Special Issue: Innovation and the Evolution of Human Behavior
Introduction

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ABSTRACT
This special issue of PaleoAnthropology concerns innovation and evolution. It contains seven contributions:
- MacDonald, K.: Introduction
- Coward, F. and Grove, M.: Beyond the Tools: Social Innovation and Hominin Evolution
- Kyriacou, A. and Bruner, E.: Brain Evolution, Innovation, and Endocranial Variations in Fossil Hominids
- Haidle, M.N. and Bräuer, J.: From Brainwave to Tradition—How to Detect Innovations in Tool Behavior
- Rugg, G.: Quantifying Technological Innovation
- Rugg, G. and Holland, N.: Quantifying Novelty in the Archaeological Record
- Gowlett, J.A.J.: The Vital Sense of Proportion: Transformations, Golden Section, and 1:2 Preference in Acheulean Bifaces

The "Innovation and Evolution" workshop was held at the Centre for the Archaeology of Human Origins, University of Southampton, United Kingdom; workshop papers guest edited by Hannah Fluck (University of Southampton; and, Landscape, Planning and Heritage, Hampshire County Council), Katharine MacDonald (Faculty of Archaeology, University of Leiden), and Natalie Uomini (School of Archaeology, Classics and Egyptology, University of Liverpool). This is article #1 of 7.

ORIGINS AND AIMS OF THE SPECIAL ISSUE

This special issue has its origins in a workshop of the same name held at the Centre for the Archaeology of Human Origins, University of Southampton, UK. This workshop brought together researchers in a range of disciplines, including primatology, archaeology, the computer sciences, neuropsychology, and developmental psychology, with experience in studying skill learning in relation to material culture. Based on the interdisciplinary dialogues that began with this workshop, and the research questions highlighted there, the aim of this special issue is to enhance current understanding of the role of innovation, and specifically innovation in material culture, in human evolution.

DISCIPLINARY CONTEXT

According to Renfrew (1978: 89), 'Innovation, the development or introduction of what is new, is evidently a process whose understanding is fundamental to the study of society and especially of change.' Archaeologists have been attempting to deal with innovation for a correspondingly long time, and the concept of innovation continues to be invoked to describe or explain change and variation in material culture. Given the importance and long history of research on this topic, work focusing on innovation is remarkably scarce. Innovation and the related topic of creativity have been addressed in a number of edited volumes (Mithen 1998a; O'Brien and Shennan 2010; van der Leeuw and Torrence 1989). The volume edited by Mithen identified a need to address this subject, because archaeologists had neglected to take into account the role of social and economic contexts in innovation (as pointed out by Renfrew ten years earlier), because archaeologists had devoted limited thought to defining the concept(s), and because research on innovation in other disciplines neglected evolutionary questions. These points are still valid and the contributions to this special issue take further steps to address these problems.

The recent volume edited by O'Brien and Shennan (2010) takes an evolutionary approach and addresses the concept of innovation specifically in the context of studies of cultural transmission, so there is an emphasis on the processes by which innovations spread and are maintained, and methods are dominated by mathematical modelling. The earlier volume edited by Mithen (1998) focused on creativity, a concept which overlaps with innovation, with the aim of contributing to the development of cognitive archaeology. Going back another decade, the volume edited by Torrence and van der Leeuw (1989) was dominated by later prehistory and also included anthropological perspectives. This special issue addresses the relatively broad concept of innovation, with a focus on material culture, covers both the factors influencing the generation of novel ideas and the process by which they are adopted and transmitted in time and space (detailed definitions follow below), and addresses questions about human evolution.

As Mithen (1998) points out, evolutionary questions need to be tackled in order to fully understand human cognition and behavior, including innovative behavior. Ideas

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about innovation are important in debates on the origins of modern humans and the fate of the Neandertals (see, for example, papers in Hovers and Kuhn 2006). While the transitions from the Middle to Upper Paleolithic and Middle Stone Age to Late Stone Age generally are viewed as involving dramatic changes, it remains necessary to examine exactly how different and distinct the behavior involved was, and whether this was preceded by changes within the earlier periods. This requires a clear concept of what constitutes a significant change and a reproducible means of describing innovation, examples of which are presented in this special issue. In addition, some of the changes in the record (particularly technological changes) are sometimes interpreted as reflecting underlying human capabilities including a capacity for behavioral, social, and technological innovation (e.g., McBrearty and Brooks 2000). Such cognitive hypotheses raise a number of questions, demanding input from related disciplines. What are the neurological bases for the human capacity for innovation? Do these capacities differ from that of other primates and in what ways? However, other factors may play a role in the continuity and accumulation of innovation in the Middle Paleolithic period, such as demographic processes (Hovers and Belfer-Cohen 2006), and these also should be explored.

As Mithen (1998b) emphasizes, we would like to know whether creative thought among anatomically modern humans is the same as that among early humans, such as *Homo erectus*. While few studies explicitly address innovative capacity in early humans, and the relatively simple technology and poorer preservation of the archaeological and fossil record makes this a challenging task, there are a number of exceptions (de Beaune 2004; Lake 1998). Ideas about innovation are also important in a number of research topics in Lower Paleolithic archaeology. These include the context in which stone tool manufacture and use developed and was adopted; the timing and nature of range expansion; the selective pressures favoring brain expansion and increased behavioral flexibility in the hominin lineage; and, stability and variation in Acheulean bifaces.

Archaeologists have turned to other disciplines for insights into the cultural and social factors influencing the frequency and spread of innovation, as is clear from the multiple disciplines represented in edited volumes on this topic (Mithen 1998a; O'Brien and Shennan 2010). The social sciences have been particularly influential (see, e.g., Haidle and Bräuer this volume, Coward and Grove this volume). As Mithen (1998b) points out, anthropologists can provide important insights into creativity and innovation in non-western societies. Recent interest in innovation by researchers studying animal behavior may provide useful concepts and comparative data (Ramsey et al. 2007; Reader and Laland 2003a). In particular, study of the primates provides insights into the evolution and nature of innovation within the primate order, including *H.sapiens* (e.g., Reader and Laland 2002; van Schaik and Pradhan 2003). Fieldwork and experiments with living primates provides more, and different, information about innovation, including innovation in tool use (Kummer and Goodall 2003), and could be a valuable supplement in our interpretation of the archaeological record.

In this special issue, relevant disciplines are represented which were absent in previous edited volumes, specifically paleoanthropology and computer science. According to Kyriacou and Bruner (this volume), improvements in methods and theory in cognitive neuroscience have improved understanding of the cognitive processes involved in complex behavior such as creative thinking. Paleoanthropological studies of cranial morphology can provide insights into changes in the spatial organization of the brain (e.g., Bruner and Holloway 2010). The benefits of combining these two fields, in order to gain insight into the evolution of human cognitive capacities for innovation, are demonstrated in the article by Kyriacou and Bruner in this volume. The fossil record also provides evidence for changes in hominin life history, which may have influenced the opportunities available for innovation and transmission (see Coward and Grove, and Kyriacou and Bruner, this volume). In mathematics and information science, methods have been developed for measuring and comparing complexity and quantifying innovation, which may be of value to archaeologists, and a number of these methods are presented by Rugg, and Rugg and Holland, in this special issue. Finally, archaeology itself provides the primary evidence for innovation prior to the emergence of *Homo sapiens* (Gowlett, Urbanowski, Haidle and Bräuer, and Coward and Grove, this volume), as well as a long-term perspective on human innovation in prehistory.

DEFINITIONS OF INNOVATION AND RELATED TERMS

The authors in this volume provide a number of definitions of innovation, and a number of additional terms and concepts arise repeatedly (cultural transmission, creativity, complexity), suggesting the need to begin with some definitions.

In a key archaeological text on the subject of innovation, Renfrew (1978: 89) highlighted the importance of distinguishing 'invention, the discovery or achievement of a new process or form, and innovation, the widespread *acceptance* of a new process or form.' In this sense, innovation is dependent on the presence of local circumstances favoring the adoption of a new process, including the existence of necessary knowledge or technology and the social environment. Renfrew's distinction and discussion are important because they emphasize the importance of considering the factors influencing invention and innovation, which may be different, and have important implications for interpretation, for example, of differences in rates of change in material culture (Hovers and Belfer-Cohen 2006).

This distinction made by Renfrew has been widely employed in archaeological studies (e.g., Hovers and Belfer-Cohen 2006; Kuhn and Stiner 1998) and is also used in articles in this volume. This distinction also is important given the limits to the resolution of the archaeological record (Coward and Grove this volume; Kuhn and Stiner 1998). Coward and Grove argue that, 'given substantial timeaveraging of the archaeological record, particularly in the Paleolithic, it is a safer assumption that archaeologists are sampling behaviors that have already proved adaptive and spread.' It is worth bearing this in mind when comparing the archaeological evidence with that from, for example, ethnography or primatology, although similar issues arise in other disciplines to a lesser extent (Reader and Laland 2003b).

Renfrew's (1978) definition is relatively broad, dealing with all 'new processes and forms.' The breadth of the definition is appropriate given that, as Haidle and Bräuer argue in this volume, 'not every innovation is an inspired invention. It may be a tiny or far-reaching variation of an existing concept that assigns a certain solution to a specific problem.' It would, as Reader and Laland (2003b) point out with reference to animal behavior, be possible to restrict the definition of innovation to a qualitatively new or cognitively demanding process. However, as these authors argue, 'subjective judgements of intelligence are vulnerable to be prejudiced based on phylogenetic proximity to humans' (ibid.: 15). Identification of cognitively challenging innovations is liable to be biased, for extinct hominins as well as other species.

Haidle and Bräuer (this volume) break down the concept of innovation in material culture further—it may involve different aspects including the material, form, function, technology of production, and technology of use, and, more rarely, a complete change of all of these. These different aspects can apply to solving a given problem, or approaches to new problems. As Rugg (this volume) points out, we also are interested in innovation in the thought processes involved in production or use of a tool. A broad definition of innovation may be particularly useful for students of human origins, making it possible to compare and identify similarities and differences in innovation in humans, and other species of hominins and primates, as represented in the archaeological record.

Creativity and innovation are clearly closely linked concepts (Mithen 1998). According to Coward and Grove (this volume), a creative individual is one with a capacity to innovate. Similarly, Kyriacou and Bruner (this volume) draw on studies in neuroscience of 'creative thinking,' in order to develop a model allowing them to interpret evolutionary changes in cranial morphology in terms of ability to innovate. According to Reader and Laland (2003), creativity, the generation of novel combinations of ideas or behavior, can be seen as one of several processes underlying innovation in animals; others include insight, exploration, and individual learning. As these authors point out, in humans, innovation is typically regarded as being found in individuals who are particularly creative and possess other personality traits or characteristics (ibid.). It is not clear if the same processes underlie innovation in other animals, or earlier hominins (ibid.). In addition, according to Simonton (2003), the definition of creativity differs from that of innovation in that it is seen as producing behavior that is useful as well as novel. This is a subjective judgement subject to bias and highlights one of several benefits to using the broader, more neutral term of innovation, particularly as we are interested in the varied strategies of earlier hominins as well as humans.

Another recurring term is 'complexity.' Innovation is often assumed to involve increasing complexity, although this is not always the case, and certainly not in all aspects of a process or form. We may be particularly interested in identifying innovations that do involve increases in complexity, because these may relate to more dramatic changes in the environmental or social context influencing innovation or even the cognitive processes involved. Rugg (this volume) emphasizes that complexity is a term rife with paradox, and raises the issue of deep structure versus surface complexity—the most complex external appearance is not necessarily based on the most complex manufacturing process or thought process. It is clear that we need to specify what aspect of complexity we are interested in, in order to address specific research questions relating to innovation.

OUTLINE OF THE PAPERS IN THIS SPECIAL ISSUE

As discussed above, key questions concern if, how, when, and in what context innovative abilities changed in the course of human evolution. Coward and Grove review the wide range of large-scale climatic and environmental factors that have been considered as causes for the evolution of the cognitive mechanisms underlying human behavioral flexibility and innovation, with an emphasis on the importance of the social environment. For example, based on evidence from studies across other species that behavioral flexibility and social learning might draw on the same underlying cognitive abilities, they suggest it is likely that for innovativeness to be adaptive it must be combined with adequate social transmission of novel behavior. These authors also explore specific aspects of social life that would have influenced innovation. They highlight the importance of the nature of connections in social networks, with 'weak links' between groups being key, and go beyond this to explore the implications of differences between individuals, not just in age and sex but also personality, leading to the intriguing suggestion that the presence of multiple behavioral polymorphisms in humans represented a biological change that was beneficial for teamwork. Because greater individual distinctiveness also is seen as influencing social networks it seems possible that this could also influence the transmission of inventions.

Several authors highlight changing hominin life histories as having an important impact on innovation and transmission. Coward and Grove argue that the continued development of the neural architecture of the brain after birth in an increasingly complex social and cultural environment could have facilitated the cumulative cultural transmission of behavior, as could a longer lifespan. Kyriacou and Bruner suggest that the adolescent stage may be associated with high levels of innovation (while noting that studies of chimpanzees indicate no age effect), and that a distinctive adolescent stage emerged in *Homo sapiens* (see also Hawcroft and Dennell 2000). Several aspects of changing life histories, some of which may have emerged early and others late in human evolution, are therefore seen as facilitating both innovation and transmission, and underlying complex human culture.

Based on a review of recent studies in neuroscience, Kyriacou and Bruner highlight the function of the frontal, parietal, and cerebellar areas of the brain in making new connections between previously disconnected concepts and also in mentally manipulating objects. Both Neandertals and humans have relatively large frontal lobes compared with earlier hominins—evidence is presented indicating that this represents a non-allometric change associated with neural adaptation in these species. In addition, Neandertals show a widening of the upper volumes of the parietal areas, while humans show a substantial expansion of the whole parietal surface, a difference which may be related to the intraparietal areas. According to these authors, the fossil record therefore provides intriguing evidence for changes in cranial morphology in Neanderthals and particularly humans in the last 200 ka which might relate to an increasing capacity for innovation particularly in technology, and which could be connected to changes in the archaeological record such as technological diversity.

Key challenges for studying innovation in the archaeological record, and testing the hypotheses discussed above, include the scarcity of systematic ways of describing and comparing innovation, both qualitative and quantitative. Three papers in this volume provide tools for describing and comparing innovation which should be useful for archaeologists. Haidle and Bräuer (this volume) describe two such methods, 'cognigrams' and a simplified version of this called an 'effective chain.' Cognigrams allow detailed description and comparison of the processes involved in manufacture of an artifact, and can highlight what is novel about it. They demonstrate this method using the example of cracking nuts and making an Oldowan tool—while these processes may seem similar in that both involve use of a hammerstone, coding highlights differences in the manufacturing processes, specfically the active use of two tools and a longer sequence of different activities involved in the latter process. This approach also can potentially identify the cognitive load associated with a novel behavior (Haidle, 2009), providing insights into the cognitive changes (if any) that underlie innovations in material culture.

Methods for visualizing and quantifying innovation are well developed in information science, and both papers by Rugg (this volume) and by Rugg and Holland (this volume) present a number of methods from this field. Rugg describes two methods for describing different aspects of complexity in tool behavior. The first, therblig notation, is useful for describing physical activity, making it possible to identify the number of actions involved, and group these into higher level categories, which in addition to being useful for analysis may have reduced the cognitive load involved for past toolmakers. In addition, graph theory is presented as a method for visualizing the materials and tools involved in manufacturing an item of material culture. These diagrams provide a basis for quantifying complexity, and a means to assess the pre-existing conditions necessary for an innovation, and can be linked to other measurements, for example, connecting to the energy consumed during manufacture in order to carry out analysis in terms of foraging theory. Rugg and Holland focus on two methods of measuring novelty from the fields of empirical or computational aesthetics, inverse frequency weighting and minimum edit distance. Both approaches make it possible to distinguish the amount of change at different levels of granularity, lending this approach flexibility for application to different research questions, and both can easily be integrated with other approaches, including graph theory. In addition, these authors explore visual factors which may consistently affect the acceptance of innovations across a wide range of cultures. While ideas about aesthetic preferences have been applied to the archaeological record (Hodgson 2009), the relevant literature from information science may be unfamiliar. Rugg and Holland review empirical approaches to visual attractiveness which could be useful for archaeologists wishing to explore this topic further.

Finally, Gowlett addresses and attempts to interpret variation in the Lower Paleolithic record in terms of cognitive abilities, including a capacity for innovation. In this paper, he explores the appearance of a consistent length-to-breadth ratio in biface assemblages, providing a valuable review of debate and developments regarding this pattern and presenting some contrasting evidence from additional assemblages. While many Acheulean assemblages, widely separated in time and space from Africa ca 1 Ma ago to Britain ca 500 ka ago, have mean ratios of 0.61, with variation probably explained by the need to keep weight relatively low in larger specimens, several Spanish assemblages as a whole have a lower mean ratio. Gowlett suggests that from an early period (at least by 1 Ma years ago) hominins were good at controlling proportions, and had weak preferences for certain ratios, perhaps based on selection for technological success, which would not be aided by extreme proportions. As this author points out, it is currently difficult to assess whether this sense of proportion was a novel capability that evolved in the context of tool use—comparative studies of primates could help in addressing this issue. This would be valuable because this evolved capacity could have played a role in the technological success of hominins, a domain which has been the focus of archaeological study of innovation. In terms of innovation, this paper also is significant in highlighting an explanation for continuity in handaxe form that is not based on limitations to cognitive abilities including the ability to invent new tool forms.

Together, the papers in this special issue provide a number of analytical methods, data from an important but under-studied time period, and theoretical perspectives adding to our understanding of the role of innovation in human evolution.

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