PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B

Phil. Trans. R. Soc. B (2012) **367**, 2091–2096
doi:10.1098/rstb.2012.0111

Introduction

New thinking: the evolution of human cognition

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Humans are animals that specialize in thinking and knowing, and our extraordinary cognitive abilities have transformed every aspect of our lives. In contrast to our chimpanzee cousins and Stone Age ancestors, we are complex political, economic, scientific and artistic creatures, living in a vast range of habitats, many of which are our own creation. Research on the evolution of human cognition asks what types of thinking make us such peculiar animals, and how they have been generated by evolutionary processes. New research in this field looks deeper into the evolutionary history of human cognition, and adopts a more multi-disciplinary approach than earlier 'Evolutionary Psychology'. It is informed by comparisons between humans and a range of primate and non-primate species, and integrates findings from anthropology, archaeology, economics, evolutionary biology, neuroscience, philosophy and psychology. Using these methods, recent research reveals profound commonalities, as well striking differences, between human and non-human minds, and suggests that the evolution of human cognition has been much more gradual and incremental than previously assumed. It accords crucial roles to cultural evolution, techno-social co-evolution and gene–culture co-evolution. These have produced domain-general developmental processes with extraordinary power—power that makes human cognition, and human lives, unique.

Keywords: cognition; evolution of cognition; cognitive development; social cognition; cultural evolution; human evolution

1. INTRODUCTION

Chimpanzees lead quite interesting lives. They build nests, form alliances with other members of their troop and use simple tools—for example, sticks to fish for termites and stones to open nuts. However, as we are reminded by comedic images of chimpanzees wearing clothes and using computers, the lives of our closest evolutionary relatives are very different from our own. Translated as 'wise man', *Homo sapiens* is an optimistic sobriquet; translated as 'knowing man' it is merely descriptive of our species. We are animals that specialize in thinking and knowing—in cognition—and our extraordinary cognitive powers have enabled us to do remarkable things. We have transformed our eating habits with agriculture and cooking, and transformed our habitats with buildings, bridges and roads. Compared with our chimpanzee cousins, we can travel over vast distances, moving our whole bodies in cars, planes and space craft, and moving our minds to yet more remote places with radio telescopes and electron microscopes. We are political and economic animals, negotiating agreements that affect millions of people, and trading instantly in rarefied currencies with completely anonymous strangers in different time zones. We know about time, we understand it to some degree and we can measure it precisely. We communicate with symbols—spoken and written languages—and using these languages, we have developed extensive knowledge of our own history and diversity, and about all aspects of the natural and physical worlds. Our lives are enriched by a fabulous range of beautiful, intricate and provocative objects—by art, architecture, music and dance—and, in addition to developing the weaponry of 'shock and awe', we engage in sports, complex rituals that channel and redirect the impulse to fight.

How has evolution produced creatures with minds capable of these remarkable feats? The articles in this theme issue address this question. They represent new thinking *about* new thinking; leading edge, evidence-based theory about the new forms of cognition that emerged in the course of human evolution. The new theory and evidence come from a range of disciplines, including anthropology, archaeology, economics, evolutionary biology, neuroscience, philosophy and psychology. The new forms of cognition include causal reasoning, imitation, language, metacognition and theory of mind.

Over the past 25 years, research on the evolution of human cognition has been dominated by a type of evolutionary psychology promoted most prominently by Cosmides and Tooby [1–3]. This framework, which I will identify using initial capitals ('Evolutionary Psychology'), is sometimes known as the 'Santa

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One contribution of 15 to a Theme Issue 'New thinking: the evolution of human cognition'.

Barbara school' or 'high church evolutionary psychology'. It suggests that the human mind consists of a large collection of computationally distinct 'modules'. Each of these modules is a way of thinking that was shaped by natural selection to solve a particular type of problem faced by our Stone Age ancestors—for example, communicating, prey stalking, disease avoidance, mate choice and coalition formation. Evolutionary Psychology's central metaphor is the Swiss Army knife. It casts the evolved human mind as a set of cognitive gadgets, each specialized to learn, remember and reason about particular types of information. Evolutionary Psychology has fulfilled an important function. It has drawn attention to the need to integrate cognitive science with evolutionary biology in order to explain not only how brains and behaviour have evolved, but also the evolution of the 'middle man'—the cognitive processes, often characterized as computational software, which are instantiated by the brain and control behaviour. However, the 'massive modularity hypothesis' has long been an object of criticism [4–8], and the articles in this theme issue represent the emerging alternative view of the evolved human mind.

The alternative view, the 'new thinking' that runs through this theme issue, sees the human mind as more like a hand than a Swiss Army knife [9].[1] The hand is a multi-purpose instrument of a very different kind to the Swiss Army knife. It has a deep evolutionary history, rooted in the earliest emergence of the pentadactyl limb, and incorporates many genetic adaptations. However, the human hand is also capable of performing a wide and open-ended variety of technical and social functions. It can strip the defensive spines from a piece of fruit, making it safe to eat, but in Thai dancing it can also signal the smallest nuances of emotion. The human hand performs with equal facility a vast array of tasks that natural selection did and did not 'foresee'.

This article introduces the theme issue by contrasting our 'new thinking' with Evolutionary Psychology in relation to three closely related questions about the evolution of human cognition: When did the most important changes take place? How did the changes happen? What have the changes produced?

2. WHEN? BEYOND THE PLEISTOCENE PAST

The first humans, apes of the genus *Homo*, appeared around the beginning of the Pleistocene geological epoch (1.8 Mya). Evolutionary Psychology has focused on this epoch as the crucible of human cognition. The primary historical aim of Evolutionary Psychology has been to explain the ways in which we think now as genetic adaptations to the reproductive challenges faced by our Stone Age ancestors [10]. The 'new thinking' does not deny that this was an important era in the evolution of human cognition [11], but it regards the Pleistocene focus as radically insufficient. An adequate understanding of the origins and functions of the human mind, like that of the human skeleton, requires a much longer historical perspective, and to achieve this—to make inferences about the cognitive abilities of extinct, ancestral species—it is necessary to compare contemporary human minds with those of other animals alive today. Accordingly, several of the articles in this theme issue look deep into the evolutionary history of human cognition, examining its roots in the common ancestors of extant eutherian mammals (125 Mya [12]), primates (85 Mya [13]) and great apes (15 Mya [14]).

Barton [12] uses phylogenetic comparative analysis to examine the evolution of brain structures, the neocortex and cerebellum, in mammals. Phylogenetic comparative analysis is a set of statistical modelling techniques that combines information about relationships of descent among species with data on their phenotypic traits. The models represent inferences about the evolutionary change in traits along the branches of a tree representing the relationships among the species. These models can be used to test hypotheses about which traits are linked, the kinds of selection pressures that shaped the evolution of the traits and, when the traits relate to the brain, about the cognitive capacities that were evolving. The analyses reported by Barton in this theme issue show that the neocortex and the cerebellum have evolved together particularly tightly not only in primates, but in mammals more generally. Traditionally, the neocortex is associated with higher cognition, such as planning and executive control, while the cerebellum is associated with sensorimotor processing of the kind involved in visually guided reaching and grasping. The co-evolution of these structures not just in primates, but over deep evolutionary time—in all mammalian lineages—implies that in evolutionary terms the division between higher and sensorimotor intelligence, between thinking and acting, is artificial. The evolution of human cognition has not merely involved the addition of processes that supervise and control more primitive ways of thinking; it has accelerated an ancient trend towards increasingly powerful and coordinated 'embodied' modes of thought.

The article by Barrett and colleagues [13] also uses new quantitative techniques, draws attention to the continuity between human and non-human cognition, and emphasizes the importance of embodied cognition; of thinking that is not fundamentally distinct from acting. Drawing on the work of Mead and Vygotsky early in the twentieth century, Barrett *et al.* argue that, in human and non-human primates, thought is a form of social action and interaction. With the emergence of language, individual humans became able explicitly to represent their roles in a social group, but this new ability was integrated with a much older way of coordinating social behaviour, in which participants generate and respond to cues from others but do not have an 'aerial view' of group dynamics or of their position within the group. This kind of embodiment hypothesis is sometimes dismissed as impractical, as a rich set of ideas that cannot be cashed out in a feasible strategy for empirical research. Challenging this view, Barrett and colleagues show that the social networks of free-living baboons can be modelled as multi-dimensional objects, and that this approach predicts the effects of natural 'knock-outs'—the disappearance of group members—on the behaviour of other members of the group.

Whiten & Erdal's [14] pre-Pleistocene perspective focuses on the comparison of humans with chimpanzees. They identify five major components of the 'human socio-cognitive niche', five dimensions on which humans excel—cooperation, egalitarianism, theory of mind, language and culture—and in each case they review evidence that the behavioural/cognitive competence was present to some degree in the common ancestor of humans and chimpanzees. For example, chimpanzees cooperate when hunting and mounting raiding parties on other troops; show signs of egalitarianism when sharing meat and forming coalitions that thwart dominant males; appear to be able to attribute perceptions and goals, if not beliefs and desires, to others; and, in addition to having an extensive repertoire of communicative gestures, chimpanzees use vocalizations in a flexible, context-dependent way to signal information about food and social roles. Whiten & Erdal note that there is a 'yawning gulf in the cultural achievements of chimpanzees and humans', but even in this domain they find signs of continuity. Field studies have yielded reports of more than 40 chimpanzee traditions—involving food processing, tool use and various social behaviours—and many of the social learning processes found in humans are also present in other animals, including chimpanzees.

These three articles—by Barton, Barrett *et al.* and Whiten & Erdal—focus on the deep, pre-Pleistocene history of human cognition. However, emphasizing the importance of this deep historical perspective in new thinking about the evolution of human cognition, all of the papers in the theme issue make comparisons between human and non-human cognitive capacities. For example, Buchsbaum and colleagues [15] compare causal understanding in human and non-human animals; Sterelny [16] discusses research on vocal and gestural communication in non-human apes; and Lewis & Laland [17] compare social learning processes in humans and a range of other animals. Even the article by Shultz *et al.* [11], presenting a new analysis of brain size evolution in hominins, focuses on changes in the Pleistocene epoch but interprets them in the light of hypotheses about the selection pressures driving the evolution of cognition in non-human primates and other mammals. They find evidence of punctuated changes in brain size evolution at approximately 100 Kya, 1 and 1.8 Mya, as well as gradual changes in the *Homo erectus* and *Homo sapiens* lineages which are not mirrored by distinct variation in global or continental climate records. They argue that their results provide no support for hypotheses suggesting that the evolution of human cognition was driven by environmental aridity or variability. Therefore, it is necessary to reconsider whether extrinsic environmental factors have really been the key drivers of human cognitive evolution or whether intrinsic factors such as social organization, demography or language have been more influential.

3. HOW?

(a) *Incremental co-evolution*

Evolutionary Psychology sometimes gives the impression that new cognitive processes appeared suddenly and fully-formed as a result of lucky genetic mutations and fierce, unimodal selection pressures. This impression is due to not only the relatively short time frame adopted by Evolutionary Psychology, but also its assumption that the mind consists of modules—mutually isolated cognitive processes that do a single job in a special way—and its tendency to focus exclusively on gene-based mechanisms of inheritance. If time was short, cognition was modular, and evolution was mediated solely by genetic mechanisms, it seems that new ways of thinking *must* have appeared suddenly. However, the articles in this theme issue suggest that time was not short (see §2), that cognition is not massively modular (§4) and—the focus of the present section—that human cognition is a product of gradual, incremental 'co-evolution'.

Two kinds of co-evolutionary process are discussed in the theme issue. The first kind, which I will call 'techno-social co-evolution', occurs when selection pressures favouring the evolution of technical skills (e.g. tool making), and selection pressures favouring the evolution of social skills (e.g. cooperation), become linked by positive feedback loops. For example, innovations in tool-making techniques may create pressure for more intensive cooperation, and more intensive cooperation, in turn, puts a premium on further advances in tool making technology. In principle, this sort of positive feedback loop can promote the evolution of two sets of cognitive processes, one mediating technical skills and the other mediating social skills [12,14], or one set of domain-general cognitive processes underwriting both types of skill [4,15,18,19].

The second kind of co-evolutionary process, 'gene-culture co-evolution', involves the interaction of genetic and non-genetic mechanisms of inheritance, i.e. mechanisms that allow individuals to acquire adaptively-relevant information from others, not via the replication of DNA sequences, but through learning. Lactose tolerance is the most widely cited example of gene-culture co-evolution or 'dual inheritance' of a non-cognitive trait [20]. The ability to digest the lactose found in milk, not only in infancy but also in adulthood, is common in Europe and western Asia, but rare in people from the Far East. This geographical distribution is thought to be due to a gene–culture co-evolutionary process in which some historical populations started dairy farming, making milk plentifully available as a source of nutrients. This meant that the small number of people in those populations who had the genes enabling them to digest lactose in adulthood, and thereby to exploit this resource, out-reproduced others in the population who lacked those genes. As the proportion of lactose-tolerant adults increased, the demand for dairy products increased, further promoting dairying practices and, in turn, demand for dairy products. Thus, there has been co-evolutionary positive feedback between dairying (a culturally inherited set of characteristics) and lactose tolerance (a genetically inherited characteristic).

Sterelny [16] assigns a fundamental role to techno-social co-evolution in the emergence of human language. He uses archaeological evidence to argue that, by 2–2.5 Mya, techno-social co-evolution was already making hominins into co-operative foragers. Increased environmental variability had selected for improvements in both technical skills (e.g. to exploit dry season food resources) and co-operative social skills (e.g. to guard against predation in more exposed environments). Supporting a 'gesture-first' model of language evolution, in which vocal language evolved from complex gestural communication, Sterelny argues that the improvements in technical (extractive foraging) and social skills (gestural communication) were mediated by common cognitive processes—processes that encode and control complex sequences of action. Therefore, pressure for improvement in technical competence enhanced social as well as technical skills, and vice versa, creating a positive feedback loop that culminated in the appearance of fully syntactic vocal communication. Barton's phylogenetic comparative analyses of mammalian brain evolution converge on a very similar conclusion about the co-evolution of technical and social skills [12].

In their article, also concerned with language, Jablonka *et al.* [19] discuss both techno-social and gene–culture co-evolution. In the former case, like Sterelny, they argue that selection pressures for technical (tool making) and social (alloparenting) skills are likely to have fostered the evolution of an overlapping set of cognitive processes. However, rather than emphasizing the common requirement for encoding of complex sequences, they point out that learning to make complex tools and to alloparent both require the kind of inhibitory control that enables patience and social tolerance and reshapes human emotions. Turning to gene–culture co-evolution, Jablonka *et al.* review several recent theories suggesting that various aspects of language were initially invented and inherited as cultural conventions, and were later 'genetically assimilated'. Their own view is distinctive in two respects: it highlights ways in which human cognition has adapted to language, not merely language to cognition, and, via the 'assimilate-and-stretch' principle, stresses that genetic assimilation makes room for further learning. Thus, when a previously learned linguistic trait, X, has been genetically assimilated—when it develops with minimal environmental input—this frees-up resources allowing a new linguistic trait, Y, to be learned.

(b) *Cultural evolution*

In contrast to Evolutionary Psychology [21], new thinking about the evolution of human cognition assigns an important role to cultural evolution. Godfrey-Smith [22] distinguishes three types of cultural evolution: Darwinian imitation (micro level), cumulative cultural adaptation (meso) and cultural phylogenetic change (macro). In the first, change occurs through differential copying of instances of cultural variants. The second and third allow a greater variety of processes at the micro-level, but make strong empirical commitments on other matters. For example, cumulative cultural adaptation requires a gradualist mode of change. The three types of model have different explanatory potential. For example, Darwinian imitation models can explain the distribution of cultural variants in a population over time, whereas cumulative cultural adaptation models can explain origins: how a complex cultural artefact, such as a canoe, could ever have been invented. Godfrey-Smith shows that different cognitive profiles are required for different types of cultural evolution. Surprisingly, Darwinian imitation requires that individuals are not too 'smart'—that they are not too intelligently choosy about the variants that they copy (see also [23]). Cumulative cultural adaptation models require social cognitive processes that enable the decisions of a group to be better than the aggregate of the group members' decisions. Frith's article suggests that these processes are likely to be metacognitive [24].

Lewis & Laland [17] use simulations to test the widely held assumption that cumulative cultural evolution—progressive improvement or elaboration of cultural traits—requires cultural variants to be transmitted over many cultural generations with minimal modification. In Godfrey-Smith's terms [22], this kind of longevity and fidelity preserves 'parent–offspring relations' between cultural entities. Lewis and Laland's modelling confirms the importance for cultural evolution of cognitive processes that support transmission fidelity. It also suggests that progress in cumulative culture depends critically on the kind of creative thought that enables cultural variants to be combined in novel ways. Compared with 'novel invention' (creating a new variant from scratch) and 'modification' (tinkering with an existing variant), new combinations of variants had a much more substantial effect on the rate of cumulative cultural change observed in their models.

Evolutionary psychologists, and even many researchers who emphasize the power of cultural evolution, assume that genetic evolution produced and maintains the core cognitive processes that enable cultural inheritance. Heyes [18] questions this assumption, using evidence from comparative psychology, developmental psychology and cognitive neuroscience, to argue that the development of imitation and other processes of social learning is remarkably similar to the development of literacy, and that the cognitive processes enabling cultural inheritance are themselves culturally inherited.

Even if cultural evolution is a major force shaping human lives, there are certainly cases where cultural change has not overcome limitations on human cognition imposed by genetic evolution. Dunbar [25] examines one of these cases in detail. He argues that constraints on time and social cognition, shared with other primates, currently prevent us from using social-networking sites (such as Facebook) to expand the range of people with whom we have enriching social relationships.

4. WHAT? DOMAIN-GENERAL DEVELOPMENTAL MECHANISMS

The final major contrast between 'new thinking' and 'old thinking' about the evolution of human cognition concerns the unique features of the human mind. Evolutionary Psychology suggested that, in contrast to our primate relatives, we have a range of distinctive, special-purpose cognitive gadgets or modules, each responsible for thinking about a particular kind of technical or social problem that confronted our Stone Age ancestors. Experience was assumed to play a limited role in the development of these modules. Many of the articles in this theme issue present a very different view. They suggest that humans are born with extraordinarily powerful cognitive-developmental mechanisms.

These mechanisms are domain-general—they use a common set of computations to process information from a broad range of technical and social domains—and they use experience, especially sociocultural experience, to forge new, more domain-specific cognitive-developmental mechanisms of the kinds that control tool-making, mentalizing, planning and imitating the actions of others. The genetically inherited cognitive-developmental mechanisms use computational processes that are also present in other animals, but they are uniquely powerful in their range, capacity and flexibility.

This aspect of the 'new thinking' is most fully articulated in the articles by Heyes [18], and by Buchsbaum *et al.* [15]. Heyes focuses on associative learning, an evolutionarily ancient domain-general developmental mechanism, and on the role that it plays in constructing the capacity to imitate. Buchsbaum *et al.* focus on causal learning, a domain-general developmental mechanism based on probabilistic models and Bayesian inference. They highlight evidence that evolution has protracted the period of juvenile dependence in humans, relative to that of other animals, and argue that one of the major functions of our extended childhood is to allow us to use causal learning to build capacities for tool making, theory of mind and future planning about counterfactuals. In support of this hypothesis, they present new data that link causal learning with pretend play. In 3 to 4-year-old children, counterfactual reasoning transfers from 'real' to 'pretend' contexts.

Key elements of the domain-generality view are also evident in the articles by Barrett *et al.* [13], Jablonka *et al.* [19], Sterelny [16] and Frith [24]. Barrett and colleagues emphasize the importance of social experience in shaping cognitive processes. Jablonka *et al.* and Sterelny argue that, as a result of techno-social co-evolution, humans have 'two-for-one' cognitive developmental mechanisms; processes that facilitate learning of both extractive foraging and social skills. Even Barton [12], although clear in denying that there could be no 'general' (non-technical, non-social) selection pressure, suggests that the combination of technical and social pressures has produced sensorimotor or 'embodied' cognitive processes that tackle technical and social problems using an overlapping set of computations.

Frith [24] reviews recent research in psychology and cognitive neuroscience on 'metacognition', the processes by which we monitor and control our own cognitive processes and those of others. He distinguishes implicit metacognition, which allows humans and other animals to take account of knowledge and intentions automatically, from explicit metacognition, which involves conscious awareness and depends on a capacity for complex communication. Frith argues that the capacity for explicit metacognition is uniquely human, and implies that the capacity is a genetic adaptation. Since metacognition is relatively domain-specific (it is thinking about thinking), this indicates that he is sympathetic to the idea that mentalizing is a module. However, in line with the view that humans have uniquely powerful cognitive-developmental mechanisms, Frith also suggests that, when we are born, 'the content of explicit meta-cognition is a blank slate on which we learn to write our experiences. And what we learn to write there is determined largely through social interactions'.

Robalino & Robson [26] also discuss the evolution of theory of mind, bringing together research on this topic from economics and from cognitive neuroscience. They provide a detailed summary of the way in which game theorists have developed the work of Harsanyi and Aumann to produce hierarchical models of theory of mind using Bayesian decision theory. These models are impressively formal and precise, but they do not fully predict the behaviour of fallible agents in real social interactions. Robalino and Robson identify a number of ways in which interdisciplinary research could produce models that are both precise and empirically grounded; an understanding of the bounded rationality of theory of mind.

5. CONCLUDING REMARKS

We have seen that, in comparison with Evolutionary Psychology, new thinking about the evolution of human cognition: (i) takes a longer historical perspective, and therefore a more comparative approach, (ii) highlights the importance of co-evolution and cultural evolution in generating gradual, incremental change and (iii) suggests that humans are endowed with uniquely powerful, domain-general cognitive-developmental mechanisms, rather than with cognitive modules. The final article in the theme issue asks whether these contrasts can be encapsulated using the concept of innateness. Perhaps the new thinking denies that distinctively human cognitive processes are innate, and is therefore less 'evolutionary' than Evolutionary Psychology. In the final article in this theme issue, Shea [27] argues that this is not a helpful or legitimate way of characterizing the direction in which the field is moving. The concept of innateness cannot capture the current trend because it implies connections and distinctions that the new thinking rejects. For example, the innateness concept implies that the development of adaptations is experience-independent, and that there is a dichotomy between individuals learning for themselves and relying on genetic information. Shea proposes that the main thrust of the new thinking can instead be captured by the concept of 'inherited representation'. This concept embraces three ways in which natural selection builds up information that is transmitted down the generations and used to produce adaptive phenotypes: genetic, epigenetic and cultural inheritance. The new thinking highlights the central role of learning and rich interactions with the physical and social environment for the development of human psychological capacities. The concept of inherited representation makes clear how this is compatible with a profoundly evolutionary focus; the new thinking points to natural selection as an important source of the adaptively relevant information encapsulated in human psychological traits, and assigns a central role to cultural evolution and gene–culture co-evolution in producing the distinctively human cognitive and social phenotypes that differ so strikingly from those of our closest primate relatives.

The papers in this Theme Issue were presented at a workshop entitled 'New Thinking: Advances in the Study of Human Cognitive Evolution', held at the University of Oxford on

23–24 June 2011. The editors of the theme issue (C.H. and U.F.) thank the co-organizers of that meeting, Susanne Shultz and Nicola Byrom, and those who provided additional help with the arrangements: Robin Dunbar, Humaira Erfan-Ahmed, Jennifer Lau, Emma Nelson, Kit Opie, Ellie Pearce and Rafael Wlodarski. We are grateful for the financial support provided by All Souls College, Oxford; The British Academy; Guarantors of Brain; and Magdalen College, Oxford. The workshop concluded a 'theme term' on the Evolution of Human Cognition generously supported by the Warden and Fellows of All Souls College.

END NOTE

[1]The hand metaphor emerged from discussion among the participants in the Evolution of Human Cognition project based at All Souls College, Oxford in May/June 2011 (Robert Barton, Alison Gopnik, Russell Gray, Cecilia Heyes, Eva Jablonka, Arthur Robson, Kim Sterelny), but it was ultimately the product of Eva Jablonka's dexterous mind.

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