From *Chaîne Opératoire* to Observational Analysis: A Pilot Study of a New Methodology for Analysing Changes in Cognitive Task-Structuring Strategies Across Different Hominin Tool-Making Events

Joanna E. Fairlie & Lawrence S. Barham

The chaîne opératoire *(CO) approach is a well-established method for the analysis of tool creation, use and discard, and associated cognitive processes. Its effectiveness in respect of cognition, however, is occasionally challenged. We briefly review key critiques of its epistemological and methodological limitations and consider alternative options. We suggest a new epistemological position and methodology which can link CO with alternative cognitive models and with the true complexity inherent in the stone tool archaeological record. Perception-action and embodied cognition theory are the proposed foundations of a new epistemology that allows us to reject the concept of thought processes underlying tool-making sequences as static entities selected from memory. Instead, they are described as arising, changing and flowing with and through bodily activity, or as the products of constant interaction between body, mind and environment. They are better understood as ongoing processes of situated task-structuring rather than as objectified concepts or symbols. The new methodology is designed to analyse individual tool-making processes rather than their products. We use a pilot study to explore how it can highlight variations in the gestural processes that structure different technologies and thus indicate potential differences in the associated cognitive strategies of the various tool-makers concerned.*

> 'Without movement or action, there is no need for thought'
> Koziol *et al.* 2012, 507

Introduction

This article aims to identify a reliable theoretical framework and methodology that allow an analysis of differences between cognitive strategies underlying a range of different prehistoric technology types. A subsidiary aim is to establish a methodology that can detect gradual as well as discontinuous or stepwise cognitive change over evolutionary time. The desired theoretical framework should describe a set of competencies which vary across individual agents and are capable of change in response to environmental factors. From an evolutionary perspective, these competencies should be able to contribute to increased fitness and be heritable via one or more routes (Jablonka & Lamb 2014). The methodology should also be able to detect motor differences between tool-making sequences and be sensitive to potential variations between tasks that might reflect differences between the cognitive strategies of individual tool-makers. The combined approach must be applicable to stone-tool technology which provides the most durable evidence of technological and cognitive evolution, but should also be relevant to organic material technologies (Barham 2013a).

The *chaîne opératoire* (CO) approach to the analysis of technology, and in particular to Palaeolithic stone tool-making, ostensibly provides a widely

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applicable approach which seeks to understand underlying cognitive processes. Recent reviews of this method highlight its main limitation as an over-emphasis on the analysis of technical skills in tool-making at the expense of an engagement with underlying cognitive processes. The result has been the construction of typologies of tool reduction that subsume individual variability within a framework of group-based norms of artefact making. The normative approach offers no mechanism for describing how technologies and associated cognitive strategies can change over evolutionary time, or even within the lifetime of an individual. This fundamental limitation has been recognized and an effort has been made to revise the CO methodology to incorporate a more modular view of tool-making tasks (Haidle 2009; 2010; Lombard & Haidle 2012). This modular approach describes a task as a progress between successive modular stages which together form a flexible hierarchy of optional pathways. Such descriptions support the concept of cognition as a task-structuring process, and do not correspond with the pre-formed linear sequence more common to the traditional CO model.

The linear concept inherent in CO is the the product of a deep-seated philosophical view of cognition called cognitivism (Malafouris 2013). This Cartesian tradition characterizes human cognition as the product of algorithmic brain processes fully completed before the commencement of activity. The processes are dependent on internal representations or intellectual concepts which control all bodily activity in humans, but not in animals. We discuss how perception-action and embodied cognition theories challenge cognitivism, and we offer a cognition-in-action view of tool-making through a description of our first pilot study.

Our pilot study is a trial run of new methodology based on observational analysis (OA). This methodology is essentially qualitative in origin and is used by occupational therapists to assess hospital-patients' behavioural sequences. A number of qualitative behavioural variables are introduced which are used to describe and compare sets of tool-making tasks. Three expert tool-makers are observed making tools associated with general patterns of development seen in the European Palaeolithic and African Stone Age. Each tool-making episode is described using the behavioural variables outlined below and comparisons are made between their relative levels of importance across tasks. Although the number of participants is small, some correspondence is identified between the type of task and variations in the levels of behavioural variables.

We discuss the parameters of the methodology and how best to adjust them in order to maximize descriptions of changes in motor patterns and cognitive strategies across tasks. We also discuss how well the methodology links with perception-action theory and provides a preliminary sketch of cognitive change operating over the Early to Middle Stone Age. We conclude that OA builds on the framework of the CO approach and may offer solutions to its theoretical and practical limitations.

Chaîne opératoire's potential as a methodology for analysing cognition

The CO approach to the analysis of tool-making was pioneered by Leroi-Gourhan (1964 [1993], 274) as part of his grand vision of human evolution. In his view, pre-industrial human technology was characterized as the work of artisans whose

> … operational sequences remained essentially the same: Workers considered the materials they were to process, drew on traditional knowledge to select a certain series of gestures, and then manufactured and possibly rectified the products of which they were the authors. Throughout the process, their expenditures of muscular effort and of thought were in balance.

This holistic perspective on tool-making could be applied to any artefacts which accounts for the wide appeal of the CO approach across the humanities and social sciences (see Tostevin 2011 for a summary). Of particular interest to cognitive archaeologists is Leroi-Gourhan's concern with the mental plan of the artisan as expressed through socially learned gestures of manufacture which guided the making of an object. The holism of this approach comes from its recognition of the central role of the body as the interface between mind, materiality and society, where the gestures of the tool-maker are learned through activity. This description contains the potential to form the basis of an integrated social and cognitive archaeology, based on evolutionary and lifetime changes in social, cultural and biological enablers of learning processes (Malafouris 2013; Nonaka *et al.* 2010; Overmann 2016; Shettleworth 2012; Tostevin 2011).

That potential, however, has not yet been realized, largely as a result of a narrow technical application of the CO approach by archaeologists (Bleed 2011; Soressi & Geneste 2011; Tostevin 2011). Bar-Yosef and van Peer (2009), in their review of its application in Middle Palaeolithic research, identify an over-emphasis on the definition of master reduction sequences for specific tool types at the expense of understanding individual variation.

Adherence to established classification systems can restrict understanding of variability within technological sequences by limiting options for describing technical skills and strategies for problem solving. Equifinality is squeezed out of the range of potential options for meeting a particular goal. This narrowing of analytical perspective arises from a closed-loop process in which technological end-products are the starting point from which steps of manufacture are reconstructed within the confines of a classification scheme. The tool-maker's thought processes can only be described as an initial decision about the tool-type she wishes to make, followed by memory recall as she accesses the appropriate reduction sequence and then an acting-out of the sequence without error. De la Torre & Mora (2009) stress the related tendency of the CO approach to place the unit of technological significance at the level of the group. The master reduction sequence is a combined cultural product. Individual variations by different makers are considered erratic and are not included in statistical representations. The resulting generic models of tool-making deny any personal content to underlying cognitions (Bleed 2011) and describe individual technological processes as either containing or not containing errors.

This linear CO model makes it difficult for its users to study technological and cognitive evolution. The reality is that socially situated differences in individual performance 'fuel technical change' (de la Torre & Mora 2009, 20; and see Delagnes & Roche 2005; Harmand *et al.* 2015). The viewpoint that variability is an essential component of evolutionary selection without which change cannot occur is reflected in the wider evolutionary community (Reed 1996; West-Eberhard 2003), but not by archaeological CO users (Jablonka & Lamb 2014). Current archaeological users of the model also lack Leroi-Gourhan's emphasis on the integration of mind with body during the act of making tools. The tool-making individual as an embodied participant in the process of creating the archaeological record is obscured by our focus on classifying the by-products of tool-making. A cognitivist epistemology has undermined the potential of Leroi-Gourhan's vision.

The influence of cognitivism

Descartes' (1641: Cottingham *et al.* 1999) belief in a body–mind dualism lies at the heart of modern cognitivism (Chemero 2009; Malafouris 2013; Reed 1996). Humans, like other animals, must use their bodily senses to collect information about their environment. This information is always partial and unreliable (Chemero 2009; Elman *et al.* 1996; Gibson & Pick 2003; Malafouris 2013; Roux & Bril 2005a,b; Wilson & Golonka 2013). While animals' resulting behaviours are basic and automatic in nature, humans can use their minds to store and manipulate environmental information and transform it into plans of action for the body which can then be goal directed and effective. The transformation is effected through the use of the human ability to form mental representations (Chemero 2009; Gibson 1979; Gibson & Pick 2003; Reed 1996; Wilson & Golonka 2013). Modern human cognition consists of the formation and manipulation of these symbols or intellectual concepts. The model presents cognition as entirely internal to the brain and focuses on trying to establish links between representations and neurology (Malafouris 2013). Modern cognitivists directly associate the brain and its representations with the software and hardware of computers (hence the importance of 'symbolism' in some archaeological theory: Barham 2013b).

This model results in various insuperable difficulties for CO researchers trying to understand how cognition changes through evolutionary time. Most importantly, it does not describe any way in which a hominin cognitive process can become more or less complex; there is no mechanism of change. An agent is either an animal or a modern human. This means that at some stage in evolutionary history a step-change must occur in the hominin line to account for the appearance of 'behavioural modernity' (Shea 2011). A gradual accretionary model of behavioural change is not easily accommodated in the cognitivist framework.

In terms of tool-making technology, the cognitivist model demands that any user must make a decision as to whether or not the hominin species responsible for the material record that they are dealing with was capable of forming internal representations or not. Most researchers assume that hominins can 'plan' a tool-making session by retrieving from memory the exact tool-making sequences for the particular type of tool they wish to make (but see Rogers *et al.* 2016). Any plan must be complete before execution, as it is the product of internal representations and is unaffected by environmental or embodied variability. The hominin must be aware of the full plan before acting on it and must mechanistically carry it out to perfection as originally conceived.

Cognitivist epistemology has reinforced the tendency of CO methodology users to concentrate on presenting prehistoric tools as standardized members of conceptual categories rather than as products of momentary interactions between agents and their local environments. It encourages the characterization of tool-making tasks as single conceptual units which cannot be broken down into smaller components. The cognitivist model also denies the body and its effector organs any significant role in cognitive processes and thus prohibits any useful enquiries into interactive evolutionary processes between morphology, perceptual ability and cognition (Bar Yosef & van Peer 2009; de la Torre & Mora 2009; Soressi & Geneste 2011). Finally, it inhibits any description of embodied cognition-in-action that allows for the flexible and adaptive application of learned task-structuring cognitive strategies (Wilson & Golonka 2013).

There is in fact a widespread recognition that our application of the CO approach has been flawed. There is a need for archaeologists to engage with cognitive theory and areas of applied psychological research and understand better the evolution of task-structuring cognitions (Bleed 2011; Bloch 2012; Garofoli & Haidle 2014; Soressi & Geneste 2011). Perception-action theory is a particularly valuable source of new ideas which incorporates an embodied cognition approach (Anderson 2003; Chemero 2009; Chiel & Beer 1997; Chiel *et al.* 2009; Clark 1999; Wilson & Golonka 2013). Motor activity allows increased perception of environmental factors. And perception directly informs the nature of appropriate motor responses, including the control through biological effector organs of tools (Baber 2006; Bleed 2011; Prinz *et al.* 2013).

Perception-action theory

In contrast to cognitivist theory, perception-action theory, derived from ecological psychology (Gibson 1979), describes perceptual information obtained from the environment by organisms as complete. There is no need for an internal cognitive reconstruction or for representations. Instead the organism, whether animal or human, can often react quickly and appropriately without conscious deliberation (Baber 2006; Prinz *et al.* 2013; Reed 1996; Wilson & Golonka 2013). This cognitive model offers a framework for the description of both individual and group learning processes. The correct immediate active response to variable perceptual stimuli by an organism or group of organisms has to be learned through experience or action (Lerner & Benson 2013; Prinz *et al.* 2013), and this learning process can be framed both as a lifetime (ontogenetic) process (Baber 2006; Gibson & Pick 2003; Lockman 2000; 2005; Smith & Thelen 2003; Thelen & Smith 1996; von Hofsten 2013), and as an evolutionary (phylogenetic or cultural) process (Andersson *et al.* 2014; Clark 1999; Malafouris 2013; Overmann 2016; Reed 1996).

The perception-action model renders differences between individuals both inevitable and informative. It allows the analysis of cognitive processes at a level common to primates, hominins and modern humans. Units of analysis can be set at levels that allow comparison between their different activity sequences and patterns of variation can be considered as relevant data for understanding cognitive change. Above all, the model offers multiple mechanisms of change for use by students of evolutionary developmental processes (Lerner & Benson 2013). Because the theory considers motor activity as a form of cognition-in-action, gestural performance becomes a source of information in its own right and OA becomes a possible new methodology for analysing prehistoric tool-making sequences.

Bleed (2011) identifies the importance of trying to understand cognitions related to task-structuring. As well as references to expert learning and the maintenance of consistent task context as good task-structuring strategies, he refers specifically to the potential benefit to CO researchers of understanding the term ‘affordance’. It was framed by Gibson (1979) as part of ecological psychology theory, and is a central concept in perception-action theory. Chemero (2009, 98) describes affordances as ‘aspects of the environment that guide action’. They are an interactive feature that only take on meaning as part of the environmental substrate when an organism is able to perceive them as accessible, is physically competent to take advantage of them and is motivated by some kind of goal attainment (Roux & Bril 2005a,b). Bleed (2011) points out that the presence of particular affordances, such as available rock nodules, must have helped hominins cognitively to structure technological tasks.

Significant numbers of researchers into the cognitions associated with tool-use and manufacture are now explicitly using the perception-action model (see all contributors to Roux & Bril 2005a; also Baber 2006; Bril *et al.* 2009; 2011; 2015; Nonaka *et al.* 2010; Roux & Bril 2005b; Stout 2010; 2011; Stout & Chaminade 2007; 2009; Stout *et al.* 2008; 2014; Wilson *et al.* 2016). Other authors attempting to explore interesting new ideas are constrained by their continued implicit involvement with a cognitivist framework. Rogers *et al.* (2016) use cognitivist ideas to express the difference between modern human and animal cognition and to define the kind of ‘planning’ cognition that is unique to modern humans. The bar for recognizing modern human cognition in the archaeological record is set so unrealistically high that it renders impossible any attempt to posit a gradual change between the important animal systems that they discuss and human cognition (Shettleworth 2012).

Haidle's cognigram papers (Haidle 2009; 2010; Lombard & Haidle 2012) are explicitly intended to develop Leroi-Gourhan's imperative of explaining evolved cognition through the study of tool-making sequences (Haidle 2010). She inherits a cognitivist framework from the CO tradition and also through her reliance on working memory theory (Wynn & Coolidge 2011; Wynn *et al.* 2016). Rogers *et al.* (2016) correctly identify the theoretical problems that result from this epistemological stance, although ironically it is a position that they also occupy.

It becomes clear that Haidle's nuanced understanding of changes in task structuring over evolutionary time as represented in her cognigrams ultimately allows her new insights into cognitive change. The papers contain an emerging emphasis on the 'modularity' of tasks. Haidle (2010) describes tasks as hierarchical constructions of separate units of action (Baber 2006; Barham 2010; 2013a,b). She identifies the quality of modularity as a source of increasing task complexity and flexibility over time (Lombard & Haidle 2012).

A hierarchical, modular task is not compatible with a linear CO description of tool-making. A modular task may not be a swift and simple product of a felt need of one individual (Haidle 2009). Instead, it might be an extended product of several communicating individuals or groups with different motivations and needs (Hallos 2005; Wragg Sykes 2015). Lombard & Haidle (2012) interpret the gradually increasing modular nature of tasks over evolutionary time as a proxy for gradual cognitive change. They reject a step-change model, thus challenging their original implicit epistemological position. They also state that modularity supports the increased cognitive effort of more complex task-structuring. This position looks like an unacknowledged move from cognitivism to some kind of ideomotor or perception-action cognitive theory, but the dichotomy is not explicitly resolved.

Observational analysis

OA is proposed as a new method that can bring together these disparate treatments of activity analysis and provide a common procedure based on informative theoretical foundations. It takes the form of experimental archaeology made possible by the data from accumulated CO analyses. The resulting reconstructed tool-making sequences can be thought of as a cognitive reconstruction allowing the reenactment of original thinking processes in front of an observer. The modern tool-makers involved have embodied cognitive systems containing a huge variety of specialized and perception-action-based information. They can select, sequence and adapt modules of tool-making activity (Baber 2006; Ericsson & Charness 1994; Ericsson *et al.* 1993; Paas & Sweller 2012; Russell 2011; Sinclair 2015; van Merrienboer & Sweller 2005). This reconstructed ongoing interaction between information perception, outcome prediction (Prinz *et al.* 2013) and motor activity will only become manifest if the tool-makers act within a normal framework of constraints and affordances. Controlled experiments may inhibit the expression of this highly individual and interactive process (Reed 1996).

Stout and Chaminade (2007) and Stout *et al.* (2008) argue that active networks stimulated in the brain of an Oldowan knapper are essentially the same as those used by experienced modern human knappers when striking flakes from cobbles. While modern humans have a larger cognitive capacity than the earliest reductive tool-makers, they do not make full use of it when engaged in a task demonstrably within hominin capabilities. Modern human groups are assumed here to have systems which have developed out of older hominin systems, but which have subsequently become more complex in connective architecture and potential function (Barton 2001; 2012; Damasio 2010; Edelman & Tononi 2000; Elman *et al.* 1996; Greenberg *et al.* 1999; Herculano-Houzel 2012a,b; Malafouris 2013; Shettleworth 2012).

The lead author has experience of using observational techniques as an Occupational Therapist (OT). The core skill of an OT is activity analysis (Kielhofner 2008; Parkinson *et al.* 2006; Turner *et al.* 1999). It was part of her job to assess brain-damaged patients by observing their behaviours in order to try and establish whether underlying cognitive processes were still intact. Reduced cognitive function leads to changes in action sequences in terms of goal outcome, sequence duration, sequence structure, the number of gestures employed, tool-using skills and the degree to which the observed individual is able to react appropriately when not acting within an accustomed context. The observing OT explicitly or implicitly uses a checklist of behavioural variables across all observed sequences. The level at which variables appear across tasks varies. An aim of the pilot study was to establish whether a list of pre-determined variables could be used to describe the differences between observed tool-making sequences and indicate possible underlying cognitive differences. A diagrammatic approach was also used in order to try and describe the comparative modular quality of the tasks and to establish whether transitions between

Table 1. *Behavioural variable groups.*

Behavioural Variable Groups	Example Variables
Postural	Seated, crouched
Mobility	Walking, bending down
Handling	Grip, hand differentiation
Flows and paces	Smooth transition between gestures and performance duration
Tool and object moving	Drag, lift, push, tilt
Muscle synergy	Force of blow, fix /activate muscles
Sequencing	Initiate, continue, terminate
Tool and object choice	Change tool, change object
Tool and object organization	Fetch more binding, cache good flakes
Appropriate reactions	Repair step fracture, straighten wooden shaft
Information search	Examine core surface, listen to hammer noise

modules corresponded with behavioural variable changes.

The data collected were derived from the observation of expert tool-makers who replicated tools typically associated with the long-term developmental changes seen in the African Stone Age and Eurasian Palaeolithic. The specific tools replicated included flakes struck from cobbles or chunks (Oldowan), flake-based bifaces (Acheulean), prepared flakes and hafted tools (Middle Stone Age/Middle Palaeolithic). The transition to hafted tools has been characterized as either a radical new approach to imagining, planning and making tools (Ambrose 2010; Barham 2010; 2013a; Wragg Sykes 2015), or alternatively as an incremental development (Lombard & Haidle 2012; Rogers *et al.* 2016). One of the main intentions here was to assess the potential of OA as a method for distinguishing between gradual and stepped change in the evolution of technology.

Given the multiplicity of raw materials used when making a hafted tool, the separate production processes that lie behind each of them, the lack of guarantee of a single tool-maker being responsible for all components and the extended lengths of time potentially involved (Barham 2013a; Hardy 2008; Wragg Sykes 2015), it was felt that a modular perspective was likely to be appropriate for the combinatorial tasks, but its suitability for other technologies had to be demonstrated as part of the pilot study.

A wide range of complementary theories was used to inform the selection of Behavioural Variables and the design of the Task Diagrams:

- Perception-action theory (Chemero 2009; Gibson & Pick 2003; Roux & Bril 2005a)
- Embodied and radical embodied cognitive science (Chemero 2009; Chiel & Beer 1997)
- Connectionist and dynamic theories (Bloch 2012; Elman *et al*. 1996; Greenberg *et al*. 1999; Roux & Bril 2005b; Simon 1962)
- Material engagement theory (Malafouris 2013; Overmann 2016)

Aims

The aims were to establish:

1. whether or not differences between tasks could be described using behavioural variables
2. the usefulness of each behavioural variable
3. the best method for illustrating the modular quality of tasks
4. the most useful units of analysis
5. the usefulness of theory-bases

Method

Expert tool-making activities were filmed on three separate occasions using a Samsung HMX-F90 handheld camcorder. After each filming session the footage was closely viewed. It was used to identify the presence and level of the selected behavioural variables (Table 1). This information was not formally recorded as accurate quantification of so many variables posed serious problems. The lead author drew on the relevant footage and on her experience as an OT in order to give an overall description of what she believed to be the important changes. She also used the footage to construct Task Diagrams which showed a potential modular structure for each task analysed, and behavioural variables marking the module boundaries.

Limited instructions were given to the experts in order to minimize constraints during the course of the task. They carried out the tasks in their own workshop spaces and used their own materials (Baber 2006). The Reductive Tool Maker (RTM) was asked

Figure 1. *RTM: Retouched Oldowan flake.*

Figure 2. *RTM: Acheulean biface.*

Figure 3. *RTM: Removing prepared flake.*

Figure 4. *RTM: Retouched prepared flake.*

to (a) knap an Oldowan core with several flakes and to retouch one of the flakes (Fig. 1); (b) knap a biface from a flint flake (Fig. 2); (c) prepare a core, detach prepared flakes and choose one flake for retouch (Figs. 3, 4). East Anglian flint was used for all sequences.

Both Combinatorial Tool Makers (CTMs) were asked to produce two hafted tools each. They used East Anglian flint for their inserts, either ash or hazel for their shafts and a mixture of pine resin, wax and charcoal for their adhesive. CTM(1) constructed a hafted scraper and an arrow (Figs. 5, 6) and used dried, twisted flax for binding (Fig. 7). CTM(2) constructed an atlatl spear and another arrow (Figs. 8, 9) and used strips of wretted lime bark as binding.

OTs use a wide range of different behavioural variables during observation and therapy sessions. Their variation is not quantified during sessions but is summarized afterwards. Table 1 shows the behavioural variable groups that were used when analysing the footage.

Postural, mobility, tool and object moving, tool and object choice, and tool and object organization variables

The contents of these groups should be self-explanatory. The observer looked to see if and why their presentation changed in frequency. It was thought likely that increases in these variables would be connected with an increased need for perceptual

Figure 5. *CTM(1): Hafted scraper.*

Figure 6. *CTM(1): Arrow(a).*

Figure 7. *CTM(1): Twisting dried flax into twine.*

awareness, accurate responses, self-organizing and tool-handling skills.

Handling variables
An increase in frequency of grip change is an indicator of increasing task complexity. This group also includes variations in the extent to which the tool-maker differentiates the roles of each hand (handedness). Recent literature suggests that this is not an inherited genetic feature, but rather a developmental product of the increasingly complex tasks that we have undertaken regularly through ontogenetic and evolutionary time (Corbetta 2005; Hill & Khanem 2009; Mosquera *et al.* 2012; Steele & Uomini 2005; Uomini 2009).

Figure 8. *CTM(2): Atlatl spear (no adhesive).*

Figure 9. *CTM(2): Arrow(b).*

Flows and paces
Flow describes the smoothness of transition between gestures. It tends to be inversely related to the levels of information search and hesitation present. Pace usually corresponds with increased flow, and thus with a lack of need to search for information. Both flow and pace are more present where gestures are rhythmically repeated. Rhythmical repetition may represent a type of gesture that requires reduced cognitive effort (Sakai *et al.* 2004; Schaal *et al.* 2004; Thelen 1979; 1981).

Muscle synergy variables
This group contains important variables that are only partially observable through postural and handling

variables. They include calibration, and other combinations of musculoskeletal interactive elements that allow controlled tool-use (Biryukova & Bril 2008; Biryukova *et al.* 2005; Bril *et al.* 2009; 2011; 2015; Hadders-Algra 2002; Ivanova 2005; Nonaka *et al.* 2010; Parry *et al.* 2014; Rein *et al.* 2013; Williams *et al.* 2014).

Sequencing variables

This group contains variables used to create modules. The cognitive ability to initiate is specific and can be lost through brain damage, as can the attentional abilities involved in maintaining ongoing activity and terminating it appropriately (Grieve 1993).

Search for information and appropriate reaction variables

Perception, or information-gathering, is an ongoing activity throughout all tasks alongside motor activity. It was assumed that it should be observable, as should the appropriate reactions provoked by the perception of events that had changed the affordance layout (Chemero *et al.* 2003). Information search is easiest to observe in its visual form, but aural and haptic processes can also be observed. It was assumed that information search would correlate negatively with flows and paces and positively with increases in all of the other groups.

Task diagrams

Task diagrams were drawn to show to what extent each task could be broken down into units with clear boundaries (Task Stages). Each Task Stage was further divided into Action Sets consisting of grouped similar gestures, for example, the Oldowan task diagram (Table 2), which has three coloured blocks marking Task Stages. The horizontal divisions within each colour block mark Action Sets. The left-hand column of the diagram shows the type of gestures being used. Single gestures were not judged to be meaningful units of analysis where so much repetition was involved, but it would be possible to subdivide the Action Sets further into 'Actions'. The right-hand column shows how changes in behavioural variables correspond to Action Set and Task Stage divisions. It also contains a description of the affordance that allowed the tool-maker to move from one Action Set to another.

Results

Changes for each group of variables across all tasks are summarized below. The usefulness of variable groups in describing change across different task-types is confirmed. Each group was assessed in terms of whether or not it was sensitive enough to show changes between every task type (gradual change), or whether it could only be used to show change between reductive and combinatorial technologies (step change).

Postural variables

These were highly predictable for the Reductive Tool Maker (RTM). A seated knapping posture was maintained throughout each task and standing was only observed at the beginning and end of tasks. For the Combinatorial Tool Makers (CTMs) a seated posture was common, but varied more due to changing muscle synergies provoked by different gesture and tool types. Both CTMs mobilized during tasks and their posture often changed at the boundaries between different Action sets. Across both reductive and hafted tasks postural variables only showed a step change at the transition to hafted tools.

Mobility variables

This group changed in the same way. The RTM only mobilized at the beginning and end of tasks. Both CTMs mobilized at the boundaries of Action Sets in order to organize new objects or tools.

Handling variables

The RTM's grip types remained constant. The only tools were hammerstones, so the hand grips only changed with tool and object size. Until the object being knapped became small, it was balanced on the left thigh in a cup grip. Small objects like points were held freehand in a pinch grip. When searching for information on the large boulder (Table 3), the RTM had repeatedly to put down his hammerstone in order to use both hands for manipulation. Otherwise visual information search was effected by moving the non-dominant hand.

The CTMs' grip types varied constantly as a wide range of tools requiring specific grips was used for each task and objects varied in terms of size and rigidity. A change in this group was essential at every Action Set boundary and even during Action Sets. However, this group was thought to have the potential to indicate gradual change (see choice of tool and object group below).

Flows and paces

The RTM's Oldowan task was audibly rhythmic with a high level of flow. These qualities were affected during the Biface task by the need to deal with the poor quality of the raw material resulting in information search and hesitation. Loss of both variables increased during the Prepared Core task as more time was taken up searching for information to inform the next flake

Table 2. *RTM: Oldowan core and flakes.*

Oldowan Core and Flakes	Tools Objects and Final Affordances
Mobilize; choose raw material	Medium hs and core
Mobilize; assume seated posture	Hammerstone & raw material stable
Tilt core to search	Suitable area located visually
Prepare striking platform, tap, strike	Flake detached
Assess flake visually and haptically	Keepers stored separately
Repeat previous 3 action sets as a unit until end of Stage	Enough keepers collected (6) Put down medium hs Put down core
Select flake for retouch	Flake
Retrieve small hammerstone	Small hs Hammerstone and flake stable
Small unifacial removals from ventral side around perimeter	Retouch completed Hammerstone and flake put down

removal. The CTMs displayed rhythmic flow during reductive Action Sets such as wood shaving or knapping; however, the variables were lost during Action Sets concerned with haft creation.

Durations (pace) for the reductive tasks were taken as follows:

Oldowan	Reduction 3.17 mins	Retouch 1.22 mins	Total 4.39 mins
Acheulean	Reduction 8.25 mins	Retouch 4.26 mins	Total 12.51 mins
Preformed	Reduction 10.04 mins	Retouch 6.04 mins	Total 16.08 mins

This group was judged to be an indicator of gradual change.

Object moving variables

This group co-varied with Mobility Variables and tool and object choice and organization. It was felt that results from this group could be incorporated into the tool and object choice results.

Muscle synergy variables

These could not be directly observed and changes had to be inferred from postural changes, changes in tool and object choice, handling variables and calibration changes. It was decided to retain this group despite its lack of immediate observability, because it provided a good link with significant bodies of work by other authors (see Method, above). The group was judged to be an indicator of gradual change.

Sequencing variables

The increasing need to use initiation and termination skills through a task and the increasing need to maintain attention for longer periods are linked to increasing numbers of Action Sets and tool changes. This group was judged to indicate gradual change.

Choice of tool and object

For the CTMs, each new Action Set required a new tool, and tool changes also occurred within Action Sets. Even where the same debitage flake was used on several occasions, it was used differently or retouched in relation to a new Action Set.

Although the reductive tasks did not present much variability in this group, it was felt that this was slightly unusual. No thinning processes were carried out which might have required the use of a soft hammer, and a separate abrading tool for platform preparation was not used throughout the Biface and Prepared Core tasks. It was decided that this group and the handling variable group had the potential to indicate gradual change.

Organisation of tools and objects

It was decided that this group was adequately represented by the choice of tool and object group above.

Appropriate reaction variables

Within a perception-action framework it is important to identify gestures performed in response to an unexpectedly altered layout of affordances. Appropriate reactions were present in the reductive tasks, such as when a step fracture occurred or the biface flint turned out to be of poor quality. They were observed more frequently during combinatorial sequences. With the increased number of raw materials and processes there was simply more that could go wrong, more to monitor, and a wider number of alternative responses to choose between.

Table 3. *RTM: flake biface.*

Biface	Tools, Objects and Final Affordances
Mobilize; choose raw material	Core
Mobilize; assume seated posture	Core stable
Two-handed lift boulder view full surface	Suitable area located visually
Retrieve large hammerstone	Large hs Hammerstone & raw material stable
Tap identified area with hammerstone	Suitable area located aurally
Strike	Flake detached
Repeat previous 4 actions sets as a unit until end of Stage	Core correct size and shape Put down large hs
Retrieve medium hammerstone	Medium hs Hammerstone & core stable
Tilt core to search for suitable area	Suitable area visually located
Prepare striking platform, tap, strike	Flake blank detached
Assess flake visually and haptically	Keepers stored separately
Repeat previous 3 action sets as a unit until end of Stage	Enough keepers collected Put down core Put down medium hs
Select flake for biface blank	Flake blank
Retrieve small hammerstone	Small hs Hammerstone and flake blank stable
Bifacial removals around perimeter	Small regular shape achieved

Table 4. *RTM: prepared core and flakes.*

Prepared Core and Flakes	Tools, Objects and Final Affordances
Mobilize; choose raw material	Core
Mobilize; assume seated posture	Core stable
Retrieve medium hammerstone	Medium hs Hammersone and core stable
Tilt core to search for suitable area	Suitable area located
Tap identified area with hammerstone	Suitable area aurally located
Prepare striking platform, tap, strike	Flake detached
Repeat previous 3 action sets as a unit until end of Stage	Potential preformed flake identified as ready for removal
Prepare platform and strike	Preformed flake detached
Alternate between 2 previous Stages (core preparation and preformed flake removal)	Enough preformed flakes detached (5) Put down core Put down hammerstone
Select preformed flake for retouch	Flake
Retrieve small hammerstone	Small hs Hammerstone and flake stable
Small unifacial removals from ventral side around perimeter	Small point completed

Search for Information

This group is also directly linked to the perception-action model. Information search became more intrusive across the reductive tasks and particularly during hafting task Action Sets concerned with bringing cleft, insert, binding and adhesive together. For CTM(2)'s tasks, assembly Action Sets became recursive as active gestures were followed by marked information search and subsequent adjustment several times over. Both this group and the appropriate reaction group were deemed to show gradual change.

Table 5. *CTM(1): Parallel production of a Hafted scraper and Arrow(a).*

Parallel Hafted Scraper and Arrow(a) Sequences	**Tools, Objects and Final Affordances**
Mobilize; choose raw material Mobilize; assume seated posture	Blade core Blade core stable
Tilt blade core to search for suitable area	Suitable area located visually
Retrieve soft hammer	Soft hammer Hammer and blade core stable
Prepare striking platform, strike and cache blade Repeat Action Set several times	Several blades detached Put down soft hammer Put down blade core
Retrieve small hammerstone	Small hammerstone Blade and hammerstone stable
Retouch flint blade unifacially from ventral side around perimeter	End scraper completed Put down small hs and end scraper
Retrieve prepared wooden shaft; assess visually and haptically	Wooden shaft Assessed as appropriate for the task
Retrieve debitage blade	Debitage blade Wooden shaft and blade stable
Use debitage blade to clear nodules and trim proximally	Area designated is clear
Retrieve soft hammer (bone)	Soft hammer Soft hammer, blade and shaft stable
Insert lateral edge of debitage blade into distal end of shaft and hammer in with soft hammer	Cleft long enough Put down debitage blade and hammer
Retrieve scraper insert	Insert Handle and insert stable
Place insert into cleft and assess visually and haptically	Scraper blade held in place by cleft
Mobilize; retrieve length of prepared twine	Twine Incomplete tool and twine stable
Bind twine tightly around distal part of cleft	Haft strongly bound Put down incomplete tool
Mobilize; retrieve two unprepared dried flax strips	Flax strips Flax strips stable
Use specific binding technique to create length of twine	Length of twine completed Put down twine
Retrieve blade debitage and assess visually	Blade debitage Assessed as appropriate for insert
Retrieve small hammerstone	Small hammerstone Blade debitage and hs stable
Retouch debitage unifacially from ventral side along one lateral	Small point completed Put down small point
Retrieve prepared shaft and assess visually and haptically	Wooden shaft Slight deviation from the straight
Gently bend shaft in direction to opposite to deviation and re-assess	Slight deviation persists
Repeat previous action set until end of Stage	Shaft assessed as straight

Table 5. (Continued)

Parallel Hafted Scraper and Arrow(a) Sequences	Tools, Objects and Final Affordances
Retrieve debitage blade	Debitage blade Blade and shaft stable
Strip bark from entire length of shaft using dorsal side of debitage blade	Designated area clear
Retrieve soft hammer	Soft hammer Soft hammer, blade and shaft stable
Insert lateral edge of debitage blade into distal end of shaft and gently hammer in with soft hammer	Cleft created Put down blade and soft hammer
Retrieve point	Insert Insert and shaft stable
Place insert into cleft and assess visually and haptically	Insert held in place by cleft
Mobilize; retrieve length of twine	Twine Twine and incomplete tool stable
Bind twine tightly around cleft	Haft strongly bound Put down incomplete tool
Mobilize; retrieve gas ring and match box	Match Striking surface Gas ring Match, striking surface and gas ring stable
Strike match and apply flame to gas ring	No flame Remove gas cylinder and dead match
Mobilize; replace gas cylinder and re-light repeating Action Set above with new match	New gas cylinder New match Flame
Mobilize; retrieve pan of solid adhesive and place over flame – repeatedly assess visually, haptically and using sense of smell	Pan of solid adhesive Adhesive melted
Mobilize; retrieve goose feather and incomplete tool	Goose feather Incomplete tool Feather and incomplete tool stable
Use feather to spread melted adhesive over bound area of scraper	Bound area fully covered Put down goose feather
Assess adhesive coverage visually	Excessive coverage
Retrieve piece of hide	Hide Hide and incomplete scraper stable
Pass incomplete scraper over flame and wipe excess adhesive onto piece of hide	Coverage appropriate Put down complete scraper Put down hide
Mobilize; retrieve goose feather and incomplete arrow	Goose feather and incomplete arrow Feather and incomplete arrow stable
Use feather to spread melted adhesive over bound area of arrow	Coverage appropriate
Use feather to spread melted adhesive between shaft and insert – assess visually	One shoulder of haft protrudes too far Put down goose feather
Retrieve debitage blade	Debitage blade Blade and incomplete arrow stable
Use debitage blade to press protruding shoulder of haft inwards – assess visually and haptically	Aerodynamic shape achieved Put down debitage blade and complete arrow
Mobilize; turn off gas ring	No flame

Table 6. *CTM(2): Arrow(b).*

Arrow(b) Sequence	Tools, Objects and Final Affordances
Retrieve existing flint point and assess visually and haptically	Point too large for arrow insert
Retrieve antler tine and hide pad	Antler tine Hide pad Pad, tine and point stable
Pressure flake to create smaller point	Point appropriate size for arrow Put down pad and tine
Tilt point to visually assess	Distal end too wide for hafting
Retrieve antler tine and hide pad	Antler tine Hide pad Tine, point and pad stable
Thin the base	Appropriate size and shape for insert Put down pad, tine and insert
Retrieve debitage flake and shaft	Debitage flake Shaft Flake and shaft stable
Use two hands on flake to scrape bark off entire shaft and remove bud points – visually and haptically assess	Shaft devoid of bark and feels smooth Put down flake
Retrieve sharp piece of flint rubble	Flint rubble Flint rubble and shaft stable
Taper distal end of shaft to encourage aerodynamic shape in haft	Sufficient wood removed Put down flint rubble and shaft
Retrieve debitage flake and assess non-working edge haptically	Debitage flake Debitage flake has non-working edge sharp enough to cut flesh
Retrieve flint rubble	Flint rubble Debitage flake and flint rubble stable
Use flint rubble piece to dull non-working edge of debitage flake and re-assess haptically	Debitage flake backed Put down flint rubble
Retrieve shaft	Shaft Backed flake and shaft stable
Push backed flake into distal end of shaft	Backed flake partially inserted
Retrieve flint rubble	Flint rubble Flint rubble, shaft and backed flake stable
Use rubble to hammer backed flake in further	Cleft created Put down rubble and backed flake
Retrieve insert	Insert Insert and shaft stable
Put insert in cleft and assess visually and haptically	Cleft acts as secure vice but more tapering needed Put down insert
Retrieve backed flake	Backed flake Backed flake and shaft stable
Continue to taper distal end of shaft using slow controlled strokes and assess visually	Distal end of shaft tapered further Put down backed flake

Table 6. (Continued)

Arrow(b) Sequence	Tools, Objects and Final Affordances
Retrieve insert	Insert Insert and shaft stable
Put insert into cleft – assess visually and haptically	Insert being pushed more strongly by one side of haft than by other side Put down insert
Retrieve backed flake	Backed flake Backed flake and shaft stable
Reduce one side of the haft	Both sides of haft appear equal Put down backed flake
Retrieve insert	Insert Insert and shaft stable
Put insert into cleft – assess visually and haptically	Point secure in haft Put down incomplete tool
Mobilize; retrieve gas ring, match and striking surface	Match Striking surface Gas ring Match, striking surface and gas ring stable
Strike match and put lit flame to gas ring	Flame
Mobilize; retrieve pan of solid adhesive and place over flame – assess visually, haptically and using sense of smell	Adhesive not melted
Leave adhesive to melt	Flame and pan of adhesive stable
Mobilize; retrieve strips of wretted, dried lime bark	Wretted lime bark strips Wretted bark stable
Split wretted bark into narrow bands	Strips completed Put down strips
Mobilize to heating adhesive and retrieve stick	Stick Stick stable
Assess adhesive visually, haptically and using sense of smell	Adhesive melted
Retrieve shaft	Stick and shaft stable
Use stick to apply melted adhesive to distal end of shaft	Sufficient adhesive applied Put down stick
Retrieve insert	Insert Shaft and insert stable
Put insert into cleft and apply pressure to close cleft while moulding adhesive around point	Haft tightly closed and covered in sticky adhesive
Mobilize; retrieve wretted bark strips	Wretted bark strips and incomplete arrow stable
Bind over adhesive to tightly constrain haft	Haft stable
Pass bound area of arrow over flame to remove binding hairs	Haft smooth
Retrieve stick	Stick and incomplete arrow stable
Use stick to apply melted adhesive over binding	Adhesive applied evenly over binding Put down stick
Manually shape adhesive aerodynamically – assess visually and haptically	Haft completed Put down arrow
Mobilize to turn off gas ring	No flame

Table 7. *CTM(2): Atlatl spear.*

Atlatl Spear Sequence – No Adhesive Stages	**Tools, Objects and Final Affordances**
Mobilize; retrieve long wooden shaft	Shaft Shaft not stable
Mobilize; retrieve flat piece of broken stone and place it on open ground	Flat stone Flat stone stable
Prop shaft upright on flat stone and hold steady with one hand	Shaft stable Put down shaft
Mobilize; retrieve large debitage flake and return to flat stone	Large debitage flake Flat stone Shaft Stone, shaft and flake stable
Crouch to hold shaft near base with one hand, strip distal end and taper it with flake in other hand	Stripping completed and some tapering completed Put down large debitage flake
Mobilize to chair and assume seated posture	Shaft stable
Retrieve small debitage flake	Small debitage flake Shaft and small flake stable
Use small flake to finish tapering using slow movements controlled by both hands	Tapering shaft completed Put down shaft
Assess small debitage flake visually and haptically	Non-working edge sharp enough to cut flesh
Retrieve large debitage flake	Large debitage flake Small and large flakes stable
Use large debitage flake to back small debitage flake and assess non-working edge of small flake haptically	Non-working edge blunted Put down large debitage flake
Retrieve shaft	Shaft Shaft and backed flake stable
Push backed flake into distal end of shaft using small slicing movements	Backed flake held in cleft to half of its depth
Retrieve large debitage flake	Large debitage flake Shaft, backed flake and large flake stable
Use large flake to hammer backed flake further into cleft	Backed flake fully inserted in cleft Put down large flake
Visually assess depth of cleft	Cleft created Put down backed flake
Retrieve wooden splinter	Wooden splinter Wooden splinter and shaft stable
Put wooden splinter into cleft as a wedge – visually assess cleft	Cleft held open and depth of cleft controlled
Retrieve pre-prepared lanceolate point	Insert Put down wedge
Put insert into cleft – visually assess cleft	Cleft at optimal depth for point but has twisted slightly around shaft Put down insert
Visually assess cleft	Further tapering required
Retrieve backed flake	Backed flake

Table 7. (Continued)

Atlatl Spear Sequence – No Adhesive Stages	**Tools, Objects and Final Affordances**
	Backed flake and shaft stable
Use backed flake to taper distal end of shaft	Tapering completed Put down backed flake
Retrieve insert	Insert Insert and shaft stable
Put insert into cleft and visually assess ability of tapered points of cleft to hold point	Points not aligned due to twist in cleft
Manually alter alignment of cleft points so that they are parallel with each other and hold	Haft stable
Retrieve two strips of wretted lime bark and use side by side	Wretted lime bark strips Haft and wretted bark stable
Bind double strand of lime bark around haft – assess stability of haft visually and haptically	Haft stable and bound Put down completed tool

Task diagrams: Reductive Tool Maker

The Oldowan task has three Task Stages (Table 2), while the Biface (Table 3) and Prepared Core (Table 4) tasks each have four. The internal repetition within each Action Set is not well defined by the diagrams, but they show repetition of entire Action Sets for all tasks and alternation between them for the Prepared Core. The latter task took 16 minutes and 8 seconds compared with 12 minutes and 51 seconds for the Biface. The diagrams are not detailed enough to provide reasons for this duration difference.

The number of tools used stays relatively constant. Tools and objects often change at the boundaries of Task Stages, but there is only ever one object and one tool in use. All three sets of Task Stages can only be performed in one order. Cognitions associated with task-structuring may not be highly challenged. Some flexibility of sequencing may be present within the Action Sets, but this is not shown in the diagrams.

Affordances allowing transition are generally closely related to physical characteristics of the core being worked in all three tasks. A less obvious kind of affordance-detection is required for the selection of an appropriate flake for retouch.

Task diagrams: Combinatorial Tool Makers

CTM(1) made two tools in parallel (Table 5) so as to avoid repetition of the adhesive stage. The five Task Stages concerned with the Hafted Scraper are in two shades of pink while the seven Task Stages for Arrow(a) are in blue and green. The two adhesive preparation Task Stages are white. The number of Task Stages per tool is thus seven for the Hafted Scraper, and nine for Arrow(a). The increased number of combinatorial Task Stages over reductive tools is due to an increased requirement for different Action Set types. CTM(1) does not repeat Action sets recursively which is reflected in his later comments that he intended to demonstrate how quick and simple hafting can be. Effectively he prioritised pace over reliability.

CTM(2)'s arrow (Table 6) takes thirteen Task Stages, while his Atlatl spear (Table 7) only takes five. He did not apply adhesive to the spear haft. There is also a markedly recursive element to the haft creation stage of Arrow(b), as compared with the Atlatl spear, which resulted in extra Action Sets. It is likely that CTM(2) balanced the relative requirements of tool reliability and pace differently from CTM(1), especially in relation to Arrow(b).

In all sequences tool and object changes occur at every Action Set boundary. There is often more than just one tool and object pair in use. This means a wider range of specific gestural types and of affordance-detection skills. All behavioural variable groups change in some way along with every change of tool and object, and these variations frequently self-organize around Action Set boundaries.

The Task Stage sequence is more flexible for combinatorial tools than for reductive tools. Preparatory Task Stages can be done in any order desired and the sequence only becomes fixed with haft creation, insert placement and subsequent haft-securing. Increased sequencing flexibility requires increased planning, but allows greater adaptiveness in the face of varying constraints.

There is a potentially gradual change in the nature of affordances being used to move between Action Sets and Task Stages which requires further investigation. Increasingly the tool-maker does not just take advantage of existing affordances, but creates them as well.

Discussion

The question being asked by this initial OA was what the best parameters might be for designing future observational analyses of tool-using behaviours. We used a dual approach of a behavioural variable analysis together with Task Diagrams showing the division of the tasks into Task Stages and Action Sets. The behavioural variable changes dove-tailed well with the modular structure shown by the Task Diagrams. The combined approach provided a holistic view of the tasks, although there was a significant lack of detail about the content of individual Action Sets.

It was established that six of the behavioural variable groups would be sufficient for future analyses. They were those sensitive enough to provide information about gradual change between tasks:

Handling variables
Flows and paces
Sequencing variables
Choice of tool and object
Appropriate reaction variables
Search for information variables

In relation to establishing the best units of analysis, it was decided that a complete-task unit was unsustainable. Local variations in constraints and affordances, individual experience and cultural background all contribute to inherent variability which is not necessarily the result of differences in cognitive function. Even during the OA executed here, the RTM used differently sized pieces of flint left over from previous knapping sequences (resource scarcity) and so the time spent reducing the raw material varied significantly between sequences. In respect of the biface his initial intention was to produce a handaxe, but the poor quality of the flint prevented its completion.

CTM(1) made two hafted tools in parallel and thus carried out only one task unit. After binding Arrow(a), he started on the scraper and then applied adhesive to both at the same time (economy of effort). CTM(2) applied adhesive to Arrow(b), but not to the Atlatl spear (resource scarcity). CTM(1) prepared his insert by removing blades off a pre-prepared blade core (planning). CTM(2) re-used two points—one had to be lengthily pressure-flaked (resource scarcity). CTM(1) had enough prepared twine to use on the scraper, but had to prepare more twine before he could bind Arrow(b). CTM(2) had enough prepared lime-bark for both tools. In the case of the binding and adhesive for both CTMs, lengthy but different back-processes of preparation were involved which were not assessed at all in this study (planning). Finally, CTM(2) was more recursive in the modules concerning haft preparation than CTM(1) (economy of effort *versus* tool reliability).

It was, however, considered that there were benefits in retaining both Task Stages and Action Sets as units of analysis and cross-task comparison.

All observations using this approach were found to be consistent with perception-action theory and an embodied approach. Increased task complexity was accompanied by more information search and increased variability of muscle synergies and physical gesture. Tool-makers appeared to be involved in a clear in-task perceptual assessment of events and selected the next appropriate Action Set type as appropriate in the moment.

Based on this pilot study, we recommend future adjustments to the OA methodology to extend its applicability and reliability. A larger number of sequences should be filmed and analysed in order to increase information on variability across tasks and through evolutionary time. The content of each Action Set should be recorded in greater detail so that analyses of differences across tasks can be more robust and quantified. Analyses should focus more on a precise identification of the behavioural variable changes which reflect changes in task-structuring strategies. The boundaries between Action Sets and Task Stages are of particular interest in terms of revealing continuities and changes in cognitive strategies. These transitions and the affordances that make them possible also warrant closer attention in future studies.

Conclusion

Despite the limited number of individuals observed, it is possible to use these data to outline a cognitive process that changes over the time-period represented by the tasks attributed to the Early to Middle Stone Age (Lower to Middle Palaeolithic).

We posit a foundational cognitive system that is reliant on a store of modular motor sequences whose appropriate selection in the moment and consequent adaptation is a learned skill. Basic tasks are rigid in their construction, but we see an increasing development of modular groups of Activity Sets that are sequenced and adapted in response to local affordances and constraints. Their structure is defined by familiar contextual elements, repetition and rhythmic action. Over time the ability to add in new Task Stages, Action Sets, tools and objects increases flexibility and possibly triggers the development of new task-structuring skills. Affordance-detection and tool-use skills are initially limited, but begin to be challenged as the tasks change internally. It is possible that manual dexterity and the need for hand-use differentiation increase as a result.

With the emergence of hafted tools, this gradual change reaches the point where the preparatory as opposed to assembly-stage modules are independent units. They need to be sequenced anew for each task and might be carried out by different individuals across potentially wide gaps of time. The load on task-structuring skills is now much higher and context, rhythm, repetition and limited affordance-detection no longer suffice. More sophisticated affordance-detection skills become necessary and planning skills at individual and group levels are required.

Our preliminary results show the value of using loosely structured experimental observations to document the real-time flow of action sequences at the level of the individual, from which more general patterns of cognitive change can be inferred and subsequently more rigorously tested. The integration of OA with perception-action and embodied cognition theory allows for the study of cognitive processes at a level common to primates, hominins and modern humans. Gestural performance as an important source of information links well with Leroi-Gourhan's vision of integrating mind and body in the study of the evolution of technology and society.

Cognitivist theory is well-entrenched in current analytical approaches including applications of the CO methodology. It offers an accessible understanding of artefacts as symbols or tightly-packed ciphers which, if read properly, might yield information about the concept-forming abilities of their makers. Newer cognitive models, however, describe cognition as something more complex, harder to grasp and more difficult to assess archaeologically. Our thought processes are the product of an ongoing dynamic interaction with a wide range of other variables also in the process of constant change, such as ecological substrates, social, physiological and cultural structures, all of which collectively modulate behaviours. For these reasons, we need a more holistic theoretical and methodological approach to the study of cognitive evolution which recognizes the complexity of the contexts in which tools are planned, made and used. This pilot study is an attempt to initiate a different perspective that treats artefacts as 'screen shots' of lost processes of cognition-in-action. The challenge ahead is to develop robust experimentally based methods to recreate and analyse those processes.

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Joanna E. Fairlie
Department of Archaeology, Classics & Egyptology
University of Liverpool
Liverpool L69 3BX
UK
hsjfairl@liv.ac.uk

Lawrence S. Barham
Department of Archaeology, Classics & Egyptology
University of Liverpool
Liverpool L69 3BX
UK
l.s.barham@liv.ac.uk

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Author biographies

Joanna Fairlie is a PhD candidate at the University of Liverpool with a particular interest in human cognitive evolution. She is a trained Occupational Therapist with specialist expertise in the neurological rehabilitation of patients suffering from brain damage. She has a MSc in Palaeoanthropology from the University of Liverpool.

Lawrence Barham is Professor of African Archaeology at the University of Liverpool. He has long-standing interest in the archaeological evidence for behavioural change in the Middle Pleistocene. The invention of hafting is the focus of *From Hand to Handle: The first industrial revolution* (Oxford University Press, 2013).