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Metaplasticity and the human becoming: principles of neuroarchaeology

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Summary - *Important recent developments in brain and cognitive sciences offer new avenues for productive cooperation between archaeology and neuroscience. Archaeologists can now learn more about the biological and neural substrates of the human cognitive abilities and use that knowledge to better define and identify their archaeologically visible traces and possible signatures. In addition, important questions and prevailing assumptions about the emergence of modern human cognition can be critically reviewed in the light of recent neuroscientific findings. Thus there is great prospect in the archaeology of mind for developing a systematic cross-disciplinary endeavor to map the common ground between archaeology and neuroscience, frame the new questions, and bridge the diverge analytical levels and scales of time. The term 'neuroarchaeology' is introduced to articulate this rapidly developing field of cross-disciplinary research, focusing on questions and problems that emerge at the interface between brain and culture over the long-term developmental trajectories of human becoming. Neuroarchaeology aims at constructing an analytical bridge between brain and culture by putting material culture, embodiment, time and long term change at center stage in the study of mind. This paper presents a critical overview of this new research field and introduces the notion of 'metaplasticity' to describe the enactive constitutive intertwining between neural and cultural plasticity. In this context, I summarize the main objectives, cross-disciplinary links, and theoretical grounding of this new approach to the archaeology of mind and outline some of the foundational issues and methodological challenges such a project might face.*

Keywords - *Neuroscience, Material culture, Cognitive archaeology, Material engagement.*

Introduction

The last three decades have seen radical advancements in the way we approach and understand the prehistory and evolution of human mind. Naturally, trying to reconstruct past *ways of thinking* as they emerge and take shape in the different cultural trajectories of our species (see Renfrew, 1994, 2006) has been a great challenge for archaeology. Yet, despite the many problems, and from its own unique long-term perspective, archaeology has managed to contribute a great deal to our knowledge about the embodied, social and cultural basis of the human mind. Especially in the past decade or so, the archaeology of mind has apparently come of age with a series of remarkable theoretical advances and a growing number of new empirical findings. The initial skepticism about "paleopsychological" investigations gave way to a systematic research endeavor, which fuses different schools of thought and research strands together (e.g. neo-evolutionary, culture-historical, processual, post-processual, anthropological, biomedical) in a highly interdisciplinary and rapidly growing research field that we call nowadays the archaeology of mind or cognitive archaeology (e.g. Renfrew & Zubrow, 1994; Renfrew & Scarre, 1998; Renfrew *et al.,* 2008; Renfrew, 2001a,b, 2004, 2007, 2008; Knappett, 2005, 2006; Stout *et al.,* 2008; Stout & Chaminade, 2007, 2009; Bruner, 2003, 2004, 2007; Mellars *et al.,* 2007; Mellars & Gibson, 1996; Davidson & Noble, 1989; de Beaune *et al.,* 2009; D' Errico, 1998; D'Errico *et al.,* 2003; Gosden, 2008; Gibson, 1993; Wynn & Coolidge, 2003, 2004; Coolidge & Wynn, 2001, 2004, 2005, 2009; Wynn, 2002; Deacon, 1997; Read & van der Leeuw, 2008; Humphrey, 1998; Hodgson & Helvenston, 2006; Mithen, 1996; Mithen & Parsons, 2008; Noble & Davidson, 1996; Malafouris, 2004, 2007, 2008a,b,c, 2010a).

Meanwhile, parallel to the developments taking place within the field of cognitive archeology, remarkable advances have been made in studies of brain function in the field of neuroscience. Technological breakthroughs in neuroimaging technologies (Cacioppo & Decety, 2009; Heeger & Ress, 2002; Miller, 2008) opened a new window on the human mind and offered a whole new set of *in vivo* exploratory possibilities. New research domains like social (Lieberman 2007; Frith 2008), affective (Davidson & Sutton,1995), developmental (Blakemore, 2008; Blakemore & Choudhury, 2006; Blakemore *et al.,* 2008), critical (Choudhury *et al.,* 2009) and cultural neuroscience (Chiao, 2009; Chiao & Ambady, 2007; Han & Northoff, 2008; Roepstorff, 2008; Wexler, 2006; Domìnguez *et al.,* 2009) have now emerged advancing our knowledge about neural plasticity and the experiential, social and cultural modulation of the developing human brain. A representative example of the recent important empirical and theoretical discoveries can be seen in the case of 'mirror neurons' and the theory of embodied simulation, which have shed new light on the neural mechanisms of imitation, and offer a new explanatory framework for approaching social cognition (Gallese & Goldman, 1998; Gallese, 2003). Moreover, hypotheses like that of 'neural exploitation', emphasize the role of sensorimotor systems in the formation of abstract concepts, providing new perspectives on how the brain facilitates and supports the transmission of cultural values, beliefs, and practices (Gallese & Lakoff, 2005; Gallese, 2005; Iacoboni, 2009).

Meanwhile, evolutionary neuroscience research has also made important steps towards an understanding of the basic principles of brain evolution and of human brain-culture co-evolution (e.g. Deacon, 1997; Stout & Chaminade, 2007, 2009). As a result, we can now make better sense of the evolutionary changes (structural/functional) that occurred, the ways in which human brains differ, as well as the manner in which these differences evolved (see Schoenemann, 2006; Holloway, 1999, 2008; Striedter, 2006). In this context, new methodological advances in the field of palaeoneurology (Bruner, 2003, 2004, 2008) enable for a more nuanced interpretation of the observed variation in endocranial morphology, and a better understanding of the patterns of growth (changes in size) and development (changes in shape) of the brain as reflected in the available record of fossil endocasts. A notable example here, is the important evidence presented recently by E. Bruner, for a non-allometric increase in parietal volume associated with the advent of anatomically modern humans (AMH) (Bruner *et al.,* 2003; Bruner 2004, 2008, 2010).

Important to note also in this connection, are the many theoretical frameworks, such as 'developmental systems theory' (DST) (Oyama, 1985, 2000; Oyama *et al.,* 2001; Griffiths & Gray, 1994, 2001, 2004; Griffiths & Stotz, 2000), 'niche construction' (Laland *et al.,* 2001a,b; Sterenly, 2001, 2003, 2004), 'neuroconstructivism' (Mareschal *et al.,* 2007a,b; Westermann *et al.,* 2006; 2007; Quartz & Sejnowski, 1997), and 'probabilistic epigenesis' (Gottlieb, 2007, 2003, 2002), which provide us a new, non-linear, and interactive model for understanding the relationship between genes, the brain, and behaviour that characterises the human cognitive becoming and helps us reframe some key issues in human evolution. Last but not least important theoretical developments in cognitive archaeology and material culture studies such as Material Engagement Theory (MET) (Fig. 1) (Malafouris, 2004, 2007, 2008a; Renfrew, 2004; Malafouris & Renfrew, 2010) and interactive network approaches (Knappett, forthcoming; Gamble, 2007) assist us in rethinking our conventional ideas about the boundaries between cognition and material culture and the embodied character of human experience.

All these different and rapidly evolving theoretical and empirical research strands offer new sources of evidence and raise new challenges for the archaeology of mind. Most importantly, they carry the promise for productive cross-disciplinary cooperation and future research synergies. The aim of neuroarchaeology is precisely to channel the huge emerging analytic potential of current neuroscientific research in the direction of an integrated research program, spanning the whole spectrum of cognitive sciences, and targeting the big picture of human cognitive becoming. The task that, at the same time confronts us, is about bringing these perspectives, insights, and ways of thinking together, avoiding to reduce the one to the other.

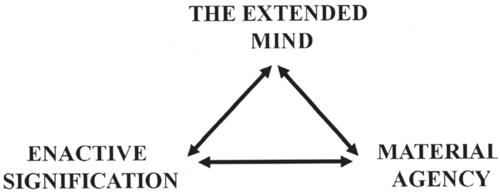

Fig. 1 - Material engagement theory (MET) as an explanatory path develops along the lines of three interrelated working hypotheses which can summarised as follows: (a)The hypothesis of extended mind, which explores the constitutive intertwining of cognition with material culture, (b) the hypothesis of enactive signification, which explores the nature of the material sign not as a representational mechanism but as a semiotic conflation and co-habitation through matter that enacts and brings forth the world, and finaly, (c) the hypothesis of material agency, which explores agency not as a human property but as the emergent product of situated activity.

More than a brain: theoretical foundation and epistemological challenges

We should start by underlying two major epistemic features that could be used to differentiate the approach of neuroarchaeology: the first of these features is found in the explicit concern of neuroarchaeology with understanding the processes by which human cognitive abilities grow, evolve, and change over time. This epistemic feature can be contrasted with more traditional approaches in cognitive archaeology pre-occupied with the task of associating specific human abilities with specific time periods, geographic regions, or fixed evolutionary stages. The objective of neurorchaeology is to move beyond the logic of the 'localizer', in order to study the emergence and cultural variation of human intelligence, the ontological ingredients of long-term cognitive change, and the causal mechanisms (evo or devo) that underlie human cognitive becoming from the Early Stone Age (ESA) to the present. Such an endeavor can only be achieved through a serious cross-disciplinary attempt to understand human cognitive abilities as enactive and distributed phenomena. At the centre of investigation is now the question about how these abilities (e.g. language, symbolic capacity, theory of mind (ToM), causal belief, learning by teaching, 'we' intentionality, sense of selfhood, working mem¬ory, autonoesis, ability to plan and innovate) relate to the embodied character of human experience. Thus, whereas the majority of studies in cognitive archaeology seem to be primarily concerned with WHEN and WHERE (e.g., to use one very common question, where and when symbolic thinking and language first appeared in the archaeological record) neuroarchaeology is primarily concerned with the WHAT, WHY and HOW (e.g., what is symbolic thinking? Why and how did symbolism emerge? What forms of signification count as symbolic *meta*-representational thinking? How do we identify the material traces of symbolic capacity in the archeological record?). Naturally, in approaching the above questions, the focus falls on the changing nature of the human brain. Nonetheless, and this brings us to the second major differentiating feature of neuroarchaeology, the quest for establishing empirical, yet culturally sensitive and philosophically informed links between the brain's functional structure and archaeologically observable behavioural traces, is grounded on the methodological 'embedment' of the human brain. The term 'embedment' derives from the fusion of the terms 'embodiment' – referring to the intrinsic relationship between brain and body - and 'embeddedness' - describing the intrinsic relationship between brain/body and environment. Northoff, in his 'Philosophy of the Brain', introduced this neologism i.e., '*embedment*' (2004, p.19) to define the inextricable connection between brain, body, and environment. Drawing upon this notion, and fusing perspectives from 'active externalism' (Clark & Chalmers, 1998; Clark, 1997), embodied (Clark, 2008, 2001; Gallagher, 2005), and distributed cognition (Hutchins, 1995, 2008; Kirsh, 1995; 1996), neuroarchaeology, approaches the human brain as an extremely plastic, and culturally situated *bio-artefact* permeated by history and mediated by material culture. Recognizing the causal efficacy and the constitutive role of material culture in the human cognitive system as exemplified by the principles of Material Engagement Theory (MET) (Fig. 1) (Malafouris 2004; Renfrew 2004; Malafouris & Renfrew 2010), and taking the brain-artefact interface (Malafouris 2010a) as its principal analytical unit, neuroarchaeology attempts to construct a new integrative approach to the study of human cognitive becoming (evo or devo). The broader objective is twofold: On the one hand, to identify new topics and questions about the emergence of human intelligence which could facilitate the partnership between archaeology and neuroscience, and, on the other hand, to rethink and restate old problems and questions from the new perspective point that such a partnership could enable.

Cognitive evolvability: the developmental challenge

To an important extent, the concern of neuroarchaeology as a theoretical framework with evolved cognitive structures and the cognitive history of our species, can be viewed as a new form of evolutionary epistemology. Seen from such an angle, it should be made clear from the start that the intellectual kinship of neuroarchaeology in this context lies with *developmental systems theory* (DST) (Oyama, 1985, 2000; Oyama *et al.,* 2001; Griffiths & Gray, 1994, 2001, 2004; Griffiths & Stotz, 2000) and *neuroconstructivism* (Mareschal *et al.,* 2007a,b; Quartz & Sejnowski, 1997) rather than classical evolutionary psychology (see review by Cosmides & Toody, 1987, 1992). No doubt, the mind, as a product of evolution, is constrained by a number of inherited genetic structures, brain circuits, and representations. The study of cognitive development and evolution requires a better understanding of how these neural substrates, structures and mental representations are shaped. In order to do so, however, we need first to recognise that these 'internal' or 'genetic' constrains cannot determine the developmental trajectory *a priori*: "The fertilised egg contains neither a 'language acquisition device' nor a knowledge of the basic tenets of folk psychology. These features come into existence as the mind grows" (Griffiths & Stotz, 2000, 31).

Developmental systems theory (DST) (Griffiths & Stotz, 2000; Oyama *et al.,* 2001; Griffiths & Gray, 2004) recognizes that the developmental trajectory of an organism is not a fixed genetic program, but rather, a matrix of resources that serve as the actual physical causes of development. The notions of 'extended inheritance' and the 'parity thesis' can exemplify the crux of this innovative framework, pointing out that we should not single out a particular type of resource as the principal source of inter-generational stability (e.g., genetic rather than environmental, internal rather than external; Oyama, 2000). Evolution is not just change in gene frequencies, but change in the entire spectrum of developmental resources. All elements of the developmental matrix matter. DST draws attention to the many causal pathways by which resources come to be deployed in development (Griffiths & Stotz, 2000, p.34). Moreover, the way in which individual resources contribute to development takes the form of an 'interactive construction' (the effect of each resource depends on its interaction with many others). It is especially in this connection that theoretical frameworks like 'neuroconstructivism' have been extremely helpful, offering a developmental account of the neural system as heavily constrained by multiple interacting factors, intrinsic and extrinsic, to the developing organism. Similarly to DST, these flexible and interacting constrains span multiple levels of analysis, i.e., from genes and the individual cell to the physical and social environment. Therefore, cognitive development is explained as a trajectory emerging from the interplay of these constraints. In this context of special interest is the view of brain and cognitive development known as *probabilistic epigenesis* (PE) (Gottlieb, 2002).

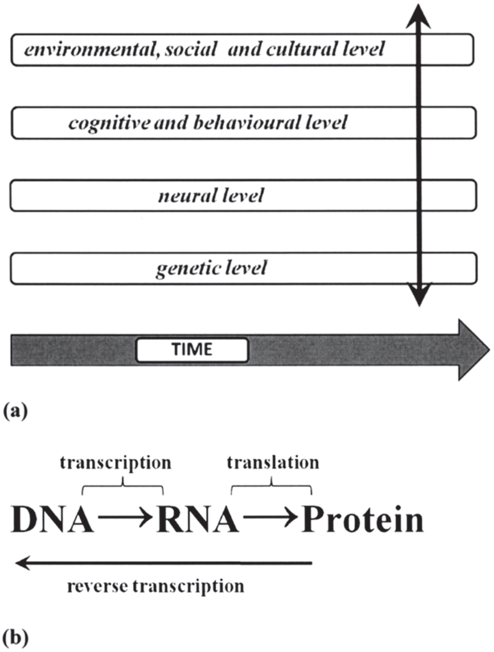

Fig. 2 - New theoretical frameworks such as that of 'neuroconstructivism' and 'probabilistic epigenesis' provide us a new, non-linear and interactive model for understanding the relationship between genes, the brain and behaviour that characterise human cognitive becoming (a). Cognitive development is no longer seen as the progressive unfolding of information that is a laid out in the genome. The traditional view of a one-directional flow of cause and effect from genes (DNA) to RNA to the structure of proteins they encode gives way to a subtler picture where physical, social, cultural aspects of environment and behaviour plays fundamental role in triggering the expression of genes (b).

In particular, the *probabilistic epigenesist* view of development emphasizes the interactions between experience and gene expression (Gottlieb, 2007). The *unidirectional* formula prevalent in molecular biology by which genes drive and determine behavior (Fig. 2) is replaced with a new scheme which explicitly recognizes the *bidirectionality* of influences between the genetic, behavioral, environmental, and socio-cultural levels of analysis. Genetic causality gives way to what has been termed "developmental-relational causality" (Gottlieb & Halpern, 2002). As summarized by Gottlieb (2007, p.1) the PE "*framework emphasizes the reciprocity of influences within and between levels of an organism's developmental manifold (genetic activity, neural activity, behavior, and the physical, social, and cultural influences of the external environment) and the ubiquity of gene–environment interaction in the realization of all phenotypes*". Put it simply, the above statement means that differences and variations in life and learning experiences caused by social, environmental, and cultural factors, can cause individuals of the same genotype to have different neural, cognitive, and behavioral outcomes. This also implies that one cannot correlate a particular genotype with a certain neural or behavioral outcome without taking into consideration the 'external' mediational properties and experiential factors. This unpredictability of the phenotype of similar genotypes when confronted with novel or different developmental trajectories and circumstances, indicates that epigenetic outcomes are "probabilistic" rather than predetermined. The problem, of course, similarly to any other 'context-based' explanatory logic, is how to identify on which, among the many, 'external' factors to focus upon. Whatever the case, the thing to note is that the key question is no longer about *if* culture influences the neural of genetic level, but rather about *which* of the manifold dimensions and developmental events in human life might have played the crucial role behind the presence or absence of certain neural or genetic outcome.

Let us illustrate that by using some characteristic empirical examples where genetic activity is shown to be influenced by neural, behavioral, and external environmental events. Take for instance the much-studied inhibitory neurotransmitter serotonin. The serotonin transporter gene (SLC6A4) contains a polymorphic region, known as 5-HTTLPR, comprising a short (S) allele and a long (L) allele version that results in differential 5-HTTexpression and function (Lesch *et al.,* 1996; Hariri, 2009). Evidence from behavioural genetics indicates that individuals carrying the S allele of the serotonin transporter gene produce significantly less 5-HTT mRNA and protein, resulting in higher concentrations of serotonin relative to individuals carrying the L allele (Lesch *et al.,* 1996). It is interesting to note that the S allele of the serotonin transporter gene is associated with increased negative emotion, including heightened anxiety (Sen *et al.,* 2004; Munafo` *et al.,* 2005) and increased risk for depression in the presence of environmental risk factors (e.g. exposure to chronic life stress, such as interpersonal conflict, loss or threat) (Uher & McGuffin, 2008; see also Munafo` *et al.,* 2009). More importantly, there is evidence that brain regions that are regulated by serotonergic neurotransmission and are critical to emotional behaviour, like the amygdala, varies as a function of 5-HTT (e.g. individuals carrying the S allele showing greater amygdala response to emotional stimuli relative to those carrying the L allele) (Chiao & Blizinsky, 2009; Hariri *et al.,* 2002).

Recently, Chiao & Blizinsky (2009) were able to demonstrate a robust association between cultural values of individualism–collectivism (Triandis, 1995) and allelic frequency of the serotonin transporter gene (5-HTTLPR). Specifically, in their study, they showed (a) that geographical regions characterized by cultural collectivism exhibit a greater prevalence of S allele carriers of the serotonin transporter gene, (b) "*that global variability in historical pathogen prevalence predicts global variability in individualism–collectivism owing to genetic selection of the S allele of the serotonin transporter gene in regions characterized by high collectivism*", and finally, (c) that "*greater population frequency of S allele carriers is associated with decreased prevalence of anxiety and mood disorders due to increased cultural collectivism*". Taken together, these findings exemplify the culture–gene co-evolution of human behavior and complement current conception of how cultural values serve adaptive functions by tuning societal behavior.

We should also note, from the perspective of animal studies, that in rhesus monkeys a positive correlation between lowered serotonin metabolism and rearing practices has been shown (Bennett *et al*., 2002). Serotonin concentration was not simply a consequence of having a certain type of short allele but also of a certain type of rearing practice (mother vs peer rearing). In other words, the neural outcome is a consequence of at least two components: a genetic component (genotype of the animal), and a behavioural/environmental component (rearing context and history of the animal).

Metaplasticity and culture effects

These examples, by showing that even gene expression can be influenced in very specific ways by environmental and experiential factors, clearly contrast to many conventional ideas in evolutionary psychology (e.g., Pinker, 1997) that would see culture as a mere epiphenomenal influence upon a biologically pre-determined and universally shared set capacities or features of human cognition. Maybe, as Griffiths & Stotz suggest, what we need to recognise is that "*what individuals inherit from their ancestors is not a mind, but the ability to develop a mind*" (2000, p.31; see also Karmiloff-Smith, 1992; Jordan, 2008). Moreover, as theory of niche construction points out, the defining feature of this ability may rest in the systematic changes that humans can bring about in its course by altering their social and technological environments (Sterenly, 2001, 2003, 2004). Archaeology may well testify that significant parts and episodes of this long developmental trajectory of the human mind appear relatively recently in the archaeological record and can certainly be seen as the emergent products of various culturally-instantiated and transmitted, embodied social and technological processes, rather than innate biological capacities. Thus, neuroarchaeology, not only adopts an interactionist, constructivist, and integrative perspective on human development and evolution, but also recognizes that many of the constitutive elements and processes of human cognitive development might be argued to extend beyond skin and skull into the realm of available technologies and cultural practices.

It has been widely known within cultural psychology and cognitive anthropology that culture modulates and mediates nearly every facet of human psychology and behavior. Drawing on this well established tradition, in recent years, the rapidly developing field of cultural neuroscience, tries to explore this 'culture effect' at the level of the human brain offering a wealth of experimental evidence. Some characteristic empirical examples of current research in cultural neuroscience can be found in (a) studies of cultural variation in memory performance (e.g. cultural difference in thinking styles - holistic versus analytic - seem to affect how people encode and retrieve information) (Chua, Boland & Nisbett, 2005; Nisbett & Masuda, 2003), (b) studies of cultural variation in the experience (Tsai, 2007), expression (Elfenbein & Ambady, 2002) and regulation of emotions (Chiao *et al.,* 2008; Mesquita & Leu, 2007), (c) studies concerning the modulation of visual experience by cultural beliefs (Hedden *et al.,* 2008), or, finally, (d) studies about the effect of culture on conceptions of selfhood (for instance, the recent cross-cultural neuroimaging findings for the modulation of medial prefrontal response during self-relevant processing as a function of individualistic and collectivistic cultural values (Chiao *et al.,* 2009a,b; see also Zhu *et al.,* 2007).

In addition, new insights about neural plasticity from cognitive, social, developmental, comparative, and affective neuroscience, has drastically changed our ideas of the brain from that of a fixed biological entity to a dynamic bio-cultural system, subject to constant transformations (functional but also structural/anatomical) caused by our ordinary developmental engagement with cultural practices and the material world.

Cognitive archaeology, from its own peculiar cross-disciplinary perspective, can confirm that one of the most distinctive features of human psychology is the extraordinary projective plasticity of mind and its reciprocal openness to cultural influence and variation: We have a plastic mind, which is embedded and inextricably enfolded with a *plastic culture*. Steven Mithen and Lawrence Parssons, echoing the DST thesis we discussed above, have recently taken the argument from plasticity a step further, proposing not only that the brain has continued to evolve in recent times (Mithen & Parssons, 2008), but that it can also be seen as an item of material culture. The brain is as much a cultural artefact as a biological entity. Like any other item of material culture, e.g. a ceramic vessel, the human brain and body can be grown and moulded into different shapes and decorated in different styles. Like a piece of clay, thrown on the wheel of culture, the human mind and brain is subject to continuous re-shaping, re-wiring and re-modelling (cf. also Malafouris, 2008c). The traditional view that takes the brain as a biological constant after the appearance of Homo sapiens and/or modern behaviour needs to be revised. "Although hidden from view within the cranium, the living brain is both an artefact of culture and a cultural artefact" (Mithen & Parssons, 2008).

It's precisely for these reasons that the focus of neuroarchaeology is not restricted to early prehistory but extends in more recent periods of human development. From the viewpoint of neuroarchaeology, human cognitive evolution is primarily based upon an ever-increasing representational flexibility that allows for environmentally and culturally derived plastic changes in the structure and functional architecture of the human brain (Malafouris, 2008a,b, 2009; Renfrew *et al.,* 2008). On this construal, the brain, far from a hard-wired modular organ adapted to a specific ancestral lifestyle emerge as a co-evolutionary process of deep enculturation, projective material engagement (Malafouris, 2004, 2008a,b), and 'profound embodiment' (Clark, 2008, 2007; Wheeler & Clark, 2008), which continues into the present. It is the study of this distinctive feature of the human mind as an extended cognitive system - what we may call *metaplasticity* - that defines the meaning and analytical scope of neuroarchaeology. I should clarify that *metaplasticity* is a term originally coined in neuroscience to refer to the emergent higher-order properties of synaptic plasticity itself and their modification (Zhang & Linden, 2003, p.896). In the context of neuroarchaeology, the term is used in a much broader sense to characterize the emergent properties of the enactive constitutive intertwining between *neural and cultural plasticity* (Malafouris 2009, 2010; Malafouris & Renfrew, 2008).

It follows from what we discussed that this empirical opening of neuroarchaeogy into the biological bases of the human mind does not aim in any way to reduce cultural change, difference, and variability to some innate biological universals. Instead, neuroarchaeology aims: (a) at explaining change and understanding the long-term developmental mechanisms of synergetic co-evolution of brain with culture and the material word, and (b) to understand the nature and meaning of cultural difference and variation across the different levels and temporal scales of human experience and explain how the one affects and interact with the other in evolutionary time. In the former sense neuroarchaeology, drawing on the lines of Material Engagement Theory (MET) (Malafouris, 2004, 2007, 2008a,b; Malafouris & Renfrew 2010; Renfrew, 2004, 2006, 2007) remains primarily concerned with figuring out the causal efficacy of the materiality and the built environment in the human cognitive system. In the second sense, neuroarchaeology can be seen as the cultural neuroscience of the past (Malafouris, 2009). As I discuss elsewhere, both disciplines, although based on a quite different scale of spatial and temporal resolution, share the common objective to investigate and characterize the mechanisms by which the bidirectional, mutual constitution of culture, brain, and genes occur (Chiao & Ambady, 2007, p.238; Chiao, 2009). Explaining cognitive variation is inseparable from the study of how cultural differences came into being which entails close examination of the way cultural phenomena, physical artefacts, and practices were created, transformed, and transmitted across the scales of time. A joint attempt at reconstructing the emergence of this embodied and interactive system in human evolution and its cultural variation could foster a two-way productive dialogue between cultural neuroscience and archaeology (Malafouris, 2009; Malafouris & Renfrew, 2008). To this end, the unique preoccupation of archaeology with material culture, change, long time-spans and large-scale processes can provide an additional means for exploring the emergence of cultural variation.

Methodological considerations: the case of neuroimaging

Having sketched the theoretical and epistemological outline of neuroarchaeology we may turn now on the issue of methods. A series of studies conducted by D. Stout and his colleagues attempting to explore the neural foundations and evolutionary antecedents of complex human tool making and tool using skills by applying functional brain imaging, offer a good example to ground our discussion (Stout *et al.,* 2000; Stout, 2005; Stout & Chaminade, 2007; Stout *et al.,* 2008; Stout & Chaminade, 2009). These studies, integrating evolutionary, archaeological, anthropological and neuroscientific approaches to human tool use, demonstrate the experimental potential and can be used to illustrate the many theoretical and methodological challenges involved.

Take, for instance, the fluorodeoxyglucose positron emission tomography (FDG-PET) study of Oldowan toolmaking (Stout & Chaminade, 2007). In this study, conducted with six inexperienced subjects learning to make stone tools of this early type, Stout & Chaminade (2007) documented, in modern humans, reliance on a parietofrontal (for a recent discussion of available data on the evolution of the fronto-parietal system in the human genus see Bruner & Holloway, 2010) perceptual-motor and grasp system, as well as bilateral activations in the dorsal intraparietal sulcus (IPS) related to human visual specializations (Orban *et al.,* 2006) associated with the distinctive demands of tool making. Of particular interest was the absence of recruitment of prefrontal cortex (PFC) activations associated with strategic action planning. These results suggest the possibility that evolved parietofrontal circuits, enhancing sensorimotor adaptation and affordance perception rather than higher abstract level prefrontal action planning systems and conceptualisations, were central to ESA technological evolution. This observation fit also nicely with current findings from paleoneurology indicating a species-specific neomorphic hyperthrophy of the parietal volumes in modern humans (Bruner, 2010). However, one problem with this study of novice toolmakers was that it did not address the question of skilled expert flaking performance, which might involve strategic elements and neural substrates not implicated in novice toolmaking. To address this question, a follow up study was conducted, involving this time skilled flaking (expert Oldowan and complex Acheulean toolmaking) (Stout *et al.,* 2008). Following the same methods, this second study of expert ESA toolmaking was based on limited sample of three professional archaeologists, each with more than 10 years toolmaking experience. Despite this limited sample size, the FDG-PET procedure yielded a large signal to noise ratio sufficient for statistical analysis. Brain activation data collected for two toolmaking tasks: Oldowan flake production and Acheulean hand axe making and were contrasted with a control task consisting of bimanual percussion without flake production and the results of the previous study with novice inexperienced subjects (Stout *et al.,* 2008, p.1941). Comparisons between Oldowan and Late Acheuelan knapping methods reveal a transition to more complex action organization in the later, accompanied by increased anterior frontal and right hemisphere (RH) contributions. Of particular interest is the RH ventrolateral prefrontal cortex activation, seen only in Late Acheulean knapping and which possibly reflects the emergence of higher levels of intentional organization in flake removal. These higher levels of intentional organization and technical competences in stone knapping can only emerge through deliberate practice and skill acquisition that would have been greatly enhanced and facilitated by joint action and communication. Thus, although imaging data derived from ‘modern’ humans and their tool using abilities cannot offer a direct proof for the co-evolution of tool use and language, they nonetheless clearly support the view that human technological, social and linguistic capacities evolved together in a mutually reinforcing way (e.g. Gibson, 1993).

So what is it that these pilot experiments tell us about the methodological potential of neuroarchaeology? Obviously, archaeology has no direct access to the human brain. Nonetheless, the use of functional MRI has the potential to play a prominent role in neuroarchaeology as part of experimental studies with modern humans. Clearly, there are many problems - not the least because of the constraints imposed by using functional imaging - but there is also a great deal of promise, especially if one considers that brain imaging itself is in a very active state of constant development.

These exciting prospects, however, come with some clear requirements. In particular: First, archaeologists must learn about neuroscience’s methods, data, and presuppositions before deciding which experimental approach and scale of temporal resolution might work best. What is it that a brain activation map actually represents, and how does it relate with broader archaeological issues and questions? Second, archaeologists must take an active role informing and influencing the questions to be asked in the environment of the brain (MRI) scanner and, of course, in interpreting and contextualizing the data derived from these studies against the background of current archaeological problems. The aim of this endeavor should be at establishing testable, empirical, and conceptual links, between brain structure, cognitive function, and archaeologically observable behaviours (see e.g. Wynn *et al.,* 2009). Naturally, there are important restrictions to the inferences that can be drawn about past cognitive operations from imaging data based on experiments with modern subjects. However, as we discussed in the example of tool making abilities, although imaging data from modern humans cannot directly reveal the neural organization of extinct hominin species, if carefully combined with available archaeological, comparative and fossil data, they could help clarify the relative demands of specific, evolutionarily significant behaviours and thus constrain hypotheses about human cognitive evolution (Stout *et al.,* 2008, p.1944). Last, it should be made clear that (a) the cognitive processes and associated neural systems engaged in a complex natural situation may differ substantially from those observed in the purified environment of the lab (cf. Kingstone *et al.,* 2008), which also means that (b) there might well be 'external' components, with a constitutive role for the enactment of a given cognitive operation, that do not correlate to any observed brain activation pattern, or evoked blood oxygenation level dependent (BOLD) response, simply because they do not participate in brain's *space* or *time*.

A final potential pitfall remains and should be pointed out. The epistemic power of the neuroimage, as an enchanting device able to translate and visualise some of the most complicated aspects of human mental life by way of a 'snapshot' view of brain activity, may mislead us to adopt an unwarranted, 'neurocentric' view of human intelligence. This attitude should be resisted by adopting a critical neuroscience perspective (Choudhury *et al.,* 2009) and by explicitly grounding neuroarchaeology, as already discussed, to the principles of material engagement theory (MET) and the distributed cognition approach. As Dietrich Stout reminds us 'PET images do not explain *how* neuronal activity contributes to mental behaviour' what they do indicate is *where* this activity takes place (2005, 280). As archaeologists, we doubt that simply knowing which area of the brain lights up during some task performance, like knapping for example, is the sort of information that will make, *in itself*, a big difference in the study of human cognition. Moreover, neuroimaging techniques often fail to capture the dynamical aspects of thought and behavior which consist of "softly assembled" patterns of activity that arise as a function of time (van Gelder, 1995; Thelen, 1995) (for a good review of the current of progress, problems and prospects of neuroimaging technologies see Miller, 2008). Real progress can only be made through a systematic attempt to contextualise the available knowledge about 'locality' within the temporal and socio-cultural frame of some working hypothesis. The approach of neuroarchaeology focused on explaining mutual constitution of brain, body and culture beyond skin and across the scales of time, may have much to offer to this end protecting us from a sterile neurocentrism that has no place in the archaeology of mind.

Practice-effects

Practice effects (also known as automatization or familiarity effects) relate to the question of how the brain changes in response to practice, or during the process of skill acquisition (Kelly & Garavan, 2005). What are the principles governing experience-dependent plastic changes in the human brain? From an archaeological perspective, knowing about how the brain responds to practice and experience is essential for understanding the neural correlates and temporal structure of learning, memory, innovation, and transmission of cultural skills and practices. Thus, practice effects is a topic particularly pertinent to neuroarchaeology.

Consider for example the knapping PET experiments discussed previously. The recorded changes in brain function in these experiments, provide a good illustration of the important differences between the different stages of skill acquisition (e.g. before vs after learning or novices vs experts). For instance, the evidence of increased sensorimotor and cognitive demands, was related to the changing nature of expert performance and to the complexity of toolmaking methods. Naturally, understanding the effect of practice on the functional anatomy of task performance on a range of motor, visuomotor, perceptual, and cognitive tasks demands a careful identification of the effects of task practice at each level of analysis - from the social, behavioural and cognitive levels, to the level of neuronal function. Nonetheless, the relationship between task practice and neurophysiological change presents additional interest from the view-point of neuroarchaeology, given its unique preoccupation with embodied action and material engagement practices.

A recent review paper by Kelly & Garavan (2005) attempts to explain the particular patterns of practice-related changes observed, and the mechanisms likely to underlie those changes in activation. They distinguish three main patterns of practice-related activation change:

a) *Activation increases* in the brain areas involved in task performance. This pattern refers to both practice-related expansions in cortical representations and increases in the strength of activations. In addition, it usually reflects recruitment of additional cortical units with practice (Poldrack, 2000).
b) *Activation decreases* in the brain areas involved in task performance. Such decreases in the extent or intensity of activations are being associated with increased neural efficiency as the result of more efficient use of specific 'neuronal circuits' or a more precise functional circuit (Garavan *et al.,* 2000; Poldrack, 2000; Petersen *et al.,* 1998).
c) *Functional reorganization* of brain activity across a number of brain areas (Kelly & Garavan 2005, p.1089). This pattern of practice-related reorganization of the functional anatomy of task performance may be distinguished into two types, namely, *redistribution* and *reorganization* both of which constitute some combination of activation increases and decreases (see Fig. 3).

Redistribution, scaffolding and reorganization

Kelly & Garavan (2005) define *redistribution* (Figure 3a) as a form a pseudo-reorganization of functional activations. Specifically, the task activation map contains more or less the same brain regions at the end as at the beginning of practice, but the activation level within those areas has changed (increase or decrease) as a result of practice. More simply, the functional anatomy of the task remains basically the same. Thus the pattern of redistribution of functional activations can be understood and broadly observed as the neurophysiological 'pruning' of attentional and control areas as a result of increasing familiarity with the task. The notion of a scaffolding system that contributes to novel task performance should be noted in this connection (Peterson *et al.,* 1998; Chein & Schneider, 2005). This system refers to the existence of a *scaffolding* network of brain regions which are recruited to cope with the increased cognitive demands of unskilled performance at the early stages of practice, and which, at a later stage, fall away (Fig. 3b). Prefrontal cortex (PFC), anterior cingulate cortex (ACC), and posterior parietal cortex (PPC), are the main areas

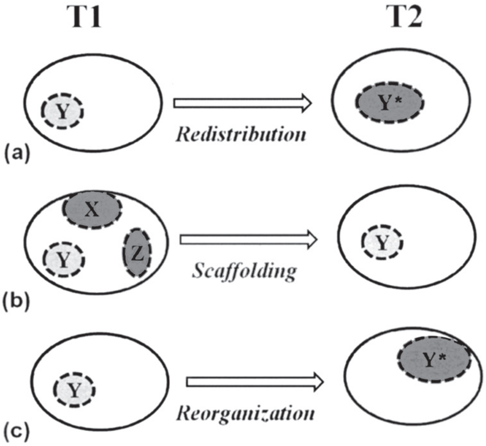

Fig. 3 - Plastic effects associated with practice: (a) Redistribution: the task activation map contains more or less the same brain regions at the end (T2) as at the beginning (T1) of practice but the activation level (Y & Y') within those areas has change (increase or decrease) as a result of practice. More simply, the functional anatomy of the task remains basically the same. (b) Scaffolding: Denotes a network of brain regions (X, Z) which are recruited to cope with the increased cognitive demands of unskilled performance at the early stages of practice (T1), and which at a later stage falls away (T2). (c) Reorganization: a shift in the cognitive processes underlying a given task performance can be observed, which is reflected as a change in the actual location of activations (Y & Y*).

considered to perform the 'scaffolding' role (Kelly & Garavan, 2005). A good example of such a neural *scaffolding* network can be seen in the way activity in the working memory system declines as a function of practice and automatization (e.g. van Raalten *et al.,* 2008). In particular, working memory is closely associated with the information processing and control mechanisms crucially involved in supporting early learning or novel task performance. Several studies in a wide range of cognitive tasks, e.g., mirror reading (Kassubek *et al.,* 2001), motor sequence learning (Toni *et al.,* 1998), verb generation (Raichle *et al.,* 1994), report practice or automatization-induced activity decreases in the working memory system. These decreases in working memory activity after practice, seem to be closely related to one's information processing abilities which reflect how well an individual can manage the complexity of information processing demands when several tasks have to be executed simultaneously. More simply, information processing abilities reflect the amount of tasks that can be processed simultaneously (Ramsey *et al.,* 2004).

Coming now to the case of *reorganization* (Fig. 3c), this refers to an actual shift in the cognitive processes underlying a given task performance. This process switching is reflected as a change in the actual location of activations. What this means is 'that neurobiologically and cognitively, different tasks are being performed at the beginning and end of practice' (Kelly & Garavan, 2005, 1090; see also Poldrack, 2000). The functional neuroanatomy and cognitive processes present early in practice are replaced by different processes and different neuroanatomy late in practice (for a good example in the case of a mirror reading task see (Poldrack *et al.,* 1998; Poldrack & Gabrieli, 2001).

In addition to the above major types or patterns of practice-effects, Kelly & Garavan also identify two further factors that influence the observed practice-related changes: The first factor is t*he effect of task domain* and refers to the divergent effect of practice on functional activations – i.e., increasing activity in sensory/motor tasks and decreasing activation in higher cognitive tasks – due to the differential mechanisms of plasticity between sensory/motor and cognitive domains. The second factor is *the effect of the time-window of imaging* and underlines the importance of *time* in understanding the effects of practice in the functional anatomy of any given task. As Kelly & Garavan observe: "*The point in practice at which participants are imaged has significant effects on the levels of activation observed. In order to make strong conclusions regarding the effects of practice in any study, researchers must be sure they have imaged the entire window of practice-related effects*" (Kelly & Garavan 2005, p.1097).

Another parameter to consider, in this context, is whether practice effects may also exert differing effects on the developing and mature brain. Blakemore *et al.* (2008), to give one example from developmental neuroscience, investigated using fMRI the development, during adolescence, of the neural network underlying thinking about intentions. Comparing brain activation of adolescent and adults answering questions about intentional causality vs physical causality they observed, on the one hand, that adolescents activated part of the medial PFC more than did adults and, on the other hand, that adults activated part of the right STS more than did adolescents. In other words, the neural network of interest remains the same but the relative roles of the different areas that comprise this network change with age - from anterior (medial prefrontal) regions to posterior (temporal) regions. These results suggest that the neural system, and thus the neural strategy, associated with intention understanding changes from early adolescence through to adulthood.

Clearly then, rather than acting in isolation, there are many factors that must be taken into account in the discussion of practice-effects. Moreover, these various factors are interactive, and any number of them can come into play in determining the particular pattern of practice-effects observed in any study. The crucial question for neuroarchaeology in this respect concerns the appropriate 'time window' that will enable us to move across the scales of time. This calls for a methodology that, among other things, must be able to integrate different temporalities (cultural, evolutionary and neuronal). This would be a methodology able to cut across the different temporalities, on the one hand, of a brain activation map obtained during the learning, conception, planning or execution of a given technical or cognitive task, and on the other, of the embodied knowledge of the cultural practices and artefacts that mediate and transmit the same task. Only then we can start thinking about the possible ways that, for instance, in our previous example of tool use, a brain activation map and a *chaîne opératoire* (Schlanger, 1994; Bar-Yosef & Van Peer, 2009) can be combined and complement each other.

From the perspective of neuroscience, this is an objective which can be accomplished by incorporating 'event-related' methods for examining the temporal profile of activity within each region of the brain (Donaldson, 2004; Handy, 2005). In addition, new innovative methods are currently developed which enable the exploration of brain responses measured with fMRI during naturalistic tasks, and thus to address questions (e.g. about social interaction, memory or navigation abilities) that are either difficult, or indeed impossible to explore using conventional passive viewing of static stimuli (see Spiers & Maguire, 2007). From the perspective of neuroarchaeology, we need to place these cognitive events at a different scale of temporal and spatial resolution. A basic precondition for this, however, is to recognize that 'a cognitive process is delimited by the functional relationships among the elements that participate in it, rather than by the spatial collocation of the elements' (Hollan *et al.*, 2000, p.176). Thus, an expansion of the unit of analysis beyond the boundaries of the individual brain in order to incorporate body and culture is a methodological *sine qua non*.

Material engagement and extended reorganization

A preliminary conclusion that can easily be drawn from current findings in the context of practice-related neuroimaging would be that simply measuring the increase or decrease of regional brain activity provides, at best, a partial view about the cognitive or behavioural tasks in question. Even if the same activation pattern can be observed to characterize any single region across several behavioural and cognitive operations, this does not also mean that the interactions of this brain region with other brain regions remained the same. In contrast to the modular pre-specified view of the human mind, where cognition is seen as the additive result of a large number of separable and localizable functions inside the brain, it is becoming increasingly clear that the different brain regions and their functional neural networks work in concert and close interaction. Therefore, a decrease in activation within a particular area may be associated with increased connectivity between that area and another as part of an efficient neural networking strategy to accomplish the task (Kelly & Garavan 2005). Notable here, is the idea of a 'neural context' introduced by McIntosh (1998, 1999) to emphasize and account for the increased connectivity of the human brain. On this construal, the function of a particular brain region should be viewed in terms of the emergent properties of large-scale neural network interactions rather than localized isolated activity. Cognitive operations are the products of such dynamic interactions. So, focusing on the changes in the neural context of activity, that is, the *interactivity* between different brain regions, may be far more significant than focusing on changes in regional activity: "*The important factor is not that a particular event occurred at a particular site, but rather under what neural context did that event occur - in other words, what was the rest of the brain doing?*" (McIntosh, 1998, p.533).

I argue that from a long-term neuroarchaeological perspective we need to extend this logic of interactivity beyond skin and skull and into the realm of cultural practices and artefacts as well (Malafouris, 2008a,b, 2010a,b). But how should we approach and describe interactivity from such an angle? Above all, what possible role material culture might have played in shaping the spatial and temporal patterns of interactivity?

As far as the micro-scale of brain processes is concerned, we suggested, that in order to understand how the brain is changed by practice we need to integrate "analysis of changes in activity within specific regions and patterns of connectivity between regions" (Kelly & Garavan, 2005). But in the case of macro-scale processes of material engagement, I argue, that simply to know what was the rest of the brain doing when a particular activation event occurred, that is, the 'neural context' of activity (McIntosh, 1998, 533), is not enough. The concern of neuroarchaeology is to understand the nature of plastic changes, not at the level of the individual, but at the system level of *metaplasticity*, that is, *where neural and cultural plasticity meet and exchange properties.* At this broader systemic context of social action, 'profound embodiment' (Clark, 2007, 2008), and material engagement (Malafouris, 2004, 2008a,b,c), material culture competes, equally with any other brain region, for a place in the cognitive network. At the level of *metaplasticity* the meaning and scope of *interactivity* takes on a new broader significance. At that level, any decrease or increase of neural activation within any given brain region, may be also the effect of the engagement of that area with another *extra-neural* resource (bodily or artefactual) that although located *outside* the brain they it can be seen as *complementary* and *continuous* with the brain. A good example to consider in this respect is gesture. Recent studies not simply show that gesture is tightly intertwined with speech in timing, meaning, and function, but also suggest that gesturing reduces cognitive load, and thus frees speakers' cognitive resources to perform other tasks (e.g. memory) (Goldin-Meadow & Wagner, 2005, p.238; Goldin-Meadow, 2003). The same enactive logic can be extended to the case of material culture and any other form of cultural practice.

The key metatheoretical difference of neuroarchaeology in comparison to the way the notion of interactivity is being understood within neuroscience is the following: from a neuroscience perspective, *interactivity* is a process that happens between activity regions inside the individual brain as a consequence of practice or other interaction with the world. For neuroarchaeology, on the other hand, interactivity is not an 'internal' consequence of practice or interaction with the material world but *continuous* and *co-extensive* with it. The claim here, as E. Hutchins argues for the distributed cognition approach, "*is that, first and foremost, thinking is interactions of brain fand body with the world. Those interactions are not evidence of, or reflections of, underlying thought processes. They are instead the thinking processes themselves*" (Hutchins 2008, p.2112). As I have argued elsewhere, "*the functional structure and anatomy of the human brain is a dynamic construct of cultural experiences mediated, and often constituted, by the use of material objects and artefacts which for that reason should be seen as continuous integral parts of the human cognitive architecture*" (Malafouris, 2008b, p.404). The aim of this argument, which I call the blind man's stick (BMS) hypothesis from the famous example in phenomenology (Merleau-Ponty, 1962; Bateson, 1973, p.318), is to enable us to think differently about the place and effect of the material world and embodiment inside the mind. The notion of the brain-artefact interface (BAI) nicely exemplifies the above synergy signifying the point of intersection between cognition and material culture (Malafouris, 2010a). It also offers a useful and widely applicable analytic unit for doing away with some deeply misconceived assumptions about the mind's function, ontology, and location.

To illustrate that, let us use the example of a Mycenaean Linear B tablet (Malafouris, in press) (Fig. 4). It cannot be too strongly emphasized that a Linear B tablet, like many other technologies of remembrance, seen as an 'external' memory resource, must have had a major effect on the cognitive structure of the people engaged with this new skill or technique. But how precisely could this effect be understood? Would it be simply a case of cultural scaffolding, where a new external resource is added to support the limited biological capacities of the hippocampus of the Mycenaean scribe? Or, is it something more drastic and closer to the phenomenon of reorganization we discussed previously? In the

Fig. 4 - Mycenaean Linear B tablet (MY Oe 106) from the House of the Oil Merchant at Mycenae (13th century BC). The tablet registers an amount of wool which is to be dyed (ko-ro-to)(National Archaeological Museum of Athens, n. 7671).

case of ‘internal’ brain processes, we said, that the way to discriminate using imaging data true reorganization from redistribution (‘scaffolding’), is by looking at how the cognitive operations underlying task performance are changed through practice. If the cognitive processes are fundamentally changed by practice, then, we have a true reorganization of functional activations which is likely to be reflected in a neurobiologically different task map. I argue that a similar logic can be applied in the case of cultural practices and technologies like that of the Linear B script. The Linear B tablets, more than simply amplifying the Mycenaean memory system, they brought about a radical change into the nature of the cognitive operations involved, and in the functional architecture of the system as a whole. They have effected an *extended reorganisation* (Fig. 5). More simply, the Mycenaean person now engages in a different sort of cognitive behaviour; a new cognitive operation, i.e. reading, now emerges and becomes available in the system (for the possible neurological implications of that see Castro-Caldas *et al.,* 1998). As Merlin Donald was one of the first to point out “unlike the constantly-moving and fading contents of biological working memory, the contents of this externally-driven processor can be frozen in time, reviewed, refined, and reformatted» (Donald, 1991, pp.308-319). The reformattable nature of exograms allows for information to be altered, and then re-entered into storage, in ways that an engram clearly cannot afford. Moreover, the decrease of brain activity in the working memory system that the use of the Linear B tablets have brought about, can be associated with an increase to the overall multitasking ability of the cognitive system (Ramsey *et al.*, 2004). Increased and skilful material engagement often correlates with neuronal disengagement which effects a

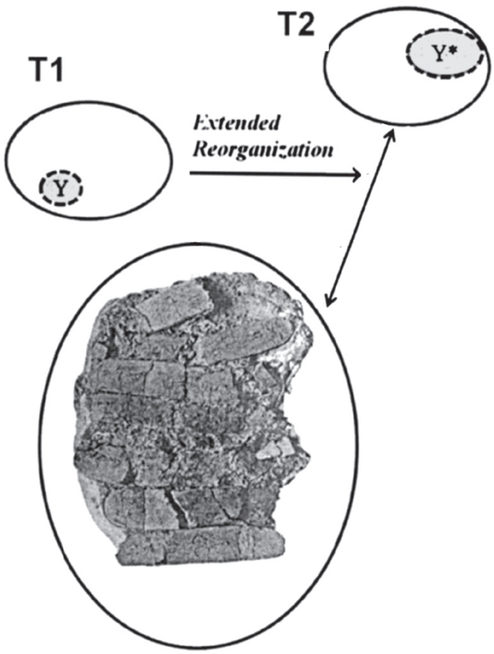

Fig. 5 - The metaplastic process of material engagement depicted schematically here as an extended reorganisation of the Mycenaean cognitive system. The change in the actual location of activations (Y & Y*) makes better sense in the context of transformations caused by the use of the Linear B script. However, to understand the nature of these transformations we need to see the Linear B tablets as an active and continuous, albeit 'extraneural', part of the cognitive system.

liberation of processing resources (e.g. Gilbert *et al.,* 2001), and facilitates 'neural recycling', i.e., the process by which cultural inventions and practices, such as reading and arithmetic, invade evolutionarily older brain circuits and inherit many of their structural constraints (Deheane, 2005; Dehaene & Cohen, 2007).

Important to keep in mind when approaching these issues is that brains, bodies, and things do not replicate, but rather complement each other. Hence instead of asking what region or neural network in the head of the Mycenaean individual is responsible for Mycenaean memory, we should ask how memory is enacted and propagated across people, artefacts, space and time (for discussion of memory as distributed process see esp. Sutton 2008, 2006). The question for neuroarchaeology becomes then one about the possible ways that observed brain changes (functional or anatomical) can be associated with the various 'complementary' strategies and culturally situated tasks that humans recruit when 'adapting the environment instead of Oneself' (Kirsh, 1996, 1995).

Epilogue

From a strictly archaeological perspective, it might seem that the numerous methodological puzzles surrounding any attempt to reconstruct the evolutionary and developmental trajectories that shaped our minds and brains, may appear to fall outside the empirical domain of archaeology proper. So long as neural ensembles and activation patterns do not fossilise, it may seem wiser to forget the brain and focus on the wider and archaeologically visible behavioural adaptations that made humans what they are. This would have been, indeed, a legitimate criticism if neuroarchaeology was to follow the usual old-fashioned 'internalist' strategy aiming to reduce archaeological visible behaviours and changes to the biological or neural level. But, as it has been exemplified in this paper neuroarchaeology is strictly an interactionist approach, aiming primarily to understand the bidirectional links between brains, minds and culture. Brain activity is a crucial component of the human mind but so is also material culture. The human mind as an interactive, embodied, and distributed autonoetic system is neither restricted to nor can it be identified with the temporal and spatial boundaries of the brain within. The real question, then, for archaeology, as with many other disciplines, is not if we should study the brain, but rather how we should study the brain (see also Clark, 1997, p.130).

Consider the example of a potter throwing a vessel on the wheel (Malafouris, 2008c; Knappett & Malafouris, 2008). Try to imagine the complex ways brain, body, wheel, and clay relate and interact with one another throughout the different stages of this activity, and think some of the resources (physical, mental or biological) needed for the enaction of this creative process. Where do we draw the boundary between biology and culture? Where does the potter's brain stop and culture begin? Trying to separate brain, body, and material culture in the above nexus of mediated activity, is like trying to construct a pot keeping your hands clean from the mud. The archaeological record may well testify that significant changes in human cognitive development are the product of engagement processes between humans and the material world of a similar interactive type, realised in different trajectories of cultural development, and of course over longer time spans (from simple tool use, navigating, hunting, and food gathering practices, to more complicated use of symbols and development of the first writing systems). It is becoming increasingly understood, that the neural circuitry and functional anatomy of the brain is changed through the social experience of action. Culturally situated, perceptual, affective, and social experiences, play a definitive role in the acquisition and maturation of neural mechanisms underlying a wide range of fundamental skills. The development of new materials and technologies, as well as of new uses of space and conceptions of time, as these can be observed in the archaeological record, bring about new constraints for the human brain. New styles, materials, manufacture techniques, and cultural practices would put novel demands on the bodies and brains of the people making and using those objects. By the same token, however, all these new artefacts and forms of engagement, construct new interactive possibilities and developmental affordances. The principal concern of neuroarchaeology lies, on the one hand, with identifying the distinctive developmental phases of these processes and, on the other, with understanding the complex ways the variety of cultural scaffolding (either in the form of material artifacts and technologies or in the form of culturally transmitted practices and learning) is able to transform, extend, and re-organise the dynamics of the cognitive system. The challenge ahead of us lies in contextualizing brain activation maps and the associated patterns of *reorganization, redistribution* and *scaffolding* (Poldrack, 2000; Kelly & Garavan, 2005; Quartz & Sejnowski, 1997; Petersen *et al.,* 1998) within their temporally and spatially extended sociotechnical networks. The role of material culture in opening up, objectifying, and helping humans realizing or exploiting new cognitive possibilities, becomes, then, a key object of study.

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