Quaternary International xxx (2015) 1–13

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Scaling up: Material culture as scaffold for the social brain

Fiona Coward

Department of Archaeology, Anthropology and Forensic Science, Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, Dorset BH12 5BB, UK

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Material culture
Social network
Palaeolithic
Neolithic
Distributed cognition

ABSTRACT

Many other species besides *Homo sapiens* are tool-users and even tool-makers, but one aspect of material culture still sets modern humans apart: our emotional and social engagement with objects. Here I argue that this engagement acted as a crucial scaffold for the scaling-up of human social networks beyond those of our closest relatives the chimpanzees to the global 'small world' of modern humans. Material culture plays a vital role in conveying social information about relationships between people, places and things that extend geographically and temporally beyond the here and now – a role which allowed our ancestors to off-load some of the cognitive demands of maintaining such extensive social networks, and thereby surpass the limits to sociality imposed by neurology alone. Broad-scale developments in the archaeological record of the Lower Palaeolithic through to the early Neolithic are used to trace the process by which hominins and humans slowly scaled up their social worlds.

1. Introduction: the small worlds of humans

Homo sapiens are perhaps the most successful mammal species ever. Over 7 billion humans are currently spread, albeit unevenly, across every terrestrial habitat on Earth. However, despite this huge number and vast geographical distribution, humans remain a remarkably densely interconnected species. The concept of 'six degrees of separation' popularized by the eponymous play and film (Guare, 1990, 1993) – the idea that our social networks connect us to everyone else on the planet via an average of only five intermediaries ('the friend of a friend … of a friend') – originally derived from sociological studies conducted by Milgram (1977). Although these have since been criticised (Kleinfeld, 2002), more recent work has provided some qualified support for the figure (Watts and Strogatz, 1998; Leskovic and Horvitz, 2007), and indeed provided even smaller figures, e.g. a figure of 4 from email chains (Dodds et al., 2003), 4.74 from Facebook data (Backstrom et al., 2012) and 3.435–4.67 from Twitter (Bakhshandeh et al., 2005; Cheng, 2010). Regardless of the precise figure itself, it is clear that even in a mind-bogglingly large and complex social world, humans live in 'small worlds' of their own creation.

The implications of this observation are huge. The dense interconnectivity of human societies means that information, genes, diseases and goods of all kinds flow readily between individuals and groups, criss-crossing the globe. On the negative side, such interconnectivity means that the December 2013 outbreak of ebola in Guinea, West Africa, reached Europe and the UK in just nine months. On a more positive note, it also means that researchers from multinational companies based in the US, Europe and Australasia have been able to develop vaccines hoped to be in global use within only two years of the initial outbreak (http://www.who.int/medicines/emp_ebola_q_as/en/). Although this is a deliberately dramatic example, it helps demonstrate that such a dense and interconnected social structure is unlikely to be evolutionarily neutral. I will argue here that strategies and mechanisms for large-scale networking are a major novel evolutionary trait that evolved in the hominin line specifically in order to extend social networks' geographical and temporal reach. I suggest that, as with so many other human behaviours, at first our networking skills depended on specific cognitive adaptations, but a neurological bottleneck ultimately led to our advanced social networking skills being enhanced by a range of externalized behaviours increasingly relying on material culture, leading to the globally networked modern day society we are so familiar with today.

2. Why network?

Humans are a highly social species, a characteristic inherited from our primate ancestors. Many other species from lions (Packer, 1986) to cetaceans (Lusseau, 2003) by way of meerkats (Madden et al., 2009, 2011; Drewe et al., 2009) and goats (Stanley and

E-mail address: fcoward@bournemouth.ac.uk.

http://dx.doi.org/10.1016/j.quaint.2015.09.064
1040-6182/© 2015 Elsevier Ltd and INQUA.

Dunbar, 2013), also live in complex social groups, suggesting that it is a highly adaptive strategy in many circumstances. Many evolutionary 'payoffs' have been identified for group living, including the potential benefits of co-operative foraging, vigilance and defence against predators, easy access to mates and alloparenting (see e.g. Van Schaik, 1983; Chapman and Chapman, 2000; Kramer, 2010 for discussion and references). However, social living is not all positive, and costs include increased competition for mates and food, an increased food budget for the group as a whole, the increased social stress of group living, which may significantly impact fertility (particularly for low-ranked individuals; see Coward and Dunbar, 2014 for references) and the ever-present threat of the social 'free-rider', taking what s/he can get from the group without contributing back (e.g. Dunbar, 1999).

A range of strategies help balance these costs and benefits. In particular, enhanced social 'monitoring' skills mitigate the negative effects of free-riders by enabling individuals to keep track not only of their relationships with one another and the payoffs of those interactions (were sacrifices reciprocated?), but also others' relationships with each other, thus allowing the ongoing 'monitoring' of others' reputations (Dunbar and Shultz, 2010, pp. 778).

Forging supportive coalitions and cliques is another such strategy, allowing individuals to mitigate the increased competition and social stress of life in large, complex groups (Dunbar, 1993). However, it could be argued that this is less a strategy than a logical by-product of expanding group size. In any network, a linear increase in the number of nodes results in an exponential increase in the number of potential connections between those nodes. In a real-world, ecological context such connections – potential relationships – are not resource-neutral. Maintaining relationships requires both time and energy (Roberts, 2010), and as groups expand in size, keeping track of individual relationships imposes significant cognitive costs (Dunbar, 1993; Lehmann et al., 2007).

For many primates, and certainly for our closest living relatives the chimpanzees (*Pan troglodytes* and *Pan paniscus*), the primary mechanism by which relationships are negotiated and maintained is fingertip grooming. Grooming maintains hygiene, but also produces neurochemical rewards which cement relationships between individuals who are subsequently more likely to support one another in disputes (Dunbar, 2010). However, such personal, one-to-one interactions take up time and energy in budgets that are already stressed by the increased time required for feeding in larger groups with more stomachs to feed. Thus, as Dunbar and colleagues have argued, grooming as a strategy for bonding groups quickly imposes a significant threshold for group size (Dunbar, 1992).

Thus as group size increases, individuals must increasingly select only a small fraction of the potential whole on whom to focus their networking efforts. The size of 'cliques' or 'clans' formed of individuals who groom one another regularly therefore decreases, the number of such cliques increases, and the density and connectivity of the group as a whole drops (Kudo and Dunbar, 2001; Lehmann et al., 2010). Unless relationships are maintained between those cliques, the group will fission rather than expand.

The question is, how have some primates managed to overcome these constraints to maintain larger, increasingly fragmented groups? Indeed, I will argue that hominins and particularly humans have turned such fragmentation into an adaptive trait in and of itself.

The hypothesis forwarded by the 'Social Brain Hypothesis' (SBH) is that more complex forms of social cognition are required among species that must negotiate not only *more* social relationships, but also – crucially – the increased social fragmentation and hence more complex relationships with individuals that are not part of your immediate clique (e.g. 'friend of a friend') that inevitably result from increased group size (Dunbar, 2003). This more complex social environment, the SBH contends, is associated with larger brain size (or indeed, vice versa).

Thus, in larger groups the social network that individuals must construct via the relationships s/he pursues, among all the many potential relationships available, necessarily comprises a series of hierarchical levels. The number of individuals at each level increases, while emotional intensity (and time and energy demands) decreases. At the most intimate level, the most time and energy is expended on just a handful (~5) of members of an individual's intimate network, on whom most of the networking time budget is lavished and from whom most support is received. At a more distant remove, a 'sympathy group' or effective network of around 15 individuals take up a significant amount of time and resources, though fewer than the intimate network, and provide proportionally less support in return; more distant still in social space are the members of an individual's 'band', comprising around 50 individuals (see Coward and Dunbar, 2014, pp. 387 for references). Of course, the individual members of these levels are not fixed, but change throughout life as individuals' situations (and those of the others with whom they interact) change (e.g. Roberts, 2010; Roberts and Dunbar, 2011).

Network levels of almost identical size and composition have been identified among both chimpanzees and cross-culturally among humans; our larger social group sizes are not different in kind, but simply in terms of the number of hierarchical levels of social distance we are able to maintain. Most famously, atop the 'band' level, humans have added an 'active network' of around ~150 individuals. Known as 'Dunbar's number', this is the number of individual relationships, it is argued, that the size of our brain (or, more accurately, the proportion of total brain size accounted for by neocortex) allows us to track. Empirical research by proponents of the SBH demonstrates this is an extremely significant threshold in human social groupings even today (Dunbar, 1993; Zhou et al., 2005; Hamilton et al., 2007). However, it is also clear that contemporary humans routinely maintain networks with many more members than this, at commensurately lower levels of input of time, energy and emotional investment. An 'expanded network' of ~400 individuals is frequently identified, and arguably further levels exist beyond this, right up to the 7 billion figure with which we started, connecting all humans into a giant globalized 'small world' in which we can connect ourselves to almost any other individual via only ~5 intermediaries.

If the SBH is correct that cognitive evolution, as manifest in brain size (or specifically, relative neocortex size) explains humans' ability to operate easily in groups of up to ~150 individuals, a question mark remains over how to explain the continued scaling-up of our social networks beyond this threshold. Arguably the outermost levels of this global network have only been added relatively recently – in the last few thousand or even hundred years. Nevertheless, the biggest increase in brain size/neocortical proportion that occurred during hominin evolution in fact occurred well before the speciation of modern humans, around 2–1.5 mya among early hominin species such as *H. erectus* and *H. heidelbergensis* (Gamble, 2010, Fig. 2.1; see also data in Miguel and Henneberg, 2001). Indeed, *Homo sapiens*' brains are absolutely smaller than those of our cousins *Homo neanderthalensis* (Miguel and Henneberg, 2001), although brain shape and organization may have changed (Bruner, 2008; Pearce et al., 2013).

Thus the global expansion of *Homo sapiens* (beginning ~160–70,000bp; see below) post-dates any brain expansion: likewise, the development of long-term communities of considerably more than ~150 individuals dates only to the early Neolithic (~12,000–9,000BCE). During this period some communities are estimated to have increased in size from around 18–59 people in the Late Natufian, to 1170–3822 in the Pre-Pottery Neolithic C

(Kuijt, 2000, Table 1), e.g. at 'Ain Ghazal in Jordan ~7000BCE (Rollefson and Simmons, 1986).

The development of truly 'urban' settlements or cities occurred relatively rapidly thereafter: Uruk in Mespotamia is estimated to have boasted ~80,000 inhabitants by 2800BCE (Modelski, 2003), while by the 1st century BCE between 450,000 and 1 million people are estimated to have lived in Imperial Rome (Storey, 1997). Although post-Roman Empire city populations were much lower, modern cities have increased dramatically in size. The Tokyo conurbation is currently home to around 38 million people and Shanghai nearly 25 million.

Since these dramatic developments have not been accompanied by any increase in brain size in recent human populations, the question is: what strategies have supplemented brain expansion, in order to allow this dramatic increase in the scale of human interaction?

3. Material culture and the 'release from proximity'

Key to this post-speciation geographical and temporal scaling up of human social networks, I argue, is material culture. When objects take on significance beyond their immediate ready-to-hand functionality, they begin to acquire other connotations and thereby fulfil mnemonic functions, becoming externalized loci of memories which act as 'prompts' for and records of the social relationships in which those objects are entangled. They thus essentially 'off-load' the cognitively demanding task of monitoring those social relationships (Coward and Gamble, 2008). It is important to note here that by 'off-load' I do not mean to imply a passive practice; instead, such distributed or external cognition is a highly active process in which cognitive processes extend beyond the biological phenotype to involve other media, not as passive depositories of information but as active elements of cognitive processing (Hutchins, 1995; Clark and Chalmers, 1998). The incorporation of physical alongside the purely neurological manipulation of objects and concepts thus opens up a range of new cognitive possibilities – as well as potential new constraints.

Notably, the significance of material culture in human cultures is still one area that marks us apart from other primates. For humans, objects habitually assume a significance far beyond that of the functional – indeed, at times far beyond the logical (e.g. Appadurai, 1986; Hoskins, 1998; Miller, 2008). Nor is this solely due to our uniquely human capacity for symbolism (although chimpanzees, and particularly captive and human-acculturated chimpanzees, seem able to manipulate symbols in some contexts, their skills appear to be limited to those of a two year old human child (Terrace et al., 1979; Savage-Rumbaugh et al., 1986; Pinker, 1994, pp. 334–341; Lyn et al., 2011)). Material culture studies from across a range of disciplines continue to demonstrate the significance that objects have for humans, even – perhaps especially – in the twenty-first century western world, and the vital role that gifting, exchange and trade of such objects plays in all human societies, in which the specific symbolic meanings of objects are only one element. Thus I and colleagues have argued elsewhere that the emotional engagement with objects is more significant than symbolism and language per se, and that this pre-dates – and indeed, is potentially an important pre-adaptation for – these capacities (Coward and Gamble, 2010; see also papers in DeMarrais et al., 2004; Malafouris, 2007).

There is however very little evidence that other animals, including primates, habitually become attached to objects or assign them any particular significance beyond their immediate use-value. There are some anecdotal reports of acculturated and language-trained apes playing with and bathing dolls, stuffed toys etc. (see summary in Gómez and Martín-Andrade, 2005, pp. 153–161), and of young wild chimpanzees treating logs, sticks of wood or pieces of coconut shell in similar ways to chimpanzee mothers caring for infants (Gómez and Martín-Andrade, 2005, pp. 146). However, such reports are rare, and the significance of the objects themselves, and the temporal and geographical extent of that significance, remain unclear.

Of course, the role of material culture in hominin evolution has long been debated. The manufacture and use of tools by 'man (sic) the tool-maker' was held from very early on to be a uniquely human trait setting us apart from our other primate relatives. However, subsequent research has demonstrated sophisticated tool behaviours not just among the genus *Homo* (Heinzelin et al., 1999; Wood and Constantino, 2007; McPherron et al., 2010; Marzke, 2013; Skinner et al., 2015) or even among great apes (McGrew, 1992; Schaik et al., 1996; Breuer et al., 2005) but also the much more distantly related capuchin monkey (Visalberghi et al., 2013) and many non-primate animal species, from elephants and dolphins to New Caledonian crows, Egyptian vultures, sea otters and octopuses (see e.g. Shumaker et al., 2011 for review and references). The implication is that tool use per se is a highly adaptive strategy in a range of selective environments.

However, some aspects of hominin tool use do point towards some potentially significant differences from that of other animals, even at a very early stage. Most notably, the time-depth of interaction with the material seems to have been significantly extended among hominins in comparison to other animal tool-users. Refitting experiments have documented a greater understanding on the part of hominins of the properties and fracture mechanics of stone (e.g. Delagnes and Roche, 2005), suggesting some cognitive specializations were already in place during the Oldowan some 2.3 mya.

The time-depth of hominin material engagement also extended considerably further than simply the manufacture and use of the object. Chimpanzees overwhelmingly use stone sourced from their immediate vicinity – usually within 20 m, and almost always within 200 m though distances of >500 m have been reported (Boesch and Boesch, 1984, Table 2). However, chimpanzees and other primates including capuchins do return to nut-cracking sites and re-use stones previously employed (Fragaszy et al., 2013; Visalberghi et al., 2013), and recent research has also suggested that apes may curate useful tools (e.g. Mulcahy and Call, 2006) and possibly even 'stockpile' material for predicted needs, suggesting a time depth of several hours for chimpanzee interactions with material culture (Osvath, 2009; Osvath and Karvonen, 2012). Other animals, notably New Caledonian crows, have also been documented to display 'safe-keeping' of tools, albeit over less than 15 min, though longer-term engagement may be within their abilities (e.g. Klump et al., 2015).

In comparison, however, raw material transport data suggest that even in the Oldowan early hominins travelled up to 1–5 km and possibly even 10–13 km (e.g. at Kanjera South; Braun et al., 2008 and references therein) to find suitable raw material on some occasions. In addition, while at some sites the débitage from tool stone manufacture is not accompanied by the 'finished product', at others, stone tools are not accompanied by any evidence of manufacture in situ (Shick, 1987), suggesting frequent movement of both raw materials and 'finished' products, though others argue that some if not all manuports could be explained by non-anthropogenic processes (de la Torre and Mora, 2005). Debate continues about precisely *how* raw materials and stone tools were incorporated into mobility patterns: some researchers suggest that stone was deliberately stockpiled/cached for future use (Potts, 1984, 1988); others that – whether deliberate or accidental – accumulations of used tools subsequently became resources in their own right in a form of niche construction or stigmergy which then

Please cite this article in press as: Coward, F., Scaling up: Material culture as scaffold for the social brain, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.09.064

structured subsequent spatial behaviour (cf. Pope and Roberts, 2005). In any case, it seems clear that even at this early stage of hominin evolution stones and stone tools were routinely carried around the landscape over much greater temporal and geographical scales than known for other primates.

Such frequent and sustained transport and curation suggests that raw material and the objects made from it had plenty of opportunity to become linked in memory to those places where the raw material was acquired, where the stone tools made from it were manufactured and/or where they were used, or re-used, or re-sharped, or found … Such activities would almost certainly have been group activities involving multiple individuals, and in this way, objects such as stone tools could have become mnemonic of particular relationships.

The essential point here is that, unlike events, interactions and relationships, stone (and to a more limited extent wood, bone etc.) persists. It persists in space, so that it can be present at a distance from the raw material source, the cache, the carcass; and it persists in time, acting as an ongoing reminder of the events, interactions and relationships it formed part of. As such, objects provide a mechanism for the 'release from proximity' described by Gamble (1998). This is crucial to maintain group bonds in larger, more fragmented groups that would otherwise fission completely, rather than persisting as fission–fusion societies in which sufficient connectivity is maintained for periodic re-aggregations.

Today, technologies like Facebook, Skype or Twitter (discussed further below) have been specifically designed to allow people to network across time and space – however alongside these technologies, the exchange of material objects continues to perform exactly the same function. Souvenirs remind us of places we have visited and people we have met; postcards, gifts and cards sent on occasions such as birthdays, holidays and other important life events remind us of significant others who may not be present; heirlooms and inheritances remind us even of those who are dead and gone. Such externalized loci of memory serve to outsource some of the cognitive demands imposed by keeping track of relationships not just among those individuals encountered every day, but those who – as in larger, more fragmented fission–fusion societies – may often be absent, perhaps for extended periods of time. Incorporating material culture into our social networks therefore allows the construction of social networks which are remarkably temporally and geographically extensive – indeed, as we have seen, potentially global in scope.

It would be a stretch to argue that Oldowan tools fulfilled precisely this kind of a role. However, the differences in the way that stone and stone tools seem to have been incorporated into hominin lifeways, compared to chimpanzees' pragmatic attitudes to material culture, do seem to represent a step towards this kind of material engagement, and subsequent developments in material culture demonstrate clearly the increasing significance of such mechanisms in hominin evolution.

4. The Acheulean and early expansion out of Africa

As noted above, the earliest hominins to expand their ranges beyond Africa (*Homo georgicus* and *Homo antecessor*) already had relatively large brains and hence presumably proportionally larger neocortices, suggesting the potential for enhanced social cognition and larger group size. However, it is notable that these early expansions out of Africa do not appear to be associated with Acheulean technologies (Carbonell et al., 2010). One possibility is that the groups represented by these sites had left Africa before the development of Acheulean technology – and hence potentially also before the requisite cognitive, technical and social skills had evolved. An alternative possibility is that such groups may have lost whatever skills they possessed during dispersal (e.g. Lycett and von Cramon-Taubadel, 2008). Given the low density of currently-known sites at this time, these are likely to have been small and highly mobile 'pioneer' groups, and extensive modelling simulations suggest that such groups are less likely to be in sufficient contact to maintain minimum 'effective' group size at the regional scale. Hence are much more likely to 'lose' more complex skills through stochastic processes such as the unexpected death of specialist lithic manufacturers in accidents (Shennan, 2001; Henrich, 2004; Powell et al., 2009, 2010; though cf. Read, 2012).

In either case, it does seem suggestive that these early Europeans clearly remained at low densities across the region for some time. Indeed, some archaeologists argue that at least some local groups may have gone extinct relatively quickly (Dennell, 2003). The cannibalism practised at Atapuerca, for example, has been interpreted as a response to severe calorific restriction rather than for any more symbolic reason (Fernández-Jalvo et al., 1999), perhaps suggesting that these hominin groups were rather poorly adapted to high-latitude environments (Dennell, 2003). The much more obviously 'successful' Eurasian expansion by *Homo heidelbergensis* which followed, in contrast, left evidence across the region at a much denser level – significantly, this time, accompanied by abundant evidence of handaxes.

The appearance of handaxes is often interpreted as evidence for more advanced cognitive skills, for example demonstrating the existence of abstract 'mental templates' (see e.g. Malafouris, 2013; Cole, 2015 for discussion and references), or stimulating new neuronal connections or ways of thought that may ultimately have provided pre-adaptations for language (Byers 1999; Stout et al., 2008; Uomini and Meyer, 2013). Such arguments remain controversial, but for many, the additional effort required to produce bifacially worked tools is suggestive of a significance to the object that goes beyond the functional. Some handaxes seem to have been made with considerable care for their aesthetic properties; some contain fossils carefully framed centrally by subsequent working; some are too large to be comfortably used for any conceivable practical purpose; some are found in striking contexts, e.g. the famous 'Excalibur', a handaxe made of distinctive rose quartz which was the sole piece of lithic technology recovered from among the remains of several hundred late *Homo heidelbergensis* and early Neanderthals recovered from the Sima de los Huesos ('pit of the bones') at Atapuerca, a context which perhaps suggests some significance to its deposition at least that goes beyond the purely functional value of the item itself (Carbonell et al., 2003); for further arguments about non-functional roles and meanings of handaxes, see e.g. Byers, 1999; Kohn and Mithen, 1999; Wynn, 2002, pp. 397; Machin et al., 2007; Porr, 2005; Pope et al., 2006; Cole, 2014; though see also e.g. McPherron, 2000.

However, I would argue the specific cognitive skills and potential cultural meanings of handaxes are secondary to the role these objects now played in mediating social relations, and that any specific cultural or potentially even symbolic meanings that may have become attached to them derive primarily from this social function (cf. Gell's argument for the significance of *effect* over *meaning*; 1998). Acheulean technology requires advanced social learning abilities to acquire: the handaxe is an 'opaque' object difficult to retro-engineer, in part because early stages such as 'roughing out' are not easily understood in immediate functional terms but only comprehensible in the light of later stages of the production sequence. Thus learning to make one potentially requires social cognitive skills currently beyond those documented for chimpanzees, such as joint attention (Carpenter and Tomasello, 1995) and, furthermore, *three-way* joint attention between expert, novice and object (Matsuzawa, 2007) and perhaps even Theory of Mind (see e.g. Petraglia et al., 2005, pp. 214–7; Roux et al., 2005;

Please cite this article in press as: Coward, F., Scaling up: Material culture as scaffold for the social brain, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.09.064

Shipton, 2010; Chazan, 2012; Cole, 2015, pp. 255 for further discussion; though see also e.g. Coolidge and Wynn, 2011). Thus individual objects are entangled from the first in the social relationships required to learn and develop the technological skills they require, and it is easy to see how objects are likely to become mnemonic of the particular social relationships involved in their production: physical tokens of social relations.

The painstakingly acquired skills of handaxe manufacture are also likely to be important signifiers of individuals. Among modern humans very few individuals progress to the level of skill required to make a handaxe – although one could of course argue that modern humans, with easy access to B&Q and Tesco, are simply not sufficiently incentivised. However, it may be the case that in hominin societies only some individuals were ever able to become 'expert' knappers, either because of particular innate 'talent' or the wherewithal (and support from others) required to put in the necessary hours of practice (Sinclair, 2015). Markedly variable expertise would have been a potential individual signifier distinguishing particular individuals (perhaps much as other individuals were expert hunters, gatherers, or shamans, or had fathered or borne many children). It may have been a skill to be proud of: something that could be used to attract prestige, better resources and/or mates (cf. Kohn and Mithen, 1999). Thus, skill in manufacturing material culture became not only a mediator of social relations, but also potentially a signifier of specific social roles and statuses.

The significance of such developments becomes clear when one considers the demands placed on hominins' social skills and social networks by the higher latitude environments of Eurasia, and particularly of northwest Europe. At higher latitudes, the reduction in insolation and increased seasonality correlates with a decline in vegetation, while the vegetation that is present is often not in a form accessible directly to hominins. In order to expand into these environments, hominins needed to access the environments' energy stores at the next trophic level, i.e. by significantly increasing the proportion of animal protein in their diets (Gamble, 1993, pp. 199; Pearce et al., 2014).

Because of the significant loss of energy at each trophic level of an ecosystem, animals are much more thinly and patchily distributed across the landscape in both time and space than are plant foods. In the open grasslands of Pleistocene northern Europe during which expansion occurred, most animal biomass came in the form of large groups of ungulates which migrated seasonally across vast grasslands. To be successful in such environments, hominin groups needed to square the circle of increased home ranges, high mobility and low population densities, while at the same time maintaining broader networks sufficiently large to maintain viable breeding demes and to maintain the sophisticated hunting technologies essential for survival at high latitudes. This involves being able to call on sufficient personnel to mount co-operative, communal hunts (an adaptive strategy when predating on herd animals in open landscapes); share information on environments, prey and predators, aka 'topographic gossip'; and also share more tangible goods such as raw material and foods as risk buffering social storage against potential lean times ahead, during which the other group might be called on to reciprocate (Pearce et al., 2014). A fission–fusion style of social organization, in which groups aggregated in favourable locations and at favourable times and disaggregated during leaner periods, would have allowed this flexibility (Grove, 2012; Grove et al., 2012) – but as we have seen, places considerable demands on social cognition that would have been significantly offset by increasingly incorporating material culture into social systems.

In this scenario, the hard cognitive work of remembering individuals, favoured hunting grounds or raw material sources etc. not encountered for months is ameliorated by 'off-loading' memories onto objects playing mnemonic functions. Such objects remind individuals of others who may have made, gifted or exchanged the object or taught them the necessary skills to make it themselves (Pope et al., 2006); hunted or scavenged alongside them while using the object; travelled with them to quarry the raw material, or traded that raw material etc.; and/or reminded them of the places and species encountered during those interactions. Of course, some individuals in the group – men or women who had 'married' in from other groups, potentially even children serving 'apprenticeships' or being fostered, may also have acted as living reminders of other groups and the links forged with them.

Many material objects were left behind at hunting or butchery or scavenging locales; however, this does not necessarily represent an abandoning of those memories, as the objects themselves form only one part of the broader externalized mnemonic system of these hominins – the locales at which objects were discarded may have been favoured places, visited and revisited by the same group or indeed multiple groups over time, potentially acting as stimuli or locales for periodic reaggregation (Grove and Dunbar, 2015). 'Abandoned' objects would have provided not only functional opportunities to re-use objects but also crucial information on what other groups were operating in the landscape and their activities, and thus functioned as inter-group mnemonic prompts instantiating memories of those other groups and potentially even individuals (Pope and Roberts, 2005).

In this way, then, material objects acted to scaffold social networks. Rather than maintaining their entire social networks even in brains that had expanded significantly since the split from the chimpanzee lineage, these hominins were increasingly able to off-load some of that computational load – the mobility, divisibility and longevity of much material culture make it ideal for helping to maintain the complex social relationships required by patchy local environments. Indeed, it could be argued that successful expansion into these more demanding high-latitude environments was not possible until such a stable mechanism for achieving this had been found (Gamble, 1999).

5. Prepared-core technology and Neanderthal material culture

If Acheulean technology requires high levels of technical and cognitive skill, then the demands of prepared-core technology (PCT), known from Africa and Eurasia after around 300bp (Ambrose, 2001) and most commonly associated with the Middle Stone Age (MSA) in Africa and the Middle Palaeolithic of Neanderthals in Europe, are commensurately higher. PCT undoubtedly requires considerable forethought and planning as well as technical skill (Schlanger, 1996; Wynn and Coolidge, 2004; Eren and Lycett, 2012), which of course places further demands on the social skills required to learn and teach. If a case can be made that the Acheulean requires Theory of Mind, it would seem a fundamental requirement for PCT.

In addition, the products of PCT were often hafted as part of multi-component tools. The impressive cognitive and technical accomplishments signalled by composite technologies have been detailed elsewhere (Barham, 2010; Wragg Sykes, 2015). Here I am more interested in the implications of increasing levels of investment in individual objects, and of the increased scale of social connections implied by the multiple chaînes opératoires of composite technologies.

These are no disposable tools, but ones which may have been curated with care, perhaps becoming important and prized possessions. Although recent work has provided an important check on an all-too-common archaeological tendency to focus on big-game hunting at the expense of other foodstuffs (Henry et al., 2011, 2014), it is clear that Neanderthals were high-level carnivores (Richards et al., 2000; Richards and Trinkaus, 2009). Indeed, it is difficult to see how they could have survived in Pleistocene Europe without being adept hunters, and in such circumstances it would seem likely that hunting (and potentially indeed gathering) toolkits would have assumed considerable significance.

Regardless of the ongoing debates surrounding the particulars of Neanderthal foraging strategies, it is clear that Neanderthals expended considerable effort on hunting and presumably also gathering. The necessary equipment may thus have assumed some importance: certainly evidence of repair and recycling of handaxes at sites like Lynford (White, 2012) suggests at least some curation, with some tools apparently carried some considerable distances across the landscape (Turq et al., 2013). It is pure speculation to wonder whether individual spears or points acquired histories of their own; however, certainly favoured lithic resources seem to have acquired some reknown among Neanderthal groups. Although local material from within 5 km and certainly 20 km was predominantly used (Fernandes et al., 2008; Turq et al., 2013), material from some flint sources, especially those with easily identifiable colouring/inclusions etc. – e.g. Bergerac flint – now circulated up to 100 km in southwestern France and 300 km in central Europe, where environmental conditions were harsher (Féblot-Augustins, 1993, 1997), arguably providing a proxy measure of the geographical scale of Neanderthal social networks (Gamble, 1996; Gamble and Steele, 1999; Pearce and Moutsiou, 2014).

Debate also continues over the mechanisms by which this material travelled within this network. Neanderthal individuals or groups may have made specific trips to distant locales to collect particular kinds of raw material, or exchange relationships may have operated between and among Neanderthal individuals and groups along which raw material may have simply been one element. Alternatively, mobility patterns over the course of a year or more would have encompassed a large territory and multiple different potential sources of raw material, some of which were preferentially curated after being collected en route (Féblot-Augustins, 1993; see Mellars, 1996, pp. 163, for discussion). Regardless, preferential utilization of resources transported from greater distances (Geneste, 1988a, 1988b; Kuhn, 2011) suggests not only appreciation of different functional qualities of raw material and willingness to expend energy and resources on obtaining better material, but also individuation of some resources and objects as 'exotic' and 'rare'.

In addition, Neanderthals would almost certainly have noticed differences between individuals in terms of their hunting, gathering and/or lithic manufacturing prowess, contributing further to individual identities that may have gained traction beyond local groups. There is also, of course, intriguing – though controversial – evidence for the deliberate manipulation of material resources in the service of creating identities. There is increasing evidence of Neanderthal exploitation of birds, especially raptors and corvids, to obtain wing feathers in particular – and furthermore, feathers of a particular colour or range of colours (Peresani et al., 2011; Finlayson et al., 2012). Ochre, sometimes in the form of 'crayons', is another relatively common find at Neanderthal sites; jewellery is potentially associated with Neanderthal remains at the Grotte du Renne of Arcy sur Cure (Hublin et al., 1996; although these have recently been questioned due to concerns about potential disturbance; Higham et al., 2010; though cf. Caron et al., 2011; Hublin et al., 2012), while finds of pigment-stained perforated (albeit naturally perforated) cockle shells are known from other Neanderthal sites (Zilhão et al., 2010). While there may be functional explanations for some such finds – for example, ochre could have been used as insect repellents or in tanning and/or and composite technology rather than in bodily decoration (d'Errico et al., 2010) – if such finds are accepted at face value they would suggest deliberate use of material culture to manipulate perceived bodily identities, presumably to enhance social interactions.

Such practices are more common in larger, more socially complex groups – indeed, arguably, they are what allow such groups to develop in the first place. Individuals in small-scale societies engage in extremely complex social interactions and relationships; however, these tend to involve individuals who are very familiar with one another, and who are therefore able to rely on 'restricted' codes of behaviour (Bernstein, 1964; Coser, 1975, pp. 254; cf. Hillier and Hanson, 1984, pp. 236; Wilson, 1988, pp. 101) involving mainly interpretation of bodily *hexis* such as gestures, expressions, bodily postures and movements (Gamble, 1999, pp. 49–51) – and potentially of course also language, though we cannot assume this for Neanderthals. Scaling societies up, however, requires more 'elaborate' codes to compensate for the greater likelihood of increased social distance between interactants. Such codes must thus rely much more heavily on elaborate material culture. If increasing use of material 'props' such as jewellery, feathers and pigments can be demonstrated for Neanderthals, it may suggest an enhancement of 'restricted' codes of primarily bodily communication, perhaps driven by the need for 'special' occasions involving the aggregation of more individuals than usual in order to maintain social networks that had been scaled-up relative to those of earlier hominins.

6. Upper Palaeolithic material culture

It is notable that the material cultures of early *Homo sapiens* do not immediately seem to represent a dramatic break from those of their forebears. Genetic data points to speciation at around 200,000BP (Pearson, 2004; Weaver and Roseman, 2008), consistent with fossil data, particularly the skulls from Omo (~195,000bp) and Herto (~160,000bp) (Bräuer, 2008). Nevertheless, the physiological, behavioural and material culture traits characteristic of *Homo sapiens* develop over extended periods of time in Africa (McBrearty and Brooks, 2000; though cf. Shea, 2011). Early populations in Africa and the Near East continue to use mode 3 lithic technologies, and although finds such as those from Blombos Cave (~75 ka; d'Errico et al., 2005; Henshilwood et al., 2001, 2009) do seem to demonstrate some changes in terms of the complexity material culture integrated into *Homo sapiens*' lives, such finds remain limited until much later.

Given the success of earlier hominins at high latitudes, we can assume that many of the cognitive and socio-ecological requirements for high-latitude success were already in place. Nevertheless, *Homo sapiens* groups did not disperse beyond Africa until some time after speciation. Sites on potential routes out of Africa such as Jebel Faya in the United Arab Emirates, dating to around 125,000bp (Armitage et al., 2011), and beyond Africa at Jwalapuram in India before 77,000bp (Petraglia et al., 2007) and in Australia before ~60,000bp (O'Connell and Allen, 2004), perhaps suggest dispersal began earlier than previously thought. However, a lack of fossils at some sites and disputes over dating at others makes much of this early evidence controversial (Dennell and Petraglia, 2012), though some recent genetic data also suggest relatively early dispersal between 95 and 62,000bp (Fu et al., 2013) and a palaeoecological window for dispersal has been identified at 105–97,000bp (Grove, 2015). However, the bulk of the archaeological evidence dates to rather later: post 45,000bp (O'Connell and Allen, 2004; Shea, 2008), suggesting that any earlier dispersals were limited in terms of numbers, extent and indeed success (Shea, 2003; Mellars, 2006).

Please cite this article in press as: Coward, F., Scaling up: Material culture as scaffold for the social brain, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.09.064

Why did *Homo sapiens* groups not colonize the world much earlier? One difference from earlier dispersals is that this time many areas were already occupied by other hominins. Even assuming low population densities on the part of the previous occupants, these species would have represented an element of much more direct competition than had been the case during earlier dispersals.

One suggestion is that a vital pre-adaptation for dispersal by *Homo sapiens* was a genetic mutation associated with rapid cognitive development underpinning new symbolic capacities, language, art etc. (e.g. Klein, 2008), which resulted in the 'creative explosion' of the Upper Palaeolithic 'revolution'. Such a mutation may have spread rapidly during a severe genetic bottleneck some geneticists believe occurred among *Homo sapiens* in Africa, which reduced numbers to perhaps as few as 10,000 individuals (see e.g. Williams et al., 2009 for review and references). However, there is little evidence for a 'creative explosion' until the admittedly dramatic florescence of art in the European Upper Palaeolithic post ~45,000 bp, while modern human populations across the globe, including groups that reached Southeast Asia long before modern humans arrived in the remote cul-de-sac of western Europe, are the same species and share the same cognitive capacities. Thus a late mutation responsible for artistic ability seems an unlikely explanation for a dispersal which began much earlier.

An alternative explanation focuses on the ecosystemic changes precipitated by the eruption of the Toba supervolcano in Indonesia ~73,000bp. Volcanic ash clouds are likely to have caused severe drought conditions in South and East Africa, and may be the ultimate cause of any dramatic decrease in population density (Ambrose, 1998), although the extent of its impact – both ecologically and on human populations specifically – remains unclear (Ambrose, 2003; Gathorne-Hardy and Harcourt-Smith, 2003; Haslam and Petraglia, 2010; Williams et al., 2010). In this scenario, faced with rapid declines in population density and difficulty in finding food, it would have been increasingly adaptive for *Homo sapiens* to up their networking game (Ambrose, 2002). In order to survive – to gain access to ever-more-scarce and patchy resources, crucial information about the environment, and increasingly rare potential mating partners – humans needed to negotiate and maintain social networks over a great temporal and geographical scale than ever before.

Previous hominins had achieved this through expanding their neocortices. However, there is considerable evidence that the brains of modern humans are reaching, or have already reached, limits as to how far they can be scaled up. Expanding brains may have been offset in earlier hominin evolution by efficiency savings elsewhere, particularly via changing diets (Aiello and Wheeler, 1995), adopting cooking (Wrangham et al., 1999) etc. However, large brains are energetically expensive and cannot store energy: maintaining a supply of energy for the synthesis of complex neurotransmitter chemicals accounts for an increasingly significant proportion of the human energy budget as brains expand. Larger brains also generate greater heat that must be dispersed effectively to reduce thermal overload (Cochrane et al., 1995). However, increased latency and crowding represent perhaps more significant constraints to increasing brain size. In larger brains, action potentials must travel greater distances, increasing conduction time (Klaas, 2000). Processes such as gyrification and myelination bring densely connected regions physically closer together and insulate and speed up long-range signalling (Barton, 2006; White et al., 2009). However, these solutions are costly and exacerbate crowding problems: myelination expands the diameter of axons, while increasing the number of neurons proportionally increases the number supporting glial cells and axons needed to maintain connectivity between them (Sherwood et al., 2006). Thus even marginal increases in grey matter result in significant increases in skull size, with potentially significant ramifications for reproductive success, both because of the difficulty of parturition and the energetic cost of the extended period over which immature infants must be nurtured subsequently (Coward and Grove, 2012).

Furthermore, the complexity of connectivity in such large brains and the increasingly extended periods of development required (Coward and Grove, 2012), may render larger brains more vulnerable to developmental perturbations such as those associated with Autistic Spectrum Disorders or schizophrenia, as well as to degenerative conditions such as Alzheimer's disease and multiple sclerosis etc. If human brains have reached natural scaling limits (Cochrane et al., 1995; Hofman, 2001), then further expansion would likely increase the prevalence of such conditions; any gains in 'brute size' computing power would likely be increasingly marginal, and indeed ultimately maladaptive.

For a solution, we only need to look at the analogous case of 'artificial' computing technology. Only 50 years ago the world's most advanced computers filled entire rooms, or indeed buildings. Today a single smartphone famously contains more computing power than the Apollo rocket. Reductions in the size of components are one explanation, but equally significant has been the rise of networked computing technology. Once computation is networked and computing power distributed via hardwired cable or wireless technology, individual 'units' no longer need to store *all* relevant information locally. Similarly, I would argue, humans were able to complement their brainpower by relying increasingly on the mnemonic, metaphorical and indeed at some point symbolic properties of material culture: off-loading and externally networking social – and ecological – information and thereby reducing the marginal cost of negotiating and maintaining the increasingly extensive social networks that may have been required during the Late Pleistocene, providing them with the edge they needed to expand successfully beyond their ancestral African environments. While the precise dating of the Toba eruption and its environmental consequences remain unclear, it is apparent that such skills would have been highly adaptive during the climatic fluctuations of the Late Pleistocene and the downturn towards the Last Glacial Maximum (LGM).

Such enhanced networking behaviours may well, of course, ultimately be associated with enhanced forms of social cognition such as symbolic capacities and more complex forms of language. However, such adaptations are much more likely to have been selected for within lifeways in which the social behaviours fundamental to 'networking' were already well developed; thus, I would argue, they are unlikely to have involved, any sudden step-changes in cognitive function (e.g. Hodder, 1994). For example, from around 47,000bp in the Near East, mode 4 ('blade') technologies make their debut in the form of the Initial Upper Palaeolithic (Bar-Yosef and Kuhn, 1999; Kuhn and Zwyns, 2014). However, there is no certainty that all the technologies currently grouped under this name were made by the same species, no sudden and monolithic shift from earlier technologies to 'volumetric' blade production techniques (see refs in Coward and Gamble, 2010, pp. 51). Hence claims that this technological shift in emphasis marks a significant cognitive leap forward in *Homo sapiens* compared to previous species are difficult to support (Bar-Yosef and Kuhn, 1999; Kuhn and Zwyns, 2014). The sophistication of prepared-core technologies demonstrates sophisticated spatial and volumetric cognition much earlier, and increased efficiency of mode 4 technologies has yet to be clearly demonstrated (see references in Coward and Gamble, 2010, pp. 51; though see also Bar-Yosef and Kuhn, 1999, pp. 324). A shift towards the 'reliable' technologies adaptive in high-latitude environments, with standardised and thus readily replaceable armatures (Bleed, 1986), seems more persuasive as an explanation for the change in emphasis. In addition, another argument has suggested that the 'big deal about blades' might be the ability to produce multiple standardised blades for distribution around social networks – that the *social* and *networking* significance of these technologies – the production of large numbers of readily exchangeable objects – may be at least as important as their functional use (Coward and Gamble, 2010). Such an interpretation may explain the sporadic outbreaks of similar (if not identical) 'blade' technologies among earlier populations, for example in MSA Africa and potentially also among some Neanderthal groups in the shape of the Châtelperronian, Uluzzian, Szeletian etc. (d'Errico et al., 1998; though see also Benazzi et al., 2011; Higham et al., 2010 and responses by Hublin et al., 2012; Zilhão et al., 2015). Such intensive 'networking' practices may have been more adaptive in particular regions at particular times, potentially afterwards dropping out of common practice for a variety of reasons. For example, the costs involved may no longer have been sustainable in changed ecological situations, good quality raw material may have been less readily available, or the required skills may have been lost in populations which were still perhaps thinly distributed and patchily networked.

Thus at first, *Homo sapiens*' enhanced ability to use material culture to network effectively across time and space may not have given them that much of a fitness advantage over their fellow Europeans the Neanderthals. The rapid and relatively patchy spread of the early Aurignacian across Europe points to relatively low population densities among the incomers (Davies, 2001). Since the low-latitude tundra environments of this time were relatively productive, competition may have been minimal. However, as environments took a turn for the worse competition would inevitably have become more intensive, and here the greater capacity for long-distance and long-term networking afforded by modern humans' intensive reliance on material culture may have finally tipped the scales in their favour. As Neanderthals' numbers declined and populations grew patchy they would have been less and less able to maintain effective social networks. In contrast, where modern humans were forced to live at lower population densities, material cultures could be used in more complex ways to mediate networking among and between groups, providing mechanisms for groups to recognise and hence negotiate and trade and exchange resources such as food, information and mating partners among one another.

Raw material of diverse kinds was now transported and/or traded over increasingly large distances; although early Upper Palaeolithic sites do not show much increase, by the Late Upper Palaeolithic the proportion of material moving over 200 km rises significantly (from ~2 to ~19%; Gamble, 1999, Fig. 6.13), with some shells possibly moving up to 800 km (Floss, 1994) – though of course the most 'exotic' material still makes up only a very small proportion of raw material and tools. More detailed studies of the better-preserved evidence also now provide tantalising glimpses of more specific networks. For example, a necklace of red deer canines from the Aven des Ibousssières in southeastern France shows significant raw materials were accumulated over considerable distances; in addition, more than 90% of the canines comprising the necklace were not accompanied by the paired tooth. The missing 'twins' travelled elsewhere – but perhaps still retained mnemonic, metaphorical and potentially symbolic links with their distant partners, linking the 'owners' and/or bearers of the necklace with others across southwest Europe. The teeth were also decorated and/or perforated by multiple distinct individuals, consistent with 'a network of gift exchanges involving a number of persons' (d'Errico and Vanhaeren, 2002, pp. 229). Similarly, although rather later in date, 'Venus' figurines may have been used to negotiate relationships between individuals and groups in the extremely challenging environments of Eurasia around the height of the LGM and its immediate aftermath (Gamble, 1982).

Similarly, rather than a 'creative explosion' powered by the abrupt evolution of the cognitive capacities for symbolism or language, the elaborate artistic endeavours of the European mid and late Upper Palaeolithic are most persuasively seen as a means of mediating social relations between and among groups at a time when populations increased in density in refugia such as southern France and Spain. As noted above, 'elaborate' social codes supported by reliance on material culture are a characteristic of larger-scale, more permanent societies. Furthermore, living at high densities imposes all of the cognitive stresses of large group size and concomitant fragmentation (living cheek-by-jowl with potential strangers) without the safety valve of periodic fission, and thus causes significant social stress (e.g. Coward and Dunbar, 2014). The remarkable florescence in parietal and mobiliary art at this time can thus be viewed as a response to denser social 'packing' and the consequent need for individual and group identities to be established, negotiated and maintained (Conkey, 1985) in the face of what must have been at some periods significant competition for the rich and geographically and temporally restricted resources of the region, e.g. major migration routes and productive salmon runs (Mellars, 1985). The specific symbolic, metaphorical etc. meanings of the art may be forever lost to us. Nevertheless, extensive ethnographic work among modern humans demonstrates similar use of art and material culture to negotiate identities and relationships among and between groups (Hodder, 1979, 1982; Weissner, 1984, 1998).

The achievements of *Homo sapiens* and our status as the 'last hominin standing' may thus owe less to what is inside our skulls than to the material environments we create. Incorporating more and more material culture into our social networks allowed us not only to expand into challenging environments, like our ancestors, but to thrive and survive in the face of extreme challenges posed by Late Pleistocene environments, and ultimately to out-network our less socially-adept rivals.

7. Epipalaeolithic and early Neolithic developments

Such developments do not of course mark the end-point of human reliance on material culture to run our social lives. As noted above, arguably the biggest scaling-up of networks in human history occurred after the Palaeolithic, during the Epipalaeolithic and early Neolithic, first in the Near East and later elsewhere. During this period, some groups became increasingly sedentary and expanded dramatically in size to become definitive villages, ultimately – but significantly not initially – supported by agricultural lifeways. Notably, these developments are associated with another perceived 'explosion' in material culture (Renfrew, 2008, 2043; see also references in Coward, 2013, pp. 247).

I have argued elsewhere (Coward, 2010) that material culture was also fundamental to this dramatic and far-reaching development in social organization. The hierarchical nature of social networks means that increasing group size resulted in individuals being familiar with only increasingly small proportions of the overall group. Living in at least semi-permanent villages, however, they were nevertheless required to interact on a daily basis with virtual strangers – potentially stressful, complicated and liable to strain the fabric of social order to the point of fission. The use of material culture environments made this considerably easier by off-loading some of the social cues required (Altman and Lett, 1970, Fig. 1; Rapoport, 1981, pp. 30, 1990, pp. 16; Strum and Latour, 1987; Sanders, 1990, pp. 71; Gamble, 1998; papers in Kent, 1990 in reference to architecture). Information about the relative roles and statuses of unfamiliar others was increasingly conveyed by material culture such as (presumably) dress and associated accoutrements – a process that arguably began with Neanderthal use of pigments, shell jewellery and feathers, as noted above. The increasingly elaborate and specialized material environments and contexts within which these early Neolithic interactions were occurring (a workshop; a 'religious' or 'special' communal building etc.), though opaque to archaeologists, were easily 'read' by those familiar with the social order and allowed interactions to proceed smoothly despite the social fragmentation that is the inevitable consequence of group size. Indeed, I argue that such elaborate material cultures are not a product of, but a prerequisite for, increased social scale, and this shift from 'complex' to 'complicated' social performance (Strum and Latour, 1987) becomes ever more significant as social scale increases with the rise of cities, states and empires. Sociological, geographical and anthropological work in modern cities demonstrates clearly the enormous significance of material culture environments in structuring human interaction, activity and identity (e.g. Hillier and Hanson, 1984; Miller, 2008), and the implications of complex, hierarchical social networks for human relationships in large-scale societies – both positive (e.g. community spirit; 'big society') and negative (e.g. the 'bystander problem'; papers in Milgram, 1977).

8. Where next?

All of the above inevitably leads to the question of future developments. Today traditional material culture practices have been added to by networking technologies specifically designed to enhance our networking prowess. Writing; mass printing technologies; postal services; telegrams; phones; the internet; specific software such as Facebook, Twitter and Skype etc. continue to reduce the costs of networking across huge distances – though it is notable that the fundamental physiological/cognitive constraints still seem to apply (Gonçalves et al., 2011; Arnaboldi et al., 2013; Dunbar et al., 2015). Cloud storage and Wikipedia reduce the need for individuals to 'remember' 'facts' and increasingly act as extended cognitive phenotypes, building on the function of books to be constantly available and updateable: outsourced external storage of a species-wide knowledge bank that can be accessed at will. Are humans evolving towards a single 'hive mind'? The ramifications are fascinating, with various researchers pointing to both the strengthening of local communities and increasing global homogenization of cultures as a result (Robertson, 1995; Albrow et al., 2003).

Furthermore, with *Homo sapiens* a globally networked species, is the next step an extra-global one? How might our evolved networking skills cope with the challenges of scaling up still further? With the Mars 1 programme forging ahead (http://www.mars-one.com/), we need to consider the challenges posed to our networking skills by the psychological privations of space travel. The effects of delays in even modern communications technologies inherent in communication across such enormous distances is one obvious factor. Once established on a different planet the challenges only grow more significant: human children born on Mars would be unlikely to be able to return to Earth because of the physiological effects of reduced gravity on Mars and in space during the long journey times involved – indeed, even Earth-born cosmonauts would find it difficult to return. This could create new local clusters in the now inter-planetary *Homo sapiens* network with potentially significant implications for cultural variation and indeed potentially the development of sub-species. All of this may seem the stuff of science fiction at present, but represent logical and fascinating developments from the long-term patterns laid out here. What role – if any – might material culture play in creating material environments which promote certain psychologies or physiologies, or in maintaining (or severing) links with far-flung communities and species?

9. Conclusion

In this paper, then, I have argued that the increasing incorporation of material culture into hominin and human social networks is fundamental to the scaling-up of those networks in time and space which has propelled us from just one group of African savannah-dwelling primate species to the globally dominant and globally distributed species we are today (I leave out, here, any discussion of the pros and cons of this development for global ecosystems more generally). I would argue that increasing reliance on material culture has enhanced the purely physiological social cognition afforded by our expanded brains to scaffold social relations and interactions among and between individuals and groups, establishing the potential for the large-scale co-operation which has proven fundamental to our survival in tough environments, and hence to our global expansion.

How might such a long-term process as that identified here be studied in more detail? Recent developments in the use of formal network analysis techniques for the study of long-term cultural and social developments suggest one potential way forward (Coward, 2010; Knappett, 2013; papers in Collar et al., 2015; papers in Brughmans et al., in press). However, the Palaeolithic poses a significant challenge to such approaches by the simple fact that very little material culture survives – and indeed, the argument itself predicts very little use of material culture in the early stages. Thus, although I do consider the potential of network analysis, particularly in the later Palaeolithic, to be currently underexplored, I would suggest that modelling and simulation also provide a useful way forward. We have a good idea of the environmental conditions in which scaled-up social networks are likely to be adaptive – notably, challenging poor or seasonal environments – and palaeoecological data available at sufficiently high resolution to allow regional-scale modelling are increasingly becoming available. Studying how various ecological parameters such as environmental variability (for which seasonality/latitude might be used as a proxy) might affect group size (for which brain size could be used as a proxy), or social cognition (which might plausibly be guesstimated from measures of the learning/teaching abilities required to manufacture different types of material culture) might not reveal the social networks of our ancestors themselves. However, it would help elucidate the geographical and temporal scales over which those networks may have operated, how and why they have been so markedly scaled up in space and time over the course of human evolution, and where such processes may take us next.

Acknowledgements

The ideas laid out here were first developed during the British Academy Centenary Project 'From Lucy to Language: the archaeology of the social brain', and the author gratefully acknowledges the influence of project members, as well as the helpful comments of two anonymous reviewers. Thanks also to the organizers of and participants in the TAG session at which an early version of the ideas discussed here were presented and discussed.

References

Aiello, L.C., Wheeler, P., 1995. The expensive-tissue hypothesis: the brain and the digestive system in human and primate evolution. Current Anthropology 36 (2), 199–221.

Albrow, M., Eader, J., Dürrschmidt, J., Washbourne, N., 2003. The impact of globalization on sociological concepts: community, culture and milieu. In: Eade, J.

(Ed.), Living the Global City: Globalization as Local Process. Routledge, London, pp. 19–34.
Altman, I., Lett, E., 1970. The ecology of interpersonal relationships: a classification system and conceptual model. In: McGrath, J.E. (Ed.), Social and Psychological Factors in Stress. Holt, Rinehart & Winston, New York, pp. 177–201.
Ambrose, S., 1998. Late Pleistocene human population bottlenecks, volcanic winter, and differentiation of modern humans. Journal of Human Evolution 34, 623–651.
Ambrose, S., 2001. Paleolithic technology and human evolution. Science 291, 1748–1753.
Ambrose, S.H., 2002. Small things remembered: origins of early microlithic industries in sub-Saharan Africa. In: Elston, R., Kuhn, S. (Eds.), Thinking Small: Global Perspectives on Microlithization. Archaeological Papers of the American Anthropological Association, No. 12, Washington, D.C., pp. 9–29
Ambrose, S.H., 2003. Did the super-eruption of Toba cause a human population bottleneck? Reply to Gathorne-Hardy and Harcourt-Smith. Journal of Human Evolution 45 (3), 231–237.
Appadurai, A., 1986. The Social Life of Things: Commodities in Cultural Perspective. Cambridge University Press, Cambridge.
Armitage, S.J., Jasim, S.A., Marks, A.E., Parker, A.G., Usik, V.I., Uerpmann, H.-P., 2011. The southern route "Out of Africa": evidence for an early expansion of modern humans into Arabia. Science 331 (6016), 453–456.
Arnaboldi, V., Guazzini, A., Passarella, A., 2013. Egocentric online social networks: analysis of key features and prediction of tie strength in Facebook. Computer Communications 36 (10–11), 1130–1144.
Backstrom, L., Boldi, P., Rosa, M., Ugander, J., Vigna, S., 2012. Four Degrees of Separation arXiv.org Computer Science, Social and Information Networks, arXiv: 1111.4570.
Bakhshandeh, R., Samadi, M., Azimifar, Z., Schaeffer, J., 2005. Degrees of separation in social networks. In: Fourth Annual Symposium on Combinatorial Search. http://www.aaai.org/ocs/index.php/SOCS/SOCS11/paper/view/4031.
Bar-Yosef, O., Kuhn, S., 1999. The big deal about blades: laminar technologies and human evolution. American Anthropologist 101, 322–338.
Barham, L., 2010. A technological fix for 'Dunbar's Dilemma'? In: Dunbar, R., Gamble, C., Gowlett, J. (Eds.), Social Brain, Distributed Mind. Oxford University Press for the British Academy, Oxford, pp. 367–390.
Barton, R.A., 2006. Primate brain evolution: integrating comparative, neurophysiological, and ethological data. Evolutionary Anthropology 15, 224–236.
Benazzi, S., Douka, K., Fornai, C., Bauer, C.C., Kullmer, O., Svoboda, J., Pap, I., Mallegni, F., Bayle, P., Coquerelle, M., Condemi, S., Ronchitelli, A., Harvati, K., Weber, G.W., 2011. Early dispersal of modern humans in Europe and implications for Neanderthal behaviour. Nature 479 (7374), 525–528.
Bernstein, B., 1964. Elaborated and restricted codes: their social origins and some consequences. American Anthropologist 66 (6(2)), 55–69.
Bleed, P., 1986. The optimal design of hunting weapons: maintainability or reliability. American Antiquity 51, 737–747.
Boesch, C., Boesch, H., 1984. Mental map in wild chimpanzees: an analysis of hammer transports for nut cracking. Primates 25 (2), 160–170.
Bräuer, G., 2008. The origin of modern anatomy: by speciation or intraspecific evolution? Evolutionary Anthropology: Issues, News, and Reviews 17 (1), 22–37.
Braun, D.R., Plummer, T., Ditchfield, P., Ferraro, J.V., Maina, D., Bishop, L.C., Potts, R., 2008. Oldowan behavior and raw material transport: perspectives from the Kanjera Formation. Journal of Archaeological Science 35 (8), 2329–2345.
Breuer, T., Ndoundou-Hockemba, M., Fishlock, V., 2005. First observation of tool use in wild Gorillas. PLoS Biology 3 (11), e380.
Brughmans, T., Collar, A.C.F., Coward, F., 2015. The Connected Past: Challenging Networks in Archaeology and History. Oxford University Press, Oxford (in press).
Byers, A.M., 1999. Communication and material culture: Pleistocene tools as action cues. Cambridge Archaeological Journal 9 (1), 23–41.
Bruner, E., 2008. Comparing endocranial form and shape differences in modern humans and Neandertal: a geometric approach. PaleoAnthropology 93–106.
Carbonell, E., Mosquera, M., Olle, A., Rodriguez, X.P., Sala, R., Verges, J.M., Arsuaga, J.L., Bermudez de Castro, J.M., 2003. Did the earliest mortuary practices take place more than 350 000 years ago at Atapuerca? L'Anthropologie 107 (1), 1–14.
Carbonell, E., Ramos, R.S., Rodríguez, X.P., Mosquera, M., Olléa, A., Vergèsa, J.M., Martínez-Navarro, B., Castro, J.M.B.d, 2010. Early hominid dispersals: a technological hypothesis for "out of Africa". Quaternary International 223–224, 36–44.
Caron, F., d'Errico, F., Del Moral, P., Santos, F., Zilhão, J., 2011. The reality of Neandertal symbolic behavior at the Grotte du Renne, Arcy-sur-Cure, France. PLoS One 6 (6), e21545.
Carpenter, M., Tomasello, M., 1995. Joint attention and imitative learning in children, chimpanzees, and enculturated chimpanzees. Social Development 4 (3), 217–237.
Chapman, Colin A., Chapman, L.J., 2000. Determinants of group size in primates: the importance of travel costs. In: Boinski, S., Garber, P.A. (Eds.), On the Move: How and Why Animals Travel in Groups. University of Chicago Press, Chicago, pp. 24–42.
Chazan, M., 2012. Handaxes, concepts, and teaching mind, brain, and education, 6 (4), 197–203.
Cheng, A., 2010. Six Degrees of Separation, Twitter Style.
Clark, A., Chalmers, D., 1998. The extended mind. Analysis 58, 10–23.
Cochrane, P., Winter, C.S., Hardwick, A., 1995. Biological Limits to Information Processing in the Human Brain. http://archive.cochrane.org.uk/opinion/archive/articles/brain9a.php.
Cole, J., 2014. The identity model: a theory to access visual display and hominin cognition within the Palaeolithic. In: Dunbar, R.I.M., Gamble, C., Gowlett, J.A.J. (Eds.), Lucy to Language: the Benchmark Papers. OUP, Oxford, pp. 90–107.
Cole, J., 2015. Handaxe symmetry in the Lower and Middle Palaeolithic: implications for the Acheulean gaze. In: Coward, F., Hosfield, R.T., Pope, M., Wenban-Smith, F. (Eds.), Settlement, Society and Cognition in Human Evolution: Landscapes in Mind. CUP, Cambridge, pp. 234–257.
Collar, A., Coward, F., Brughmans, T., Mills, B., 2015. The connected past: critical and innovative approaches to networks in archaeology. Journal of Archaeological Method and Theory Special Issue 22 (1).
Conkey, M.W., 1985. Ritual communication, social elaboration, and the variable trajectories of Paleolithic material culture. In: Douglas-Price, T., Brown, J.A. (Eds.), Prehistoric Hunter-Gatherers: the Emergence of Cultural Complexity. Academic Press, New York, pp. 299–319.
Coolidge, F.L., Wynn, T., 2011. Comment on Henshilwood, C. S., & Dubreuil, B. (2011). The still Bay and Howiesons Poort, 77–59 ka. Current Anthropology 52 (3), 361–400.
Coser, R., 1975. The complexity of roles as seedbed of individual autonomy. In: Coser, L.A. (Ed.), The Idea of Social Structure: Essays in Honor of Robert Merton. Harcourt Brace Jovanovich, New York, pp. 237–265.
Coward, F., 2010. Small worlds, material culture and ancient near eastern social networks. In: Dunbar, R., Gamble, C., Gowlett, J. (Eds.), Social Brain, Distributed Mind. British Academy, London, pp. 449–480.
Coward, F., 2013. Grounding the net: social networks, material culture and geography in the Epipalaeolithic and early Neolithic of the near east (~21,000–6,000 cal BCE). In: Knappett, C. (Ed.), Network Analysis in Archaeology. Oxford University Press, Oxford, pp. 247–280.
Coward, F., Dunbar, R.I.M., 2014. Communities on the edge of civilisation. In: Dunbar, R.I.M., Gamble, C., Gowlett, J.A.J. (Eds.), Lucy to Language: the Benchmark Papers. Oxford University Press, Oxford, pp. 380–405.
Coward, F., Gamble, C., 2008. Big brains, small worlds: material culture and human evolution. Philosophical Transactions of the Royal Society Series B 363, 1969–1979.
Coward, F., Gamble, C., 2010. Materiality and metaphor in earliest prehistory. In: Malafouris, L., Renfrew, C. (Eds.), The Cognitive Life of Things: Recasting the Boundaries of the Mind. McDonald Institute, Cambridge, pp. 47–58.
Coward, F., Grove, M., 2012. Rethinking phylogeny and ontogeny in hominin brain evolution. Human Origins 1, 65–91.
d'Errico, F., Henshilwood, C., Vanhaeren, M., van Niekerk, K., 2005. Nassarius kraussianus shell beads from Blombos Cave: evidence for symbolic behaviour in the Middle Stone Age. Journal of Human Evolution 48 (1), 3–24.
d'Errico, F., Vanhaeren, M., 2002. Criteria for identifying red deer (*Cervus elaphus*) age and sex from their canines. Application to the study of Upper Palaeolithic and Mesolithic ornaments. Journal of Archaeological Science 29, 211–232.
d'Errico, F., Zilhão, J., Julien, M., Baffier, D., Pelegrin, J., 1998. Neanderthal acculturation in Western Europe?: a critical review of the evidence and its interpretation. Current Anthropology 39, S1–S44 (2: Supplement: Special Issue: The Neanderthal Problem and the Evolution of Human Behavior).
d'Errico, F., Salomon, H., Vignaud, C., Stringer, C., 2010. Pigments from the middle Palaeolithic levels of Es-Skhul (Mount Carmel, Israel). Journal of Archaeological Science 37 (12), 3099–3110.
Davies, W., 2001. A very model of a modern human industry: new perspectives on the origins and spread of the Aurignacian in Europe. Proceedings of the Prehistoric Society 67, 195–217.
de la Torre, I., Mora, R., 2005. Unmodified lithic material at Olduvai Bed I: manuports or ecofacts? Journal of Archaeological Science 32 (2), 273–285.
Delagnes, A., Roche, H., 2005. Late Pliocene hominid knapping skills: the case of Lokalalei 2C, West Turkana, Kenya. Journal of Human Evolution 48, 435–472.
DeMarrais, E., Gosden, C., Renfrew, C. (Eds.), 2004. Rethinking Materiality: the Engagement of Mind with the Material World. McDonald Institute Monographs, Cambridge.
Dennell, R., 2003. Dispersal and colonisation, long and short chronologies: how continuous is the Early Pleistocene record for hominids outside East Africa? Journal of Human Evolution 45, 421–440.
Dennell, R., Petraglia, M.D., 2012. The dispersal of Homo sapiens across southern Asia: how early, how often, how complex? Quaternary Science Reviews 47 (0), 15–22.
Dodds, P.S., Muhammad, R., Watts, D.J., 2003. An experimental study of search in global social networks. Science 301 (5634), 827.
Drewe, J.A., Madden, J.R., Pearce, G.P., 2009. The social network structure of a wild meerkat population: 1. Inter-group interactions. Behavioral Ecology and Sociobiology 63 (9), 1295–1306.
Dunbar, R., Shultz, S., 2010. Bondedness and sociality. Behaviour 147 (7), 775–803.
Dunbar, R.I.M., 1992. Neocortex size as a constraint on group size in primates. Journal of Human Evolution 20, 469–493.
Dunbar, R.I.M., 1993. Coevolution of neocortical size, group size and language in humans. Behavioral and Brain Sciences 16, 681–735.
Dunbar, R.I.M., 1999. Culture, honesty and the freerider problem. In: Dunbar, R.I.M., Knight, C., Power, C. (Eds.), The Evolution of Culture. Edinburgh University Press, Edinburgh, pp. 194–213.
Dunbar, R.I.M., 2003. The social brain: mind, language and society in evolutionary perspective. Annual Review of Anthropology 32, 163–181.

Dunbar, R.I.M., 2010. The social role of touch in humans and primates: behavioural function and neurobiological mechanisms. Neuroscience & Biobehavioral Reviews 34 (2), 260–268.
Dunbar, R.I.M., Arnaboldi, V., Conti, M., Passarella, A., 2015. The structure of online social networks mirrors those in the offline world. Social Networks 43, 39–47.
Eren, M.I., Lycett, S.J., 2012. Why Levallois? a morphometric comparison of experimental 'Preferential' Levallois flakes versus debitage flakes. PLoS One 7 (1), e29273.
Féblot-Augustins, J., 1993. Mobility strategies in the Late Middle Palaeolithic of Central Europe and Western Europe: elements of stability and variability. Journal of Anthropological Archaeology 12, 211–265.
Féblot-Augustins, J., 1997. La circulation des matières premières au Paléolithique. ERAUL, Liège.
Fernández-Jalvo, Y., Carlos Díez, J., Cáceres, I., Rosell, J., 1999. Human cannibalism in the Early Pleistocene of Europe (Gran Dolina, Sierra de Atapuerca, Burgos, Spain). Journal of Human Evolution 37 (3–4), 591–622.
Fernandes, P., Raynal, J.-P., Moncel, M.-H., 2008. Middle Palaeolithic raw material gathering territories and human mobility in the southern Massif Central, France: first results from a petro-archaeological study on flint. Journal of Archaeological Science 35 (8), 2357–2370.
Finlayson, C., Brown, K., Blasco, R., Rosell, J., Negro, J.J., Bortolotti, G.R., Finlayson, G., Sánchez Marco, A., Giles Pacheco, F., Rodríguez Vidal, J., Carrión, J.S., Fa, D.A., Rodríguez Llanes, J.M., 2012. Birds of a feather: Neanderthal exploitation of raptors and corvids. PLoS One 7 (9), e45927.
Floss, H., 1994. Rohmaterielversorgung im Paläolithikum des Mittelrheingebietes. Habelt, Römisch-Germanisches Zentralmuseum, Forschunginstitut für Vor–und Frühgeschichte 21, Bonn.
Fragaszy, D.M., Biro, D., Eshchar, Y., Humle, T., Izar, P., Resende, B., Visalberghi, E., 2013. The fourth dimension of tool use: temporally enduring artefacts aid primates learning to use tools. Philosophical Transactions of the Royal Society B: Biological Sciences 368 (1630), 1–10.
Fu, Q., Mittnik, A., Johnson, Philip L.F., Bos, K., Lari, M., Bollongino, R., Sun, C., Giemsch, L., Schmitz, R., Burger, J., Ronchitelli, Anna M., Martini, F., Cremonesi, Renata G., Svoboda, J., Bauer, P., Caramelli, D., Castellano, S., Reich, D., Pääbo, S., Krause, J., 2013. A revised timescale for human evolution based on ancient mitochondrial genomes. Current Biology 23 (7), 553–559.
Gamble, C., 1982. Interaction and alliance in Palaeolithic society. Man 17, 92–107.
Gamble, C., 1993. Timewalkers: the Prehistory of Global Colonization. Penguin Books, London.
Gamble, C., 1996. Making tracks: hominid networks and the evolution of the social landscape. In: Steele, J., Shennan, S. (Eds.), The Archaeology of Human Ancestry: Power, Sex and Tradition. Routledge, London, pp. 253–277.
Gamble, C., 1998. Palaeolithic society and the release from proximity: a network approach to intimate relations. World Archaeology 29 (3: Intimate Relations), 426–449.
Gamble, C., 1999. The Palaeolithic Societies of Europe. Cambridge University Press, Cambridge.
Gamble, C., 2010. Technologies of separation and the evolution of social extension. In: Dunbar, R., Gamble, C., Gowlett, J. (Eds.), Social Brain, Distributed Mind. Oxford University Press for the British Academy, Oxford, pp. 17–42.
Gamble, C., Steele, J., 1999. Hominid ranging patterns and dietary strategies. In: Ullrich, H. (Ed.), Hominid Evolution: Lifestyles and Survival Guides, pp. 396–409.
Gathorne-Hardy, F.J., Harcourt-Smith, W.E.H., 2003. The super-eruption of Toba, did it cause a human bottleneck? Journal of Human Evolution 45 (3), 227–230.
Gell, A., 1998. Art and Agency: an Anthropological Theory. Clarendon Press, Oxford.
Geneste, J.-M., 1988a. Les industries de la Grotte Vaufrey: technologies du débitage, économie et circulation du matière première lithique Mémoires de la Société. In: Préhistorique Française special issue: La Grotte Vaufrey à Cenac et Saint-Julien (Dordogne), Paléoenvironments, chronologie et activités humaines, vol. 19, pp. 441–518.
Geneste, J.-M., 1988b. Systèmes d'approvisionnement en matières premières au Paléolithique moyen et au Paléolithique supérieur en Aquitaine. L'homme de Néandertal 8, 61–70.
Gómez, J.-C., Martín-Andrade, B., 2005. Fantasy play in apes. In: Pellegrini, A.D., Smith, P.K. (Eds.), The Nature of Play: Great Apes and Humans. The Guilford Press, New York, pp. 139–172.
Gonçalves, B., Perra, N., Vespignani, A., 2011. Modeling users' activity on twitter networks: validation of Dunbar's number. PLoS One 6 (8), e22656.
Grove, M., 2012. Space, time, and group size: a model of constraints on primate social foraging. Animal Behaviour 83 (2), 411–419.
Grove, M., 2015. Palaeoclimates, plasticity, and the early dispersal of Homo sapiens. Quaternary International 369 (0), 17–37.
Grove, M., Dunbar, R., 2015. Local objects, distant symbols: fission-fusion social systems and the evolution of human cognition. In: Coward, F., Hosfield, R.T., Pope, M., Wenban-Smith, F. (Eds.), Settlement, Society and Cognition in Human Evolution: Landscapes in Mind. CUP, Cambridge, pp. 15–30.
Grove, M., Pearce, E., Dunbar, R.I.M., 2012. Fission-fusion and the evolution of hominin social systems. Journal of Human Evolution 62 (2), 191–200.
Guare, J., 1990. Six Degrees of Separation. Random House, New York.
Guare, J., 1993. Six Degrees of Separation. MGM/UA Home Entertainment, Los Angeles.
Hamilton, M.J., Milne, B.T., Walker, R.S., Burger, O., H, B.J., 2007. The complex structure of hunter-gatherer social networks. Proceedings of the Royal Society B: Biological Sciences 271, 2195–2202.
Haslam, M., Petraglia, M., 2010. Comment on "Environmental impact of the 73 ka Toba super-eruption in South Asia" by M.A.J. Williams, S.H. Ambrose, S. van der Kaars, C. Ruehlemann, U. Chattopadhyaya, J. Pal and P.R. Chauhan. Palaeogeography, Palaeoclimatology, Palaeoecology 284 (2009), 295–314. Palaeogeography, Palaeoclimatology, Palaeoecology 296 (1–2), 199–203.
Heinzelin, J.d., Clark, J.D., White, T., Hart, W., Renne, P., WoldeGabriel, G., Beyene, Y., Vrba, E., 1999. Environment and behavior of 2.5-million-year-old Bouri hominids. Science 284 (5414), 625–629.
Henrich, J., 2004. Demography and cultural evolution: how adaptive cultural processes can produce maladaptive losses – the Tasmanian case. American Antiquity 69 (2), 197–214.
Henry, A.G., Brooks, A.S., Piperno, D.R., 2011. Microfossils in calculus demonstrate consumption of plants and cooked foods in Neanderthal diets (Shanidar III, Iraq; Spy I and II, Belgium). Proceedings of the National Academy of Sciences 108 (2), 486–491.
Henry, A.G., Brooks, A.S., Piperno, D.R., 2014. Plant foods and the dietary ecology of Neanderthals and early modern humans. Journal of Human Evolution 69 (0), 44–54.
Henshilwood, C.S., D'Errico, F., Marean, C.W., Milo, R.G., Yates, R., 2001. An early bone tool industry from the Middle Stone Age at Blombos Cave, South Africa: implications for the origins of modern human behaviour, symbolism and language. Journal of Human Evolution 41 (6), 631–678.
Henshilwood, C.S., d'Errico, F., Watts, I., 2009. Engraved ochres from the Middle Stone Age levels at Blombos Cave, South Africa. Journal of Human Evolution 57 (1), 27–47.
Higham, T., Jacobi, R., Julien, M., David, F., Basell, L., Wood, R., Davies, W., Ramsey, C.B., 2010. Chronology of the Grotte du Renne (France) and implications for the context of ornaments and human remains within the Châtelperronian. Proceedings of the National Academy of Sciences 107 (47), 20234–20239.
Hillier, B., Hanson, J., 1984. The Social Logic of Space. Cambridge University Press, Cambridge.
Hodder, I., 1979. Economic and social stress and material culture patterning. American Antiquity 44 (3), 446–454.
Hodder, I., 1982. Symbols in Action. Cambridge University Press, Cambridge.
Hodder, I., 1994. Comment on A. Martin Byers 'Symboling and the Middle-Upper Palaeolithic transition: a theoretical and methodological critique'. Current Anthropology 35 (4), 369–399.
Hofman, M.A., 2001. Evolution and complexity of the human brain: some organizing principles. In: Roth, G., Wulliman, M.F. (Eds.), Brain Evolution and Cognition. Wiley & Sons, New York, pp. 501–521.
Hoskins, J., 1998. Biographical Objects: How Things Tell the Stories of People's Lives. Routledge, London.
Hublin, J.-J., Talamo, S., Julien, M., David, F., Connet, N., Bodu, P., Vandermeersch, B., Richards, M.P., 2012. Radiocarbon dates from the Grotte du Renne and Saint-Césaire support a Neandertal origin for the Châtelperronian. Proceedings of the National Academy of Sciences 109 (46), 18743–18748.
Hublin, J.J., Spoor, F., Braun, M., Zonneveld, F., Condemi, S., 1996. A late Neanderthal associated with Upper Palaeolithic artefacts. Nature 381, 224–226.
Hutchins, E., 1995. Cognition in the Wild. The MIT Press, Cambridge, MA.
Kent, S., 1990. Domestic Architecture and the Use of Space: an Interdisciplinary Cross-cultural Study. Cambridge University Press, Cambridge.
Klaas, J.H., 2000. Why is brain size so important: design problems and solutions and neocortex gets bigger and smaller. Brain and Mind 1, 7–23.
Klein, R.G., 2008. Out of Africa and the evolution of human behaviour. Evolutionary Anthropology: Issues, News, and Reviews 17 (6), 267–281.
Kleinfeld, J., 2002. The Small World Problem Society, vol. 39(2), pp. 61–66.
Klump, B.C., van der Wal, J.E.M., St Clair, J.J.H., Rutz, C., 2015. Context-dependent 'safekeeping' of foraging tools in New Caledonian crows. Proceedings of the Royal Society of London B: Biological Sciences 282 (1808), 20150278.
Knappett, C. (Ed.), 2013. Network Analysis in Archaeology: New Approaches to Regional Interaction. Oxford University Press, Oxford.
Kohn, M., Mithen, S.J., 1999. Handaxes: products of sexual selection? Antiquity 73, 518–526.
Kramer, K.L., 2010. Cooperative breeding and its significance to the demographic success of humans. Annual Review of Anthropology 39 (1), 417–436.
Kudo, H., Dunbar, R.I.M., 2001. Neocortex size and social network size in primates. Animal Behavior 62, 711.
Kuhn, S., 2011. Neanderthal technoeconomics: an assessment and suggestions for future developments. In: Conard, N., Richter, J. (Eds.), Neanderthal Lifeways, Subsistence and Technology. Springer, Netherlands, pp. 99–110.
Kuhn, S.L., Zwyns, N., 2014. Rethinking the initial upper Paleolithic. Quaternary International 347, 29–38.
Kuijt, I., 2000. People and space in early agricultural villages: exploring daily lives, community size, and architecture in the late pre-pottery Neolithic. Journal of Anthropological Archaeology 19, 75–102.
Lehmann, J., Andrews, K., Dunbar, R., 2010. Social networks and social complexity in female-bonded primates. In: Dunbar, R., Gamble, C., Gowlett, J. (Eds.), Social Brain, Distributed Mind. Oxford University Press, Oxford, pp. 57–82.
Lehmann, J., Korstjens, A.H., Dunbar, R.I.M., 2007. Group size, grooming and social cohesion in primates. Animal Behaviour 74 (6), 1617–1629.
Leskovic, J., Horvitz, E., 2007. Planetary-scale Views on an Instant-messaging Network. arXiv.org Physics and Society, arXiv:0803.0939.
Lusseau, D., 2003. The emergent properties of a dolphin social network. Biology Letters 270, S186–S188.

Lycett, S.J., von Cramon-Taubadel, N., 2008. Acheulean variability and hominin dispersals: a model-bound approach. Journal of Archaeological Science 35 (3), 553–562.
Lyn, H., Greenfield, P.M., Savage-Rumbaugh, E.S., 2011. Semiotic combinations in Pan: a comparison of communication in a chimpanzee and two bonobos. First Language 31 (3), 300–325.
Machin, A.J., Hosfield, R.T., Mithen, S.J., 2007. Why are some handaxes symmetrical? Testing the influence of handaxe morphology on butchery effectiveness. Journal of Archaeological Science 34, 883–893.
Madden, J., Drewe, J., Pearce, G., Clutton-Brock, T., 2009. The social network structure of a wild meerkat population: 2. Intragroup interactions. Behavioral Ecology and Sociobiology 64 (1), 81–95.
Madden, J.R., Drewe, J.A., Pearce, G.P., Clutton-Brock, T.H., 2011. The social network structure of a wild meerkat population: 3. Position of individuals within networks behavioral. Ecology and Sociobiology 65 (10), 1857–1871.
Malafouris, L., 2007. Before and beyond representation: towards an enactive conception of the Palaeolithic image. In: Renfrew, C., Morley, I. (Eds.), Image and Imagination: a Global History of Figurative Representation. The McDonald Institute, Cambridge, pp. 287–300.
Malafouris, L., 2013. How Things Shape the Mind. MIT Press, Cambridge, MA.
Marzke, M.W., 2013. Tool making, hand morphology and fossil hominins. Philosophical Transactions of the Royal Society B: Biological Sciences 368 (1630), 20120414.
Matsuzawa, T., 2007. Comparative cognitive development. Developmental Science 1 (1), 97–103.
McBrearty, S., Brooks, A.S., 2000. The revolution that wasn't: a new interpretation of the origin of modern human behaviour. Journal of Human Evolution 39, 453–563.
McGrew, W.C., 1992. Chimpanzee Material Culture: Implications for Human Evolution. Cambridge University Press, Cambridge.
McPherron, S.P., 2000. Handaxes as a measure of the mental capabilities of early hominids. Journal of Archaeological Science 27, 655–663.
McPherron, S.P., Alenseged, Z., Marean, C.W., Wynn, J.G., Reed, D., Geraads, D., Bobe, R., Béarat, H.A., 2010. Evidence for stone-tool-assisted consumption of animal tissues before 3.39 million years ago at Dikika, Ethiopia. Nature 466, 857–860.
Mellars, P., 1985. The ecological basis of social complexity in the upper Paleolithic of southwestern France. In: Douglas-Price, T., Brown, J.A. (Eds.), Prehistoric Hunter-Gatherers: the Emergence of Cultural Complexity. Academic, New York, pp. 271–294.
Mellars, P., 1996. The Neanderthal Legacy. Princeton University Press, Princeton.
Mellars, P., 2006. Why did modern human populations disperse from Africa ca. 60,000 years ago? A new model. Proceedings of the National Academy of Sciences 103 (25), 9381–9386.
Miguel, C.D., Henneberg, M., 2001. Variation in hominid brain size: how much is due to method? Homo 52 (1), 3–58.
Milgram, S., 1977. The Individual in a Social World: Essays and Experiments. Addison-Wesley Publishing Company, Reading, MA.
Miller, D., 2008. The Comfort of Things. Polity, Cambridge.
Modelski, G., 2003. World Cities: −3000 to 2000. FAROS, Washington.
Mulcahy, N.J., Call, J., 2006. Apes save tools for future use. Science 312 (5776), 1038–1040.
O'Connell, J.F., Allen, J., 2004. Dating the colonization of Sahul (Pleistocene Australia-New Guinea): a review of recent research. Journal of Archaeological Science 31 (6), 835–853.
Osvath, M., 2009. Spontaneous planning for future stone throwing by a male chimpanzee. Current Biology 19 (5), R190–R191.
Osvath, M., Karvonen, E., 2012. Spontaneous innovation for future deception in a male chimpanzee. PLoS One 7 (5), e36782.
Packer, C., 1986. The ecology of sociality in felids. In: Rubenstein, D.I., Wrangham, R.W. (Eds.), Ecological Aspects of Social Evolution: Birds and Mammals. Princeton University Press, Princeton, pp. 429–451.
Pearce, E., Moutsiou, T., 2014. Using obsidian transfer distances to explore social network maintenance in late Pleistocene hunter–gatherers. Journal of Anthropological Archaeology 36 (0), 12–20.
Pearce, E., Stringer, C., Dunbar, R.I.M., 2013. New insights into differences in brain organization between Neanderthals and anatomically modern humans. Proceedings of the Royal Society of London B: Biological Sciences 280 (1758), 20130168.
Pearce, E.H., Shuttleworth, A., Grove, M., Layton, R.H., 2014. The costs of being a high-latitude hominin. In: Dunbar, R.I.M., Gamble, C., Gowlett, J.A.J. (Eds.), Lucy to Language: the Benchmark Papers. OUP, Oxford, pp. 356–379.
Pearson, O.M., 2004. Has the combination of genetic and fossil evidence solved the riddle of modern human origins? Evolutionary Anthropology: Issues, News, and Reviews 13 (4), 145–159.
Peresani, M., Fiore, I., Gala, M., Romandini, M., Tagliacozzo, A., 2011. Late Neandertals and the intentional removal of feathers as evidenced from bird bone taphonomy at Fumane Cave 44 ky B.P., Italy. Proceedings of the National Academy of Sciences 108 (10), 3888–3893.
Petraglia, M., Korisettar, R., Boivin, N., Clarkson, C., Ditchfield, P., Jones, S., Koshy, J., Lahr, M.M., Oppenheimer, C., Pyle, D., Roberts, R., Schwenninger, J.-L., Arnold, L., White, K., 2007. Middle Paleolithic assemblages from the Indian subcontinent before and after the toba super-eruption. Science 317 (5834), 114–116.
Petraglia, M.D., Shipton, C., Paddaya, K., 2005. Life and mind in the Acheulean. In: Gamble, C., Porr, M. (Eds.), The Hominin Individual in Context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and Artefacts. Routledge, London, pp. 197–219.
Pinker, S., 1994. The Language Instinct: the New Science of Language and Mind. Penguin, London.
Pope, M., Roberts, M., 2005. Observations on the relationship between Palaeolithic individuals and artefact scatters at the Middle Pleistocene site at Boxgrove, UK. In: Gamble, C., Porr, M. (Eds.), The Hominin Individual in Context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and Artefacts. Routledge, London, pp. 81–97.
Pope, M., Russel, K., Watson, K., 2006. Biface form and structured behaviour in the Acheulean lithics, 27, 44–57.
Porr, M., 2005. The making of the biface and the making of the individual. In: Gamble, C., Porr, M. (Eds.), The Hominin Individual in Context: Archaeological Investigations of Lower and Middle Palaeolithic Landscapes, Locales and Artefacts. Routledge, London, pp. 68–80.
Potts, R., 1984. Home bases and early hominids. American Scientist 72, 338–347.
Potts, R., 1988. Early Hominid Activities at Olduvai. Aldine, New York.
Powell, A., Shennan, S., Thomas, M.G., 2009. Late Pleistocene demography and the appearance of modern human behavior. Science 324, 1298–1301.
Powell, A., Shennan, S.J., Thomas, M.G., 2010. Demography and variation in the accumulation og culturally inherited skills. In: O'Brien, M.J., Shennan, S. (Eds.), Innovation in Cultural Systems: Contributions from Evolutionary Anthropology. MIT Press, Cambridge, M. A, pp. 137–161.
Rapoport, A., 1981. Identity and environment: a cross-cultural perspective. In: Duncan, J.S. (Ed.), Housing and Identity: Cross-cultural Perspectives. Croom Helm, London, pp. 6–35.
Rapoport, A., 1990. Systems of activities and systems of settings. In: Kent, S. (Ed.), Domestic Architecture and the Use of Space: an Interdisciplinary Cross-cultural Study. Cambridge University Press, Cambridge, pp. 9–20.
Read, D., 2012. Population Size Does Not Predict Artifact Complexity: Analysis of Data from Tasmania, Arctic Hunter-Gatherers, and Oceania Fishing Groups. UCLA: Human Complex Systems. http://ssrn.com/abstract=2460379.
Renfrew, C., 2008. Neuroscience, evolution and the sapient paradox: the factuality of value and of the sacred. Philosophical Transactions of the Royal Society of London Series B 363, 2041–2047.
Richards, M.P., Pettitt, P.B., Trinkaus, E., Smith, F.H., Paunovic, M., Karavanic, I., 2000. Neanderthal diet at Vindija and Neanderthal predation: the evidence from stable isotopes. Proceedings of the National Academy of Sciences 97 (13), 7663–7666.
Richards, M.P., Trinkaus, E., 2009. Isotopic evidence for the diets of European Neanderthals and early modern humans. Proceedings of the National Academy of Sciences 106 (38), 16034–16039.
Roberts, S.G.B., 2010. Constraints on social networks. In: Dunbar, R., Gamble, C., Gowlett, J. (Eds.), Social Brain, Distributed Mind. British Academy, London, pp. 115–134.
Roberts, S.G.B., Dunbar, R.I.M., 2011. The costs of family and friends: an 18-month longitudinal study of relationship maintenance and decay. Evolution and Human Behavior 32 (3), 186–197.
Robertson, R.G.m, 1995. Glocalization: time-space and homogeneity-heterogeneity. In: Featherstone, M., Lash, S., Robertson, R. (Eds.), Global Modernities. Sage, London, pp. 25–45.
Rollefson, G.O., Simmons, A.H., 1986. The Neolithic settlement at 'Ain Ghazal. In: Garrard, A., Gebel, H.G. (Eds.), The Prehistory of Jordan: the State of Research in 1986, vol. 396. BAR, Oxford, pp. 393–421.
Roux, V., Bril, B., Stout, D., 2005. The social and cultural context of stone-knapping skill acquisition. In: Roux, V., Bril, B. (Eds.), Stone Knapping: the Necessary Conditions for a Uniquely Hominin Behaviour. McDonald Institute for Archaeological Research, Cambridge, pp. 331–340.
Sanders, D., 1990. Behavioral conventions and archaeology: methods for the analysis of ancient architecture. In: Kent, S. (Ed.), Domestic Architecture and the Use of Space: an Interdisciplinary Cross-cultural Study. Cambridge University Press, Cambridge, pp. 43–72.
Savage-Rumbaugh, S., McDonald, K., Sevcik, R.A., Hopkins, W.D., Rubert, E., 1986. Spontaneous symbol acquisition and communicative use by pygmy chimpanzees (Pan paniscus). Journal of Experimental Psychology: General 115 (3), 211–235.
Schaik, C.P.v., Fox, E.A., Sitompul, A.F., 1996. Manufacture and use of tools in wild Sumatran orangutans. Naturwissenschaften 83, 186–188.
Schlanger, N., 1996. Understanding Levallois: lithic technology and cognitive archaeology. Cambridge Archaeological Journal 6, 231–254.
Shea, J.J., 2003. Neandertals, competition, and the origin of modern human behavior in the Levant. Evolutionary Anthropology: Issues, News, and Reviews 12 (4), 173–187.
Shea, J.J., 2008. Transitions or turnovers? Climatically-forced extinctions of Homo sapiens and Neanderthals in the east. Mediterranean Levant Quaternary Science Reviews 27 (23–24), 2253–2270.
Shea, J.J., 2011. Homo sapiens is as Homo sapiens was. Current Anthropology 52 (1), 1–35.
Shennan, S., 2001. Demography and cultural innovation: a model and its implications for the emergence of modern human culture. Cambridge Archaeological Journal 11 (1), 5–16.
Sherwood, C.C., Stimpson, C.D., Raghanti, M.A., Wildman, D.E., Uddin, M., Grossman, L.I., Goodman, M., Redmond, J.C., Bonar, C.J., Erwin, J.M., Hof, P.R., 2006. Evolution of increased glia-neuron ratios in the human frontal cortex. Proceedings of the National Academy of Sciences 103 (37), 13606–13611.

Please cite this article in press as: Coward, F., Scaling up: Material culture as scaffold for the social brain, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.09.064

Shick, K.D., 1987. Modeling the formation of Early Stone Age artifact concentrations. Journal of Human Evolution 16 (7–8), 789–807.
Shipton, C., 2010. Imitation and shared intentionality in the Acheulean. Cambridge Archaeological Journal 20 (02), 197–210.
Shumaker, R.W., Walkup, K.R., Beck, B.B., 2011. Animal tool behavior: the use and manufacture of tools by animals. JHU Press, Baltimore.
Sinclair, A., 2015. All in a day's work? Early conflicts in expertise, life history and time management. In: Coward, F., Hosfield, R.T., Pope, M., Wenban-Smith, F. (Eds.), Settlement, Society and Cognition in Human Evolution: Landscapes in Mind. CUP, Cambridge, pp. 94–116.
Skinner, M.M., Stephens, N.B., Tsegai, Z.J., Foote, A.C., Nguyen, N.H., Gross, T., Pahr, D.H., Hublin, J.-J., Kivell, T.L., 2015. Human-like hand use in Australopithecus africanus. Science 347 (6220), 395–399.
Stanley, C.R., Dunbar, R.I.M., 2013. Consistent social structure and optimal clique size revealed by social network analysis of feral goats, Capra hircus. Animal Behaviour 85 (4), 771–779.
Storey, G.R., 1997. The population of ancient Rome. Antiquity 71 (274), 966–978.
Stout, D., Toth, N., Schick, K., Chaminade, T., 2008. Neural correlates of Early Stone Age toolmaking: technology, language and cognition in human evolution. Philosophical transactions of the Royal Society of London Series B 363, 1939–1949.
Strum, S.S., Latour, B., 1987. Redefining the social link: from baboons to humans. Social Science Information 26, 783–802.
Terrace, H.S., Petitto, L.A., Sanders, R.J., Bever, T.G., 1979. Can an ape create a sentence? Science 206 (4421), 891–902.
Turq, A., Roebroeks, W., Bourguignon, L., Faivre, J.-P., 2013. The fragmented character of Middle Palaeolithic stone tool technology. Journal of Human Evolution 65 (5), 641–655.
Uomini, N.T., Meyer, G.F., 2013. Shared brain lateralization patterns in language and Acheulean stone tool production: a functional transcranial doppler ultrasound study. PLoS One 8 (8), e72693.
Van Schaik, C.P., 1983. Why are diurnal primates living in groups? Behaviour 87 (1), 120–144.
Visalberghi, E., Michael, H., Noemi, S., Dorothy, F., 2013. Use of stone hammer tools and anvils by bearded capuchin monkeys over time and space: construction of an archeological record of tool use. Journal of Archaeological Science 40 (8), 3222–3232.
Watts, D.J., Strogatz, S.H., 1998. Collective dynamics of 'small-world' networks. Nature 393 (6684), 440–442.
Weaver, T.D., Roseman, C.C., 2008. New developments in the genetic evidence for modern human origins. Evolutionary Anthropology 17 (1), 69.
Weissner, P., 1988. Style and changing relations between the individual and society. In: Hodder, I. (Ed.), The Meaning of Things: Material Culture and Symbolic Expression. Harper Collins, London.
White, M.J., 2012. The lithic assemblage from Lynford quarry and its bearing on Neanderthal behaviour in Late Pleistocene Britain. In: Boismier, W., Gamble, C., Coward, F. (Eds.), Neanderthals Among Mammoths: Excavations at Lynford Quarry, Norfolk. English Heritage, Swindon, pp. 219–261.
White, T., Su, S., Schmidt, M., Kao, C.-Y., Sapiro, G., 2009. The development of gyrification in childhood and adolescence. Brain and Cognition 72 (1), 36–45.
Wiessner, P., 1984. Reconsidering the behavioral basis for style: a case study among the Kalahari San. Journal of Anthropological Archaeology 3 (3), 190–234.
Williams, M.A.J., Ambrose, S.H., der Kaars, S.v., Ruehlemann, C., Chattopadhyaya, U., Pal, J., Chauhan, P.R., 2010. Reply to the comment on "Environmental impact of the 73 ka Toba super-eruption in South Asia" by M. A. J. Williams, S. H. Ambrose, S. van der Kaars, C. Ruehlemann, U. Chattopadhyaya, J. Pal, P. R. Chauhan. Palaeogeography, Palaeoclimatology, Palaeoecology 284 (2009), 295–314. Palaeogeography, Palaeoclimatology, Palaeoecology 296 (1–2), 204–211.
Williams, M.A.J., Ambrose, S.H., van der Kaars, S., Ruehlemann, C., Chattopadhyaya, U., Pal, J., Chauhan, P.R., 2009. Environmental impact of the 73ka Toba super-eruption in South Asia. Palaeogeography, Palaeoclimatology, Palaeoecology 284 (3–4), 295–314.
Wilson, P., 1988. The Domestication of the Human Species. Yale University Press, New Haven.
Wood, B., Constantino, P., 2007. Paranthropus boisei: fifty years of evidence and analysis. American Journal of Physical Anthropology 134 (S45), 106–132.
Wragg Sykes, R., 2015. To see a world in a hafted tool: birch pitch composite technology, cognition and memory in Neanderthals. In: Coward, F., Hosfield, R.T., Pope, M., Wenban-Smith, F. (Eds.), Settlement, Society and Cognition in Human Evolution: Landscapes in Mind. Cambridge University Press, Cambridge, pp. 117–137.
Wrangham, R., Jones, J.H., Laden, G., Pilbeam, D., Conklin-Brittain, N., 1999. The raw and the stolen: cooking and the ecology of human origins. Current Anthropology 40 (5), 567–594.
Wynn, T., 2002. Archaeology and cognitive evolution. Behavioral and Brain Sciences 25 (03), 389–402.
Wynn, T., Coolidge, F.L., 2004. The expert Neandertal mind. Journal of Human Evolution 46, 467–487.
Zhou, W.-X., Sornette, D., Hill, R.A., Dunbar, R.I.M., 2005. Discrete hierarchical organization of social group sizes. Proceedings of the Royal Society of London Series B 272, 439–444.
Zilhão, J., Angelucci, D.E., Badal-García, E., d'Errico, F., Daniel, F., Dayet, L., Douka, K., Higham, T.F.G., Martínez-Sánchez, M.J., Montes-Bernárdez, R., Murcia-Mascarós, S., Pérez-Sirvent, C., Roldán-García, C., Vanhaeren, M., Villaverde, V., Wood, R., Zapata, J., 2010. Symbolic use of marine shells and mineral pigments by Iberian Neandertals. Proceedings of the National Academy of Sciences 107 (3), 1023–1028.
Zilhão, J., Banks, W.E., d'Errico, F., Gioia, P., 2015. Analysis of site formation and assemblage integrity does not support attribution of the Uluzzian to modern humans at Grotta del Cavallo. PLoS One 10 (7), e0131181.

Please cite this article in press as: Coward, F., Scaling up: Material culture as scaffold for the social brain, Quaternary International (2015), http://dx.doi.org/10.1016/j.quaint.2015.09.064