



Cumulative culture and future thinking: Is mental time travel a prerequisite to cumulative cultural evolution?

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ABSTRACT

Cumulative culture denotes the, arguably, human capacity to build on the cultural behaviors of one's predecessors, allowing increases in cultural complexity to occur such that many of our cultural artifacts, products and technologies have progressed beyond what a single individual could invent alone. This process of cumulative cultural evolution underlies human cultural success and has enabled us to reach and inhabit some of the most inhospitable environments on this planet. Why humans, but not other animals, have exhibited a cultural explosion has caused much deliberation. The human propensity to imitate, teach, "mind-read" and cooperate have all featured prominently in accounts of the prerequisites for cumulative culture. However, this may not represent the complete picture. In this article we consider whether there exists a link between future thinking, specifically prospective mental time travel, and the observed distribution of cumulative culture.

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Re-experiencing events from one's past and imagining events in one's future is referred to as "mental time travel" (Suddendorf & Corballis, 1997; Tulving, 2002a) and is well documented in humans (*Homo sapiens*). Many of the decisions we make in our daily lives involve some form of prospective thinking – imagining future scenarios by recasting past experiences – which, in turn, enables us to anticipate our likely reactions to potential future events. This ability releases humans from living solely in the present (Suddendorf & Busby, 2005; Suddendorf & Corballis, 2007), allowing the human lineage to act now to secure or avoid probable futures. In this paper we examine the implications of this release from the present, afforded by mental time travel and future thinking. Specifically, we examine whether the extent of future thought present in humans and nonhuman animals (henceforth referred to as animals) has influenced their extent of cumulative culture, a proposition that has received little attention. Since research effort in both domains has predominantly centered upon corvids and great apes, we restrict our discussions to these species.

Mental Time Travel and Episodic Thought in Nonhuman Animals

Much of the evidence of early future thinking in humans has been heavily reliant on verbal tasks (Atance & Meltzoff, 2005; Busby & Suddendorf, 2005; Hudson, Shapiro, & Sosa, 1995), posing a considerable hurdle when searching for comparable modes of future thinking in animals. This is especially true for the study of episodic foresight and mental time travel since they include a phenomenological component whereby the content of projections incorporate an awareness of self in subjective time (Tulving, 2002b), rendering them particularly difficult to assess without the aid of introspection and language. Despite

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this, considerable progress has been made in identifying behavioral markers of future thinking that can be tested in non-verbal species (Suddendorf & Busby, 2005).

Many animal behaviors are orientated toward the future: for example, hibernation constitutes a fixed behavioral pattern that is orientated to future survival (Suddendorf & Corballis, 2007). While such behaviors are clearly adapted toward the future, fixed behavioral patterns do not necessitate future thought. In contrast, human modes of future thinking, present in young children (Busby & Suddendorf, 2005; Hayne, Gross, McNamee, Fitzgibbon, & Tustin, 2011), extend beyond fixed behavioral patterns to incorporate flexible forms of cognition that allow present behavior to be tailored toward possible future events. Thus, the question is posed: do all future orientated behaviors present in the animal kingdom represent relatively fixed evolved behavioral solutions, or can animals engage in mentally traveling backwards and forwards in subjective time? That is, as phrased by Roberts (2002, p. 473), “are animals stuck in time?”

Innovative studies have investigated the extent to which animals anticipate future events (discussed in Roberts, 2012; see also Martin-Ordas, Atance, & Louw, 2012). Chimpanzees, bonobos and orangutans (*Pan troglodytes*, *P. paniscus*, and *Pongo pygmaeus*) have been found to select and retain functionally appropriate tools that enabled them to obtain future rewards, indicating future planning capabilities and perhaps even anticipation of future hunger (Mulcahy & Call, 2006; Osvath & Osvath, 2008). In corvids, scrub jays have been shown to preferentially cache food in a location they knew would be devoid of food in the forthcoming morning (*Aphelocoma californica*: Raby, Alexis, Dickinson, & Clayton, 2007) and alter their cache recovery and re-caching patterns dependent upon whether cache creation was observed by a conspecific, thus avoiding potential future cache pilfering (*A. coerulescens*: Emery & Clayton, 2001). Correia, Alexis, Dickinson, and Clayton (2007) found Western scrub jays (*A. californica*) moved beyond current motivational states, induced by food satiation, to preferentially cache food that was preferred at the time of cache recovery rather than at the time of caching (contrary to the predictions of the Bischof-Köhler hypothesis: Bischof-Köhler, 1985 and Bischof, 1978, cited in Suddendorf & Corballis, 1997). Finally, scrub jays (*A. coerulescens*) have been reported to possess “what”, “where” and “when” memories (WWW) or “episodic-like memory” (Clayton & Dickinson, 1998, 1999), which is of interest since the recall of events from the personal past has been closely linked to pre-experiencing events in the future (Addis, Wong, & Schacter, 2007; Schacter, Addis, & Buckner, 2008). Specifically, depending on the time lapse prior to cache recovery, scrub jays have been shown to recover a non-perishable food after a long delay and preferred, perishable larvae after a short delay (Clayton & Dickinson, 1998).

These examples of future thought in animals generated debate. Recent reviews by Suddendorf and colleagues raise concerns over whether such studies report genuine cases of future planning, future need anticipation and episodic thought (Suddendorf & Corballis, 2007, 2008, 2010; Suddendorf, Corballis, & Collier-Baker, 2009). The most prominent criticisms relate to the possibility of tasks being solved by associative learning rather than future need anticipation and planning (Suddendorf & Corballis, 2008, 2010), the frequent lack of control for current motivational states that could persist throughout investigations or be reinstated by cueing that negate explanations of motivation by future need (Osvath & Osvath, 2008; although see Correia et al., 2007) and the potential for behavior to be based upon semantic knowledge rather than episodic thought (the knowing versus remembering distinction; Roberts & Feeney, 2009; Suddendorf & Corballis, 2007; see Martin-Ordas et al., 2012). In line with this latter point, there is no evidence that “WWW” memories require projection of the self, a feature essential to episodic memory as described by Tulving (2001, 2005), nor the auto-noetic awareness that captures the conscious experience of recounted episodes and mental time travel. Thus, “WWW” learning may be “neither necessary nor sufficient” to surmise the presence of episodic memory or mental time travel (Zentall, 2006, p. 174).

Thus, while researchers have teased apart behavioral concomitants that may be representative of different forms of future thinking, much of the evidence in animals remains controversial. Although various animals appear capable of future cognition (see Roberts, 2012), there are at present little grounds to suppose that non-humans display mental time travel akin to humans, leading many to conclude that mental time travel, particularly into the future, is unique to our species (Atance & O'Neill, 2005; Suddendorf & Busby, 2005; Suddendorf & Corballis, 1997, 2007; Tulving, 2005). Hence we are left with the interesting question of what might be the consequence of living in the present or at least being confined to the immediate future, a question we now turn to by relating future thinking capacities to the, arguably, human capacity to ratchet up our cultural complexity.

Cumulative Culture in Humans and Animals

Culture, broadly defined, denotes group typical behavior that is transmitted via social learning (Laland & Hoppitt, 2003). Human cultures, including our technologies, artifacts and traits, have progressed over time, becoming more sophisticated, complex and efficient as generations pass. This cumulative process, often described as the “ratchet effect”, specifically encapsulates how high-fidelity social learning maintains our cultural accomplishments until such a time as new, beneficial modifications are invented, which in turn are propagated via high fidelity social learning (Tomasello, 1999). Thus, modifications accumulate across generations to gradually yield cultural products or traits that move beyond an individual's innovation remittance (Tomasello, 1999; Tomasello, Kruger, & Ratner, 1993), or “zone of latent solutions” (Tennie, Call, & Tomasello, 2009). For example, when tracing academic achievement in various domains over the centuries, patterns of elevated knowledge discovery arise (Lehman, 1947) with contributions following a ubiquitous pattern of exponential growth (Enquist, Ghirlanda, Jarrik, & Wachtmeister, 2008). Similar cumulative processes are evident in human artifacts and artifact production; for example, Lower Paleolithic stone technology shows cumulative progression in its complexity and

diversity, with hierarchical modifications occurring in flake production and shaping methods achieved through building on pre-existing methods (Stout, 2011).

The empirical study of cumulative culture, like that of episodic foresight, remains in its infancy. Nevertheless, employment of “micro-societies” within “transmission chain” designs, originating from Bartlett (1932), have allowed cumulative change to be studied in the laboratory. Caldwell and Millen (2008, 2009) were among the first to study cumulative culture in this manner. Their experimental design involved micro-societies building spaghetti towers as tall as possible or a paper plane that flew as far as possible. Each generation in the micro-society received some form of relevant information from a previous generation, thus allowing social learning. Each new generation then created their own artifacts before being replaced by the next generation. The typical result of this micro-society replacement method was that artifacts gradually improved (i.e. higher towers and longer flights) across generations, with artifacts later in a chain outperforming those earlier in the chain (Caldwell & Millen, 2009). Thus, these participants learned from the developments of others, leading to successive improvements from one generation to the next.

Similar patterns of cumulative improvements are observed in the transmission of artificial languages across diffusion chains in adults (Kirby, Cornish, & Smith, 2008) and in children’s tool use (Flynn, 2008). Flynn (2008) employed the diffusion chain method to assess whether 2- and 3-year olds were prone to imitation of non-functional actions. Children were presented a puzzle box in which a series of defenses held a reward in place. Each child at the start of the chain watched an initial demonstration containing both task irrelevant actions, which had no bearing on gaining a reward, and task relevant actions, which allowed reward retrieval. Children parsed out task irrelevant actions early in the diffusion chains, modifying the technique employed and creating a more efficient and effective means to gain the reward. These results suggest that even 2-year-old children display the capacity to solve problems in a cumulative manner.

In animals, many species are said to have behavioral traditions or “culture”, including rats (*Rattus rattus*, Terkel, 1996), fishes (*Thalassoma bifasciatum*, Warner, 1988; see Laland & Hoppitt, 2003 for discussion), birds (*Molothrus ater*, Freeberg, 1998, 2004), cetaceans (*Tursiops*, Sargeant & Mann, 2009, see Rendell & Whitehead, 2001 for a review), monkeys (*Macaca fasciata*, Kawamura, 1959; *Cebus capucinus*, Perry et al., 2003) and apes (*P. troglodytes*, Whiten et al., 1999; *P. pygmaeus*, van Schaik et al., 2003). But are they cumulative?

Empirical investigations have reported that the capacity to build on the accomplishments of others in a cumulative manner appears to be absent in animals. For example, Marshall-Pescini and Whiten (2008) presented chimpanzees (*P. troglodytes*) with a foraging device, which allowed the use of two tool-use techniques to extract food rewards. One technique used a relatively simple, but less productive, “dipping” method, while the other “probing” technique constituted a more complex but more productive method that built upon the “dipping” technique. Thus, the question of whether subjects could build upon a suboptimal foraging strategy to adopt a more complex but higher yielding extraction method was addressed. Upon acquiring the “dipping” technique, subjects failed to progress to the more productive “probing” method, despite supplementary evidence showing that chimpanzees were capable of mastering the more productive technique. The authors concluded that the process of learning a successful technique may have inhibited the ability to learn further techniques irrespective of their enhanced efficiency. Such a finding lies in contrast with humans, where a majority of 3- and 4-year-old children tested were shown to progress to the more sophisticated foraging strategy (Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009).

Similar conservatism to initially learned techniques has been reported in other studies of chimpanzees (Hopper, Schapiro, Lambeth, & Brosnan, 2011; Hrubesch, Preuschoft, & van Schaik, 2009). The implication of strong conservatism is that modifications will not be incorporated into an existing behavioral repertoire, thus limiting the possibility of cultural ratcheting. This is not to suggest that chimpanzees cannot adopt new innovations or conspecific preferences, as has been shown in numerous studies (Hopper et al., 2007; Horner, Whiten, Flynn, & de Waal, 2006; Whiten, Horner, & de Waal, 2005). Rather the conservatism argument suggests that once successful or proficient in a given technique chimpanzees are unlikely to switch to a new behavior (see Gruber, Muller, Reynolds, Wrangham, & Zuberbühler, 2011; Hanus, Mendes, Tennie, & Call, 2011 for related discussions of functional fixedness), thus limiting modifications to existing behaviors. Note, however, a recent study of cumulative culture in chimpanzees, capuchins and children did not find behavioral conservatism or satisficing in the non-humans to be implicated in their lack of cumulative problem solving (Dean, Kendal, Schapiro, Thierry, & Laland, 2012; see also Lehner, Burkart, & van Schaik, 2011 for evidence of behavioral flexibility in orangutan innovation, *P. pygmaeus abelii*).

As with future thinking, some of the best evidence for behavioral modification has been observed in corvids, specifically New Caledonian crows (*Corvus moneduloides*, Hunt & Gray, 2003, 2004). New Caledonian crows show impressive tool use capabilities in the wild (Hunt & Gray, 2003, 2004) and in captivity (Weir, Chappell, & Kacelnik, 2002). One particular foraging technique, utilizing *Pandanus* leaf tools of varying complexity, has been suggested to have arisen through modification of an ancestral design (Hunt & Gray, 2003). In the absence of evidence that the complex (stepped) tools are indeed derived from, and modifications of, an ancestral tool, this evidence remains circumstantial. Furthermore, New Caledonian crows seem to possess an unlearned predisposition for tool use, suggesting that social learning need not be required for some aspects of their impressive tool use behavior (Kenward, Rutz, Weir, & Kacelnik, 2006; Kenward, Weir, Rutz, & Kacelnik, 2005) and casting doubt on whether some aspects of tool manufacture are cultural.

While further investigation of animal cumulative learning is warranted, to date the few studies that have addressed the question of whether animals are capable of incremental social learning have reported negative results (Dean et al., 2012; Marshall-Pescini & Whiten, 2008; although see Hunt & Gray, 2003). This absence of cumulative culture appears to

be corroborated by observations from the wild. We note however the proposal that some chimpanzee cultural behaviors, including nut-cracking and ectoparasite removal during grooming, are cumulative, as different populations vary in the complexity of this behavior (Boesch, 2003). Specifically, Boesch suggested that the use of a hammer to crack nuts seen in West Africa constitutes an expansion of hitting nuts against trees with the hand and that the use of the anvil and balancing stone seen in Bossou, represent two embellishments on this behavior. Again, this interpretation lacks direct evidence to suggest that cracking nuts with the hand against roots or tree trunks is indeed ancestral to other nut cracking behaviors. Furthermore, as is the case for the New Caledonian crow, there is little reason to suppose that these (nut-cracking) behaviors are beyond what an individual could invent alone (Tennie et al., 2009). This being true, attributing the variation in nut-cracking behavior to cumulative elaboration is premature. A similar concern is true of complex ectoparasite removal methods seen in chimpanzees.

Although the evidence for culture in animals is clear (although see Langergraber et al., 2010), there is a lack of compelling evidence that past generations' behaviors have undergone modifications to ratchet up their complexity or efficiency. Consequently, at present, the notion of cumulative culture in animal species remains speculative (Tennie et al., 2009). This inevitably raises the question of why humans and not other animals display cumulative cultural evolution.

Mechanisms and Processes Underlying Cumulative Culture

Much of what we know about the factors affecting cumulative culture has been contributed by mathematical models, with factors such as social learning and innovation (Boyd & Richerson, 1996; Enquist, Eriksson, & Ghirlanda, 2007), large population sizes and high migration rates (Powell, Shennan, & Thomas, 2009, 2010) and evaluative means to assess the adaptive value of traits (Enquist & Ghirlanda, 2007) influencing cultural evolution. Such findings have informed recent theories addressing why humans and not animals display cumulative cultural evolution, and here we outline what we consider the three main theories.

Most prominent is the argument that cumulative culture rests on the human capacity for complex social learning mechanisms, such as imitation and teaching (Dean et al., 2012; Flinn, 1997; Fogarty, Strimling, & Laland, 2011; Tomasello, 1999). Teaching (broadly defined as “costly information donation” from tutor to pupil, Fogarty et al., 2011, p. 1) and imitation (broadly defined as copying behavioral acts or action sequences) play an essential role since these high fidelity social learning mechanisms allow complex behaviors to disseminate and be retained in populations until beneficial modification occurs. Then, once beneficial innovations arise, they can be transmitted via these high-fidelity social learning routes and, thus, retained in a population. Such high fidelity social learning mechanisms have been contrasted with low-fidelity transmission mechanisms, such as emulation (copying of end products, goal of actions without copying exact behavioral actions; see Subiaul, 2010; Whiten & Ham, 1992) which are thought to result in insufficient copying fidelity to support cumulative culture (Shea, 2009; Tomasello, 1999). However, one potential challenge to this theory is that animals imitate (e.g. *Tursiops truncatus*, Jaakkola, Guarino, & Rodriguez, 2010; *P. troglodytes*, Custance, Whiten, & Bard, 1995; Horner et al., 2006; Whiten et al., 2009; *Gorilla g. gorilla*, Byrne & Tanner, 2006) and show rudimentary signs of teaching (Byrne & Rapoport, 2011; Hoppitt et al., 2008; Thornton & Raihani, 2008) yet lack cumulative culture. However, imitation, though present in animals, appears to be diminished compared to humans with emulation being more broadly utilized than imitation. Likewise, animal teaching appears to be extremely rare and mechanistically different to human teaching (see Fogarty et al., 2011 for discussion). Perhaps more importantly, human's cumulative learning may occur simply through attendance to the end products of past generations' actions without requiring observation of the actions themselves or active instruction (Caldwell & Millen, 2009). This suggests that at least for some technologies (e.g. building spaghetti towers or paper planes), cumulative improvements do not require imitation or teaching. Moreover, emulation in the form of copying end products rather than actions has recently been found to result in high fidelity cultural transmission, supporting cumulative technological progression (Caldwell, Schillinger, Evans, & Hopper, 2012). Thus, to the extent that emulation may also enable high fidelity social learning in chimpanzees, the lack of cumulative culture in this species may not be due to reliance upon emulation over imitation (or indeed teaching) (although see Dean et al., 2012).

Alternatively, demographic features of *H. sapiens* that facilitate social transmission of knowledge may, in part, explain species differences in cumulative culture. Based on mathematical models, Powell et al. (2009, 2010) propose that the cultural changes apparent in the archaeological record during the late Pleistocene can be interpreted in terms of demographic factors (see also Henrich, 2004; Kline & Boyd, 2010). Specifically, they posit that large regional subpopulations with high migration rates were fundamental to cumulative cultural evolution and trait maintenance. Hill et al. (2011) highlight various hunter gatherer group composition properties unique among the primates that may have implications for the emergence of cumulative culture. These include hunter gatherer bands being composed of a large proportion of non-kin (suggesting cooperation between unrelated individuals), flexible patterns of male and/or female dispersal, maintained lifelong social bonds (Chapais, 2011; Rodseth, Wrangham, Harrigan, & Smuts, 1991) and bands forming constituent parts of larger social networks. A likely by-product of these group structures is pronounced social transmission and continued flow of cultural practices, knowledge and ideas between bands and sub-populations, accentuating the probability that traits will accumulate within and across populations. In contrast, for chimpanzees (affiliative) contact between communities is composed almost exclusively of female migration, upon which contact with the natal group is lost (Chapais, 2011). Thus we see that human band compositions are especially well suited to cultural transmission on a large scale. As such, a species' demography may play an important role in whether or not their culture has accumulated over generations.

A further explanation for the disparity in human and animal cumulative culture is the role social learning strategies play in cumulative culture, and whether the absence of certain strategies may impose limitations on animals. An essential ingredient of cumulative culture is that knowledge or artifacts may only improve with selectivity regarding “who”, “when” and “what” is copied. This is because copying others is not, itself, a recipe for success (Laland, 2004; Pike, Kendal, Rendell, & Laland, 2010). Instead indiscriminate copying has the potential for the propagation of sub-optimal, maladaptive or outdated traits. Accordingly, various evolved heuristics dictating the circumstances under which individuals exploit other’s information have been thought to influence cumulative cultural evolution. These include direct copying biases, such as “copying in proportion to success/payoff”, and indirect biases, such as copying based on a model’s characteristics such as “prestige bias”, or trait frequencies, such as “copy the majority” (Boyd & Richerson, 1985; see Rendell et al., 2011 for a recent, albeit slightly different classification of social learning strategies). Mathematical analyses have revealed that manipulation of the presence/absence or strength of various social learning strategies can alter the rate of cumulative cultural change and what information is exchanged within and across populations (Rendell et al., 2011). One critical issue to the suggestion that social learning strategies have played an important role in human cultural evolution is that social learning strategies are not limited to humans (see Kendal, Coolen, van Bergen, & Laland, 2005). For instance, fish show a whole suite of social learning strategies (see Kendal, Coolen, & Laland, 2009 for review). Similarly, chimpanzees display social learning strategies, for example, it has been claimed that a combination of the age, rank and prior history of “success” of potential models influences “who” chimpanzees learn from (Horner, Proctor, Bonnie, Whiten, & de Waal, 2010). Thus, if social learning strategies are present in other animals, why do these animals lack cumulative culture? One explanation lies in the specific strategies animals employ. To illustrate, a “copy the dominant or older individuals” strategy reported in chimpanzees (Biro et al., 2003; Horner et al., 2010) would minimize the uptake of potential innovations given the seeming propensity for innovation to occur at a higher rate in juveniles rather than older chimpanzees (Biro et al., 2003; Reader & Laland, 2001). Therefore, the process of cumulative improvement through adding beneficial modification is reduced. Equally, important content biases may be present in animals to a lesser extent than in humans. For example, “copy in proportion to the payoff or the success of an observed behavior” seems important for the uptake of beneficial traits, yet there is little evidence to suggest animals engage in such social learning strategies (Pike et al., 2010 notwithstanding), although further research is required in this area.

The most probable answer to the question of why animals lack cumulative culture is that this process rests not on one specific learning process, mechanism or demographic detail, but that it is the combination of all these (and other) factors that has led to its presence in humans. Indeed, recent empirical considerations suggest this is the case, with a suite of socio-cognitive factors identified that appear to underlie human cumulative learning abilities. These factors include, in addition to those mentioned, human prosocial motivations (Dean et al., 2012) and the human capacity for shared intentionality (Tomasello, Carpenter, Call, Behne, & Moll, 2005). In the next section we add another contributing factor to this set; namely, that our heightened capacity to orientate current behavior to the future has facilitated our cultural progression.

Future Planning, Mental Time Travel and Cumulative Culture

The adaptive benefits of mental time travel are clear; it allows preparation and prediction, that is, we can act now to secure or avoid potential futures (Suddendorf & Corballis, 2010). This is clearly evident in human behavior, for example in building houses that maximize security from future intrusion, that will withstand potential future earthquakes or floods, and in our development of food preservation and storage techniques. The interesting aspect of these and many other examples is they are cultural, either in the form of behavior or technologies. Moreover, across generations they have undergone beneficial modifications. Thus, they are examples of cumulative culture. The point we wish to make here is that many of our cultural artifacts, technologies and traits are themselves orientated to the future or future need and that mental time travel and planning into the future may have facilitated the advancement of these cultural products.

This notion that mental time travel is related to cultural evolution is not new. Tulving (2002b) proposed the “proscopic chronesthesia hypothesis”, stating that an essential force in human cultural evolution has been our capability to consciously experience subjective time in which we live (chronesthesia; Tulving, 2002b). Specifically, Tulving proposed that a fundamental precondition to human cultural niche construction (see Kendal, Tehrani, & Odling-Smee, 2011), that is our heightened capacity to change our environment to adapt it to ourselves, is the conscious awareness of “a future”, not just for ourselves, but also for generations to come. It is this future orientated mental activity and conscious awareness of self in subjective time that is hypothesized to have allowed humans to transcend the unidirectional aspect of time. That is, chronesthesia has meant, instead of the past just influencing the present and the present the future, present behavior can also be influenced by the future (Tulving, 2002b), an argument similar to Suddendorf and Corballis (2007).

While the link between cultural evolution and mental time travel into the future has been proposed, an in-depth consideration of how mental time travel may influence culture has received little attention. One exception has been Coolidge and Wynn (2008) who provided an examination of the role of episodic thought on Upper Paleolithic life. Their main premise was that episodic thinking promoted a shift in the life of Upper Paleolithic *H. sapiens* (and human life beyond), since aspects of the archeological record from this time are indicative of behaviors being orientated toward the past and future. For example, Paleolithic artworks, such as the tableau at Lascaux and cave art of Chauvet, were provided as evidence of episodic thought, representing remembered episodes later depicted by an individual. This could be the case, but equally these images could have been formed using more general knowledge, for example semantic knowledge of animal configurations/anatomy or general scripts of hunting events. Burial finds, such as the grave goods at Sungir, along with their ceremonial artifacts were

also posed as examples, thought to reflect the anticipation of an afterlife and, thus, autozoetic experience. However, this is somewhat circumstantial, since object placement to mark, honor or mourn the dead could also explain these finds.

Nevertheless, [Coolidge and Wynn \(2008\)](#) highlight the role that episodic thought played in the early cultures of man. Of particular importance to our current discussion is Coolidge and Wynn's speculation that the long range social networks, evident in European societies after 33 kyr (spanning distances of hundreds of kilometers, see [Gamble, 1999](#)), would have developed only if episodic thought was present to represent and encode long range social exchange. Taking this notion one step further, the emergence of episodic thought may have had larger ramifications for the evolution of human culture if large scale social exchange facilitated the cultural ratchet. Indeed, as discussed above, demographic features apparent in human bands, which lend themselves to large, sustained social networks, are theorized to have played an important role in cumulative cultural evolution ([Hill et al., 2011](#)). Consequently, if Coolidge and Wynn are accurate in their observation of episodic processes underpinning the human shift toward longer-ranged social obligations, the emergence of episodic thought may have had a profound effect on the levels of social information transfer between individuals and groups and the cumulative cultural change evident in our cultural history. Interestingly, Upper Paleolithic life has long been characterized as a transition period during which rapid shifts in technological advancement and cultural complexity are evident ([Ambrose, 2001](#); [Powell et al., 2010](#)). Thus we tentatively suggest that, without the emergence of episodic thought, large social networks, which characterize human societies and promote high levels of cultural exchange, would be curtailed as specific social exchanges would neither be remembered or influence future exchange, thus posing constraints on cumulative cultural evolution.

The proposition that cultural artifacts show evidence of future thinking, and reversing this, that cultural products are influenced by modes of future thinking also deserves greater attention. Making the leap to modern cultures, for which beneficial modification over generations is evident, we propose that many examples have been influenced by, or are even dependent upon, our capacity for mental time travel or future planning. For example, human tools that are designed to be kept (e.g. refillable pens) and even the materials tools and artifacts are made from (*durable* manmade materials such as plastics) would seem to require an understanding of future need, or at least potential uses beyond current motivations. The same can be said of multifunctional tools since they extend beyond a single use or purpose (e.g. multifunctional pocket knives). While script based knowledge will have played a role in the advent of many such products, it may also be postulated that our capacity to recall specific episodes from our past, and our capacity to project and reconstruct these episodes, may have better equipped humans to tailor cultural products to future need. That is, if cultural artifacts were based solely on scripts, products would become relatively fixed, reflecting only needs experienced within general routines. Contrasting this, the episodic system that enables recall of specific events and reconstruction of these episodes to simulate variable futures would seem better positioned to allow artifact refinement toward future needs that deviate from scripts. That is, mental time travel would promote greater flexibility and reflectivity in our cultural invention.

The most impressive tool users seen in the animal kingdom, the chimpanzees, who possess tool kits currently estimated in the region of eight (Budongo, Uganda) to 22 tools (Gombe, Tanzania; [Sanz & Morgan, 2007](#)), rarely carry tools for future use or fashion multifunctional tools ([Boesch, Head, & Robbins, 2009](#)). The exception to this are the hammer and anvil stones used for nut-cracking in some chimpanzee populations for which re-use and transport occurs ([Carvalho, Biro, McGrew, & Matsuzawa, 2009](#); [Carvalho, Cumba, Sousa, & Matsuzawa, 2008](#)), perhaps indicating future use anticipation. However, transportation of these hammers and anvils seems to arise from tool preferences rather than systematic selection of tools ([Carvalho et al., 2009](#)), with transportation occurring despite raw materials for these tools being present at the traveled to locations ([Carvalho et al., 2008](#)). If mental time travel was present in chimpanzees, we would also expect tool modification, such that tools could be used in multiple future scenarios, coupled with flexible tool transportation according to future demand, as seen in humans. This is clearly not the case. Thus, the tool-use behavior evident in one of the more advanced animal tool users shows little evidence of future planning or mental time travel, which in turn may have posed constraints on potential tool modification and innovation.

It must be noted that other factors contribute to the stark differences in the complexity, functionality and use of tools observed in man compared to other apes; including basic anatomical differences affording more precision to human's tool manufacture and use than other apes ([Ambrose, 2001](#)) and differences (both quantitative and qualitative) in causal reasoning ([Seed, Hanus, & Call, 2011](#)). It is also worth noting that multifunctional tools, for example, may not be evident in chimpanzees simply because the raw materials for individual tools are readily available at each location in which tools are used. Thus, unless the time and energy demands involved in fashioning separate tools for each use are prohibitive we will not see creation and transport of single multifunctional tools.

As noted in the preceding section, an important finding in terms of cumulative culture in animals is their failure to switch to more efficient and productive behaviors once a prior food extraction behavior has been mastered ([Hrubesch et al., 2009](#); [Marshall-Pescini & Whiten, 2008](#)). Here we propose that the apparent lack of mental time travel in animals may contribute to conservative learning. To illustrate, if an organism is restricted to the past and present, behaviors that have been effective and thus reinforced in the past are likely to be repeated. Such an orientation to past behavior may be at the expense of switching to more complex behaviors that maximize future gain, but do not immediately pay due to the cost of learning the new behavior. This is similar to the idea of satisficing, wherein animals fail to adopt more productive behaviors if a present need is met using an existing behavior ([Marshall-Pescini & Whiten, 2008](#)). Accordingly, if animals fail to move beyond current drives (although see [Correia et al., 2007](#)), we may expect strategies and outcomes including satisficing and conservatism to prevail. In the case of humans, detachment from current goals or drives may have released

us from conservatism or satisficing since we think not only in terms of satisfying our current, but also our future needs. This would facilitate behavioral innovations and cultural ratcheting which have led to increased payoffs, as seen in agriculture.

An alternative hypothesis for the inability of animals to switch to more complex yet more productive behaviors is the lack of abilities to “copy if better” or “copy in proportion to behavioral payoffs” (see Laland, 2004). Yet many animals show impressive numerical/quantification skills that should allow the assessment of behavioral payoff (Beran, 2001; Hanus & Call, 2007; Honig & Stewart, 1989; McComb, Packer, & Pusey, 1994). An important aspect of “copy if better” strategies, however, is that they are inherently future-orientated since the likelihood of an increased payoff is often contingent upon both immediate and future behavioral payoffs. We, thus, speculate that a potential mediator for adopting more complex behaviors, when proficient in less productive ones, and possessing the prerequisite social learning channels, is the capacity to recognize an observed behavior’s future value to oneself. That is, to mentally travel in subjective time and recognize not just its current value, but its potential value in the future; something akin to “copy in proportion to future payoff”. Such a strategy would absorb any additional immediate cost of learning the more complex behavior due to the subsequent and repeated increased future payoffs gained. Of course, one limitation to this proposal is the observation that some animals can delay gratification (Dufour, Pelé, Sterck, & Thierry, 2007; Dufour, Wascher, Braun, Miller, & Bugnyar, 2012), which necessitates an assessment of future and present reward values. The difficulty postulated in “copy if better” strategies, however, lies in the assessment of behavioral success through an evaluation of payoff to self compared to other (see Laland, 2004), which becomes more cognitively demanding with the addition of assessing future payoff to self (based on the behavioral payoff gained by another agent) relative to those of a previously learned behavior. Thus, we might expect that the episodic system features more prominently in a “copy in proportion to future payoff” strategy that may require projection of the self, while other cognitive factors such as inhibitory control may underlie delay of gratification. Furthermore, a copy in proportion to future payoff strategy requires a form of cost/benefit assessment of the cost of socially learning a new skill and predicted payoffs in the future, thus needing more than inhibition of a present reward.

Returning to human culture, even some of the channels through which we transmit information seem driven by our ability to plan for the future. As noted, teaching has been proposed as a mechanism supporting cumulative culture, leading to high fidelity learning that can prevent loss of beneficial behaviors (Dean et al., 2012; Tomasello, 1999). To the extent that human teaching does not rely purely upon past experience (i.e. knowledge gained by the teacher in the past which is then transmitted), but is guided by imagined futures and our planning for the future of our students, we suggest that mental time travel and future planning may have facilitated cumulative culture by improving this complex social learning mechanism (see also Fogarty, Rendell, & Laland, 2012, for a consideration of the beneficial impact of mental time travel on social learning strategies). For example, what is taught in and, indeed, outside of schools depends on the skills we expect pupils to require in the future, at a time when the teacher is no longer present. Although we may consider teaching as the process of transmitting simply what we ourselves have acquired during our lifetimes, this is not the case. For instance, through mental time travel we teach others how to behave or what may occur in future events that we have not directly experienced. In doing so, we can transmit information relevant to the learners’ futures and prepare them for probable events by recasting our own similar experiences. Thus, the capacity to mentally travel forwards and back in time coupled with our planning abilities generates better information exchange. Thus we propose that cumulative culture is enhanced by mental time travel and future planning since the application of these capabilities to the imagined futures of others acts to filter the transmission of knowledge, reducing or enhancing the propagation of information unlikely or likely to be of use to future generations, respectively.

There are many ways in which mental time travel, its underpinning episodic system, and related future planning abilities may have influenced the cultural accomplishments of humans. Today, much of our cultural knowledge and technologies have reached levels of complexity that necessitate learners investing in years of study, with little immediate payoff. If we view this in the light of humanity’s capacity for future planning and our ability to live beyond the present, we can postulate that these capabilities, in part, mediate this costly endeavor. Indeed, students’ future time perspectives regarding school performance and potential careers are found to affect academic achievement through learning investment (Peetsma & van der Veen, 2011). This, along with similar findings that one’s time perspective in school constitutes a good predictor of academic achievement and learning behavior (Peetsma, 2000), suggest that human learning is influenced by how we see our futures and the future goals we set. While one’s future time perspective does not necessarily include episodic thought or mental time travel (referring instead to individual’s conceptions of the future within a given domain; Peetsma & van der Veen, 2011), the goals we set and the future we imagine for ourselves are likely to influence our investment in social and asocial learning. This is because simulation of our possible futures and their outcomes allows the maximization of positive ends and the avoidance of negative ones (Spreng, Mar, & Kim, 2008) and is likely to provide motivation in the present to engage in tasks that are not immediately beneficial but fruitful in our future. Thus, we suspect that the presence of these factors, plays an important role in our capacity to embark on lengthy learning ventures expending energy and time with little immediate payoff, required to sustain (and indeed modify) the levels of cultural knowledge attained in modern society.

Conclusion

We propose that a link exists between humanity’s cultural accomplishments and the capacity for mental time travel. Human modes of future thinking seem well positioned to (i) promote cultural innovation, (ii) facilitate knowledge exchange by enabling larger social networks, (iii) enhance teaching capabilities through their orientation to pupils’ futures, and (iv)

increase human investment in domains such as learning and long term goal pursuit. In addition to the prerequisite social learning channels required for cultural exchange, it is difficult to imagine how our species would have reached the levels of cultural complexity so evident today without the capacity to disengage from current motivations, or to imagine and plan for the future. This is especially true for the maintenance of knowledge, skills and technologies that require years to attain with little immediate payoff. It is also worth noting that mental time travel may have influenced human culture in ways not considered here. For example, episodic memory and episodic foresight would seem essential for economic trade to succeed on a large scale, are likely to have influenced the formation and maintenance of cultural institutions and played an important role in cooperation and social regulation (e.g. rules, norms and law maintenance through the prospect of future punishment or reward). Moreover, a reduction in one's ability to imagine their personal future coupled with diminished control of impulsivity may hinder cumulative culture through the transmission and maintenance of maladaptive traits (e.g. substance abuse, Madden, Petry, Badger, & Bickel, 1997). Thus, we hypothesize that mental time travel constitutes one of a suite of abilities that play a role in our extraordinary cultural accomplishments.

We do not suggest that mental time travel is *sufficient* for cumulative culture, rather that it may have facilitated the process of cumulative cultural evolution through the release it affords from the present (Suddendorf & Corballis, 2007). Indeed, since mental time travel typically emerges around 4-years of age (Suddendorf, Nielsen, & von Gehlen, 2011), finding that cumulative improvement in behavioral efficiency occurs in children as young as two years (Flynn, 2008) illustrates that mental time travel need not be present for cases of cumulative cultural change to occur. Furthermore, we recognize that any link between mental time travel and cumulative culture is not a unidirectional process. It is noteworthy that many human cultures have enabled man to move beyond immediate motivational drives through need alleviation. In Western populations, for instance, the time and energy expended on foraging has been minimized through the advent of agriculture and local institutions/markets that trade in consumables. Thus with current needs more easily satiated now and in the future, a shift toward contemplating and pursuing needs or goals in the more distant future may have occurred, promoting future modes of thinking. Similarly, culture will invariably influence our simulations of future selves and long term goals, for example the age at which we plan to marry, have children and the career paths we take. Moreover, the link between mental time travel and culture may be stronger than proposed here. Further postulation concerns the extent to which material culture, such as calendrical systems, has supplemented and enhanced episodic thought through its provision of greater accuracy in recording past events and predicting the future (De Cruz, 2011; De Cruz & De Smedt, 2007). Furthering this, it has been posited that mental time travel evolved as a recent adaption associated with the acceleration of behavioral diversity in *H. sapiens*, functioning as a store of past experiences from which beneficial courses of actions can be selected and flexibly applied to anticipated future situations (Boyer, 2008). This would suggest that the accumulation of (cultural) traits itself may have contributed to the emergence of mental time travel.

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