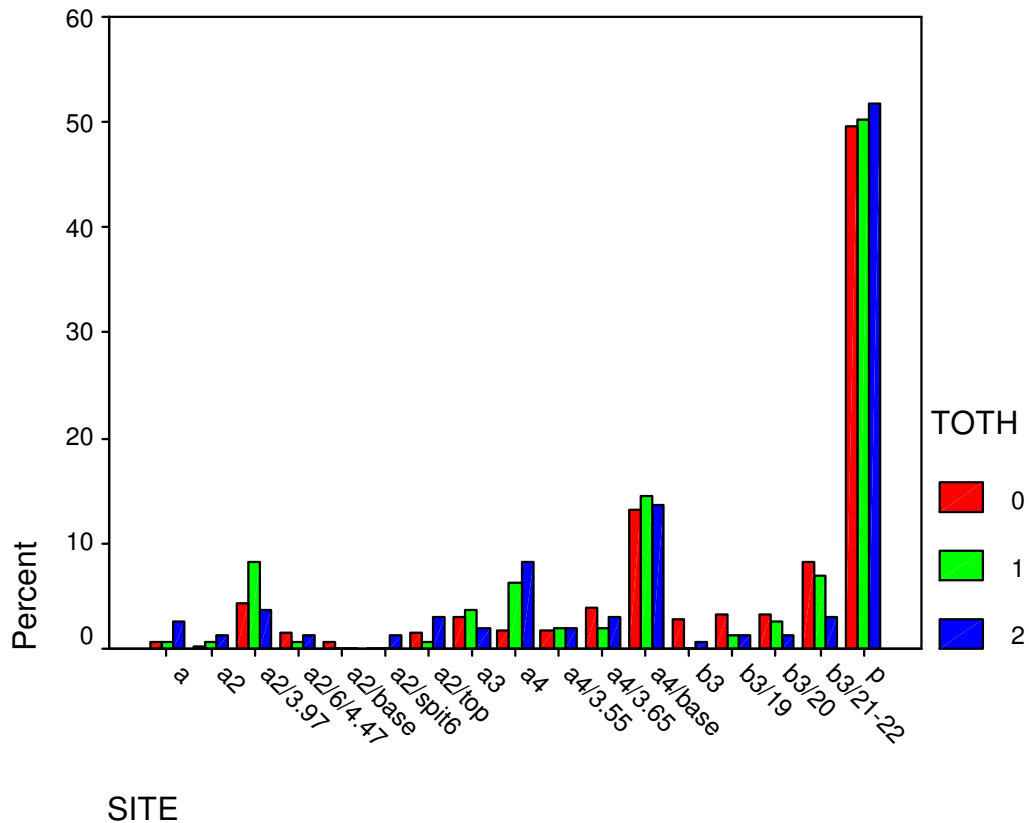


Figure 10.2.2.2.b Proportions of R and L flakes assigned by Ctx, categorised by knapping complex. 0 = unassignable; 1 = L; 2 = R.

There is a significant R bias in seven of the 16 sites, representing 75 of 109 assignable flakes. The overall figures are 45.8 % L and 54.2 % R, similarly to the proportions obtained with Ctx. The occurrence of strongly L-biased complexes suggests that some knapping sessions and some individuals produce high numbers of L flakes, as Pobiner (1999) and Rugg & Mullane (2001) mentioned. Therefore it is appropriate to identify separate knapping scatters in order to "reduce the risk of over-representation in the record from individuals with a particularly high proportion of skewed cones of percussion in their flakes" (Rugg & Mullane, 2001) and to control for the effects of sessions in which "one of the right-handed individuals produced only left-handed flakes" (Pobiner, 1999). Unfortunately, individual knapping scatters are not well-known in the archaeological record, so this analysis is not feasible for a larger-scale study.

### 10.2.2.3 Unassignability of flakes

314 flakes of 645 analysed (48.7 %) were unassignable by CP for the following reasons and in the following frequencies:

243 had no / broken / damaged cone or bulb (77.4 %)

32 had a worn or unidentifiable cone or bulb (plus 5 twin cones, removed from analysis) (10.2 %)

23 had no / broken / damaged platform (7.3 %)

11 had a worn or unidentifiable platform or platform angle (including uneven, rounded, pointed, or platform on an edge) (3.5 %)

5 had a worn or unidentifiable dorsal surface (1.6 %).

A detailed breakdown of the occurrences of each type of flake is given in Appendix 1b.

The largest proportion of unassignable flakes using CP were thus because of broken, damaged, missing, worn, or otherwise unidentifiable cones or bulbs of percussion. Many of the remaining flakes were unassignable due to platforms that did not lend themselves to angle estimation (because the platform was broken, damaged, missing, worn, uneven, rounded, or pointed), and for a small number of flakes the dorsal surface could not be identified (either because no bulb of percussion could be found, or the surfaces were too worn). Several flakes had other missing attributes in addition to lacking a cone of percussion; these were coded as "no cone or bulb".

Although incomplete cones were the main hindering factor in CP analysis, the number of assignable flakes could be increased by rendering incomplete platforms more productive. It was sometimes the case, for example, that the platform's position could be extrapolated from the few bits of it that were present.

### **10.3 Agreement between cortex and cone of percussion analyses**

An estimate of reliability or error can be obtained by measuring the agreement between the two methods. Of the 645 flakes which were analysed with both CP and Ctx, 177 were assignable by BOTH methods (27.44 %). However, only 113 were laterally assignable (were able to be classified as either R or L) by both methods (17.52 %). A scale reliability analysis yielded a poor coefficient ( $\alpha = 0.1758$ ).

The advantage of using both methods to complement each other is evident in the increase of assignable flakes: 472 were assignable by EITHER method (73.18 %) and 418 were laterally assignable by either method (64.81 %). If a reliable estimate of the accuracy of each method can be obtained experimentally, then both methods can be used in conjunction with one another to classify a maximum number of flakes.

Of the 113 lateral flakes assignable by both methods, 61 (53.98 %) were assigned to the same category by both methods. Conversely, 52 were assigned to the opposite category (46.02 %).

Of the flakes that were judged to be straight by the CP method, 54 were unassignable with Ctx, 23 were judged L and 41 judged R. This suggests that straight-angled cone of percussion flakes are produced more abundantly by knappers that produce Ctx-R flakes than those that produce cortex-L flakes. A detailed breakdown of the occurrences of assignable flakes by both methods is given in Appendix 1c.

## **10.4 Additional comments**

### **10.4.1 Refits**

It had been hoped that some refitted specimens would be useful to serve as checks on the accuracy of the methods. Unfortunately, only 14 flakes had been refitted, producing six separate refits. Each consisted of two or three flakes, with the exception of a core reconstruction with four flakes, and a set of five associated flakes. None of these refits provided the experimenter with neither a knapping sequence with which to check the Ctx method, nor any information about the hand used to hold the hammerstone. Future studies will have to analyse refits consisting of knapping sequences longer than a few blows, or else cortex must be present on a maximum area of the core's surface. An example of such an ideal refit is shown in Figure 10.4.1.a overleaf (page 68).

### **10.4.2 Flake size**

The flakes were partially classified and analysed according to size, as it was later suggested that the size of the flakes might have an effect on their laterality. However, no significant effect of size on R and L ratios was discovered. It was not possible to perform a full analysis of the effects of size because the flake sizes had been assigned to entire boxes rather than to each flake. Thus some flakes coming from boxes containing different sized flakes are marked with several sizes and it is not possible to distinguish individual flakes.

### **10.4.3 Degree of skew**

An interesting fact observed in the CP-analysed flakes relates to the degree of slanting. In the future this will have to be investigated more thoroughly (perhaps in conjunction with more precise and objective angle measurement techniques). Several flakes (14) were noted by the experimenter as having very strong degrees of skew in their cone of percussion. Only three of these were L-skewed.

This indicates that right skew is more strongly expressed than left skew. It would be interesting to obtain information from Rugg or further experimental studies about whether R or L handers produce such strongly skewed cones of percussion. In any case, the fact that strong left skew occurs much less often than strong right skew in the archaeological record demonstrates a type of knapping behaviour that produces preferentially right-skewed cones of percussion. If we accept Rugg's hypothesis that skewed cones of percussion are the result of a mis-hit from the intention of striking the core with a course of blow that is perpendicular to the platform, then it can be inferred that there was a consistent behaviour responsible for most of the strongly skewed cones.

Figure 10.4.1.a Example of a refit with many removals. From Martingell & Saville, 1988 (p. 21).

## **11. Discussion and conclusion**

### **11.1 Discussion**

The following hypotheses and questions (sec. 8.6) were addressed in this study:

1. how useable the methods are for an untrained experimenter;
2. whether the archaeological samples yield similar ratios to the published ratios;
3. whether the two methods yield the same results;
4. left-handers produce more unassignable flakes.

From the results in the previous section, several conclusions arise. Both the Ctx and the CP method were quite easy to learn and apply to large numbers of archaeological specimens. However, the reliability of the methods proved disastrous: the ratios obtained did not resemble those published, except for Patterson & Sollberger (1986). In fact, the Purfleet and Swanscombe samples appear to be divided at chance between right and left flakes. One of the major problems of both methods remains the large signal to noise ratio, which was noted by Rugg & Mullane (2001). At least half of the 647 flakes analysed in this study were unassignable for various reasons. One wonders, therefore, whether the absence of lateral bias in these collections is due to the extremely low assignability of flakes produced by left-handers (Rugg & Mullane, 2001). It is possible that left-handedness becomes archaeologically invisible, thus creating the appearance of a right-hand bias in the record. If two different reliable methods could be devised which make use of different features of the flake, then the assignable proportions could be greatly increased. The Ctx and CP methods are not good candidates for this because of their very poor agreement.

There are many problems with Toth's cortex approach (cf. Patterson & Sollberger, 1986; Pobiner, 1999). These lie in the assumptions that have been outlined in section 8.5.2 above. This study has confirmed the uselessness of the Ctx method for inferring handedness, as well as pinpointing some disadvantages

of the CP method. Unfortunately, the obvious deficiencies of the Ctx approach have been overlooked by researchers ignorant of knapping concepts, and Toth (1985) has frequently been cited as evidence for the early emergence of language.

An ideal method would not rely on knapping sequences, as does Ctx, but rather could be applied to isolated flakes. The CP method approaches this ideal, in that the assumptions behind it depend on aspects of individual striking blows. The main drawback of the CP method lies in its high subjectivity. As was mentioned earlier, assessing the angle of the cone of percussion to the platform depends on many factors. Fox & Frayer (1997) use a rigorous angle-measurement method to study tooth striations, using image analysis software. This method could prove useful for measuring platform angles objectively. Furthermore, it could provide finer-grained analyses by detecting subtle angles that are not noticeable by eye.

## **11.2 Possible scenario for the evolution of handedness, cognition, and language**

It was not possible with the present results to answer the question of whether Purfleet and Swanscombe flint knappers were right-handed. The negative results could be related to the invisibility of left-handedness in the archaeological record, or to an actual lack of handedness in hominids. From the discussions presented in the sections on Handedness, Hemispheric specialisation, and Lithics, possible dates for the emergence of modern cognitive and linguistic capabilities appear to converge on the appearance of *Homo*, namely within the transition from Oldowan to Acheulean tool-making. At that time, the advantages gained by successful tool use and production would have greatly increased reproductive fitness. The right-shift proposed by Annett (1985) could have occurred via selective advantages for learning flint knapping from people with similar handedness. The preference of the right hand to hold the hammerstone would have emerged naturally from a latent preference which is evident in

modern primates and is due to motor and cognitive constraints; the increasingly demanding processing skills required for habitual tool making would have pressured the brain to become more hemispherically specialised, especially for the "new" and complex function of language.

In spite of the plausibility of such a scenario for this stage in human evolution, one issue remains to be resolved. Namely, the problem of surviving left-handers must be addressed. Annett (1985) proposes an elegant solution in terms of genetics, suggesting that left-handedness comprises a heterozygote advantage and therefore will remain at the current prevalence in populations. However, there are other possibilities, related to language and lithic production. Michel & Harkins (1985) argue that the presence of language provided an advantage to technical skill learners and teachers. The pressure for hominids to conform to the same handedness (i.e. the right) would have decreased when language was available to transmit information. Therefore the shift towards right-handedness would have occurred before the emergence of language, if it were driven by tool-making skill transmission.

The rightward tool-related pressure would have gradually shifted frequencies of right-handers from 50 % towards 100 %. But apparently, this shift was stopped in mid-flow, having only attained a right prevalence of about 90 %. To remove the selective advantage of conforming handedness, another advantage must have appeared and prevailed. This could have been language. If language emerged soon after the onset of tool-making, then there would no longer have been any advantage to concordant handedness. Thus the remaining 10 % of left-handers would not have been selected out of the population because their disadvantage (being lateralised to the wrong side) could have been compensated by the newly-found linguistic capabilities of these hominids.

### **11.3 Directions for future research**

There is a clear need for continuing research in many fields to elucidate the question of the origins of handedness. Primatology, anatomy, neuroscience, linguistics, archaeology, and genetics are some of the main areas where ongoing research can contribute greatly to this issue. Some of the suggestions raised in the Handedness section for primate observations and experiments can easily be implemented, and much progress is being made in osteoarchaeology to determine the anatomical correlates of handedness -- both in living humans and in the fossil record. Linguistic research is providing a greater understanding of the universals of human language, the biological correlates of language, and its lateralised functions. Finally, when the genetic components responsible for handedness are identified, they will give an insight into the evolutionary mechanisms of lateral preference in humans.

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## Appendix 1

### Appendix 1a - occurrences of types of unassignable specimens using Ctx method

no cortex	165
lower cortex (bottom)	52
entirely corticated	42
unidentifiable dorsal side	19
upper cortex (upside-down U/pf)	18
unidentifiable platform	10
bilateral cortex (R and L sides)	8
unidentifiable/insufficient cortex	5
U-shaped cortex (around)	4
cortex on front (??)	3
central cortex (middle patch)	1
cortex on ventral (back)	1
TOTAL	328

Examples can be found on page 51.

### Appendix 1b - occurrences of types of unassignable specimens using CP method

no bulb	128
no cone	65
damaged cone	24
no platform	22
broken cone	15
unidentifiable cone	15
broken bulb	8
unidentifiable bulb	7
worn cone	6
pointed platform	6
worn bulb	4
unidentifiable attributes	
due to glued together	4
damaged bulb	3
broken platform	1
worn platform	1
uneven platform	1
rounded platform	1
platform on edge	1
unidentifiable platform	1
unidentifiable dorsal	1
TOTAL	314

Examples can be found on page 54.

### Appendix 1c - agreement of methods

Ctx	CP	number	test
R	R	32	agreement
L	L	29	agreement
L	R	37	disagreement
R	L	15	disagreement
		----	
		113	(total)
x	x	173	inconclusive
L	S	23	inconclusive
L	x	70	inconclusive
R	S	41	inconclusive
R	x	71	inconclusive
x	S	54	inconclusive
x	R	55	inconclusive
x	L	45	inconclusive

## Appendix 2a

### TOT

SITE		Frequency	Percent	Valid Percent	Cumulative Percent
a	Valid 0	2	28.6	28.6	28.6
	1	1	14.3	14.3	42.9
	2	4	57.1	57.1	100.0
	Total	7	100.0	100.0	
a2	Valid 0	1	25.0	25.0	25.0
	1	1	25.0	25.0	50.0
	2	2	50.0	50.0	100.0
	Total	4	100.0	100.0	
a2/3.97	Valid 0	14	42.4	42.4	42.4
	1	13	39.4	39.4	81.8
	2	6	18.2	18.2	100.0
	Total	33	100.0	100.0	
a2/6/4.47	Valid 0	5	62.5	62.5	62.5
	1	1	12.5	12.5	75.0
	2	2	25.0	25.0	100.0
	Total	8	100.0	100.0	
a2/base	Valid 0	2	100.0	100.0	100.0
a2/spit6	Valid 2	2	100.0	100.0	100.0
a2/top	Valid 0	5	45.5	45.5	45.5
	1	1	9.1	9.1	54.5
	2	5	45.5	45.5	100.0
	Total	11	100.0	100.0	
a3	Valid 0	10	52.6	52.6	52.6
	1	6	31.6	31.6	84.2
	2	3	15.8	15.8	100.0
	Total	19	100.0	100.0	
a4	Valid 0	6	20.7	20.7	20.7
	1	10	34.5	34.5	55.2
	2	13	44.8	44.8	100.0
	Total	29	100.0	100.0	
a4/3.55	Valid 0	6	50.0	50.0	50.0
	1	3	25.0	25.0	75.0
	2	3	25.0	25.0	100.0
	Total	12	100.0	100.0	
a4/3.65	Valid 0	13	61.9	61.9	61.9
	1	3	14.3	14.3	76.2
	2	5	23.8	23.8	100.0
	Total	21	100.0	100.0	
a4/base	Valid 0	43	48.9	48.9	48.9
	1	23	26.1	26.1	75.0
	2	22	25.0	25.0	100.0
	Total	88	100.0	100.0	
b3	Valid 0	9	90.0	90.0	90.0
	2	1	10.0	10.0	100.0
	Total	10	100.0	100.0	
b3/19	Valid 0	11	73.3	73.3	73.3
	1	2	13.3	13.3	86.7
	2	2	13.3	13.3	100.0
	Total	15	100.0	100.0	
b3/20	Valid 0	11	64.7	64.7	64.7
	1	4	23.5	23.5	88.2
	2	2	11.8	11.8	100.0
	Total	17	100.0	100.0	
b3/21-22	Valid 0	27	62.8	62.8	62.8
	1	11	25.6	25.6	88.4
	2	5	11.6	11.6	100.0
	Total	43	100.0	100.0	
p	Valid 0	163	50.0	50.0	50.0
	1	80	24.5	24.5	74.5
	2	83	25.5	25.5	100.0
	Total	326	100.0	100.0	

**Appendix 2b**

**RUGG**

SITE			Frequency	Percent	Valid Percent	Cumulative Percent
a	Valid	0	3	42.9	42.9	42.9
		1	1	14.3	14.3	57.1
		3	3	42.9	42.9	100.0
		Total	7	100.0	100.0	
a2	Valid	0	2	50.0	50.0	50.0
		2	1	25.0	25.0	75.0
		3	1	25.0	25.0	100.0
		Total	4	100.0	100.0	
a2/3.97	Valid	0	13	39.4	39.4	39.4
		1	5	15.2	15.2	54.5
		2	8	24.2	24.2	78.8
		3	7	21.2	21.2	100.0
	Total	33	100.0	100.0		
a2/6/4.47	Valid	0	3	37.5	37.5	37.5
		2	2	25.0	25.0	62.5
		3	3	37.5	37.5	100.0
		Total	8	100.0	100.0	
a2/base	Valid	1	1	50.0	50.0	50.0
		2	1	50.0	50.0	100.0
		Total	2	100.0	100.0	
a2/spit6	Valid	0	2	100.0	100.0	100.0
a2/top	Valid	0	3	27.3	27.3	27.3
		1	4	36.4	36.4	63.6
		2	3	27.3	27.3	90.9
		3	1	9.1	9.1	100.0
	Total	11	100.0	100.0		
a3	Valid	0	7	36.8	36.8	36.8
		1	3	15.8	15.8	52.6
		2	4	21.1	21.1	73.7
		3	5	26.3	26.3	100.0
	Total	19	100.0	100.0		
a4	Valid	0	12	41.4	41.4	41.4
		1	5	17.2	17.2	58.6
		2	5	17.2	17.2	75.9
		3	7	24.1	24.1	100.0
	Total	29	100.0	100.0		
a4/3.55	Valid	0	3	25.0	25.0	25.0
		1	3	25.0	25.0	50.0
		2	1	8.3	8.3	58.3
		3	5	41.7	41.7	100.0
	Total	12	100.0	100.0		
a4/3.65	Valid	0	12	57.1	57.1	57.1
		1	2	9.5	9.5	66.7
		2	4	19.0	19.0	85.7
		3	3	14.3	14.3	100.0
	Total	21	100.0	100.0		
a4/base	Valid	0	38	43.2	44.2	44.2
		1	10	11.4	11.6	55.8
		2	23	26.1	26.7	82.6
		3	15	17.0	17.4	100.0
		Total	86	97.7	100.0	
	Missing	9999	2	2.3		
	Total	88	100.0			
b3	Valid	0	7	70.0	70.0	70.0
		2	2	20.0	20.0	90.0
		3	1	10.0	10.0	100.0
		Total	10	100.0	100.0	
b3/19	Valid	0	10	66.7	66.7	66.7
		1	2	13.3	13.3	80.0
		2	2	13.3	13.3	93.3
		3	1	6.7	6.7	100.0
	Total	15	100.0	100.0		
b3/20	Valid	0	8	47.1	47.1	47.1
		1	2	11.8	11.8	58.8
		2	6	35.3	35.3	94.1
		3	1	5.9	5.9	100.0
	Total	17	100.0	100.0		
b3/21-22	Valid	0	29	67.4	67.4	67.4
		1	4	9.3	9.3	76.7
		2	5	11.6	11.6	88.4
		3	5	11.6	11.6	100.0
	Total	43	100.0	100.0		
p	Valid	0	162	49.7	49.7	49.7
		1	47	14.4	14.4	64.1
		2	57	17.5	17.5	81.6
		3	60	18.4	18.4	100.0
	Total	326	100.0	100.0		

### Appendix 3

Raw data recorded for flake analysis

#### Legend (letters refer to columns)

- A.** Box numbers as they were labeled in the Museum.
- B.** Identification numbers of the flakes. If they were not labeled, numbers were assigned from top to bottom, left to right in the box.
- C.** Additional identifying numbers for flakes with the same ID in B.
- D.** Number of refit group.
- E.** Collection. P = Purfleet, S = Swanscombe.
- F.** Knapping complex (Swanscombe only). Trench number/level.
- G.** Size of flake. 1 = tiny, 2 = small, 3 = medium, 4 = large.
- H.** Results with Ctx. 0 = unassignable, 1 = Left, 2 = Right.
- I.** Reasons for unassignability. Btm = bottom, cx = cortex, nc = no cortex, nid = unidentifiable, pf = platform, dors = dorsal side, ac = entirely corticated, 2c = bilateral cortex.
- J.** Results with CP. 0 = unassignable, 1 = Left, 2 = Right, 3 = Straight.
- K.** Reasons for unassignability. Codes as in I. with also: Bkn = broken, cn = cone, ncn = no cone, mdl = middle, dmg = damaged, rip = ripples, b = bulb.

## **Appendix 4**

Examples of hand use in nonhuman wild primates. From Bloom (1999).

1. Chimpanzees fishing for termites.
2. Orangutan mother drinking water while her baby reaches for some.
3. Japanese macaques grooming.
4. Chimpanzee.

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