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Is cultural evolution always fast? Challenging the idea that cognitive gadgets would be capable of rapid and adaptive evolution

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Abstract

Against the background of "arms race" style competitive explanations for complex human cognition, such as the Social Intelligence Hypothesis (Byrne & Whiten, 1988; Humphrey, 1976; Jolly, 1966), and theories that tie complex cognition with environmental variability more broadly (Godfrey-Smith, 1996, 2001), the idea that culturally inherited mechanisms for social cognition would be more capable of responding to the labile social environment is a compelling one. Whilst it is tempting to think that the evolvability of culturally inherited cognitive mechanisms such as Cecilia Heyes' (2018) cognitive gadgets would be akin to culturally inherited tools like axes or canoes (i.e., relatively easy to modify to adaptive benefit, and relatively robustly inherited), I draw on established theory in evolutionary developmental biology to show that this is a mistake. Their causal translucency, along with the degree to which they would be integrated within the organism, make cognitive gadgets far more like genetically inherited traits with respect to their evolvability. Consequently, their evolution is unlikely to be particularly fast or nimble. In making clear the constraints on the evolution of culturally inherited cognition and how they must influence our theorising, the discussion also highlights the value of thinking about evolvability in this domain.

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Introduction

Rapid and widespread shifts in culture are (as any fan of fashion or popular music can attest) a hallmark of human culture. In contrast, widespread genetic change is almost always a slow affair. As a general rule, unless a population is under extreme selection pressure, large adaptive shifts in genetic composition happen over multiple generations and are difficult to meaningfully observe in real-time. It is in this context that cultural evolution is generally seen as "faster" and "nimbler" than straightforward biological evolution.

Although making a general assessment regarding the relative rate of different forms of evolutionary change across the entire of human history would be incredibly difficult, this common view has strong support. The cultural evolution of human cultural artefacts has been demonstrated to be significantly faster than is possible via genetic evolution in at least some cases (Perrault 2012). More broadly, the success and rapid expansion of our own culture-soaked species is palpable proof of the comparative speed at which cultural traits can evolve. Culture has obviously played a central role in the prodigious capacity of humanity adapt to, and modify, its environment and ultimately exploit great swathes of the planet. Also telling are the many cultural traits maintained in human populations via social learning alone to have undergone rapid, widespread change within single generations. The speed at which dance crazes (such as the macarena) and "earworms" (like Baby Shark) sweep the world are stark illustrations of this phenomena in our everyday lives.

Approaches to human social cognition[1] that emphasise cultural inheritance typically straightforwardly adopt this "faster and nimbler" moniker. Competitive explanations for complex human cognition, such as the Social Intelligence Hypothesis (Byrne & Whiten, 1988; Humphrey, 1976; Jolly, 1966), and theories that tie complex cognition with environmental variability more broadly (Godfrey-Smith, 1996, 2001) lend intuitive credence to the idea that culturally inherited mechanisms for social cognition would be more capable of responding to the labile human social environment than genetically inherited ones. In this paper, however, I argue that extent to which the "faster and nimbler" moniker—which appears derived largely from thinking about human technological artefacts and cultural elements, like fashion and music—can be applied to culturally inherited cognitive traits is actually very limited. For a number of compelling reasons relating to the composition of culturally inherited cognitive traits and their physical integration in the body, they are far more likely to evolve in a manner akin to genetically inherited traits, than the archetypally cultural traits. This discussion makes clear a number of important factors relating to constraint and evolvability which must be taken into account when thinking about the nature of culturally inherited social cognition and its evolution.

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[1] Which (taking a leaf from Heyes (2018a)) I take to include various "distinctly human" capacities, such as language, imitation, social learning and theory of mind.

Throughout, I focus on Cecilia Heyes' (2018) expansive Cognitive Gadgets Hypothesis (CGH), though the lessons learned are of relevance to any model of social cognition which is heavily reliant on cultural inheritance. I have chosen the CGH for two reasons. First, the sort of critique I offer here requires a sufficiently developed and empirically adequate target and it is the most well-developed and well-defended account of culturally inherited human social cognition to-date. Although most cohesively presented in her 2018 book, Heyes has amassed a great body of work, both empirical and theoretical, building and supporting the CGH (and most especially regarding the cultural inheritance of imitation (Catmur et al., 2009a, 2015; Cook et al., 2014; Heyes, 2010, 2016b; Heyes et al., 2007)). A second reason to focus on Heyes' work is because she clearly assumes the "faster and nimbler" moniker does straightforwardly extend to her culturally inherited cognitive gadgets. Specifically, in considering the lack of evidence for the genetic assimilation of the cognitive gadgets she proposes (as one might predict given their adaptive value), Heyes offers invokes their capacity for rapid change; offering this as a reason why they would remain culturally inherited, rather than becoming gradually more and more genetically canalised over time (Heyes, 2018, Chapter 9, 2019b).

As I show, however, the "faster and nimbler" moniker cannot be simply applied to culturally inherited cognitive mechanisms (such as Heyes' gadgets) because it is not cultural *inheritance* that is the key to rapid cultural evolution at all. Cognitive gadgets, whilst culturally inherited, would be more akin to genetically evolved traits in a number of evolutionarily salient ways; ways which effect the speed of evolutionary change. These affinities with genetically evolved traits undermine the plausibility of Heyes' expectation (and that of others) that the evolution of culturally inherited cognitive gadgets would be rapid and flexible in nature (or at least more so than genetically inherited cognitive mechanisms). This does not present a refutation of the CGH (Heyes having offered extensive independent empirical evidence for its plausibility in *Cognitive Gadgets* (2018a) and elsewhere (Heyes, 2018b, 2019b, 2020), but it does point to places where the account, and related accounts of social cognition which emphasise cultural inheritance (e.g. Fiebich & Coltheart, 2015; Haslanger, 2019; McGeer, 2015; Spaulding, 2018; Zawidzki, 2013), are lacking. Although dealing directly with the CGH, this analysis highlights some key concerns that any evolutionarily plausible account of social cognition which relies heavily on cultural inheritance must address. It also highlights the features which serve to make cultural evolution flexible and rapid when it is.

My analysis begins in Section 1 with a brief summary of the Cognitive Gadgets Hypothesis focussing in particular on the role that the claimed rapidity and flexibility of cultural change plays in Heyes' presentation of that hypothesis. In Section 2, I point out the similarities and differences between paradigmatically cultural and genetic inheritance which I take to underwrite the commonly held assumption that cultural evolution is faster than genetic evolution. I do this by comparing and contrasting evolvability in two paradigmatic cases— (i) the genetic evolution of the human forelimb, and (ii) the cultural evolution of the bow-and-arrow. In Section 3, I consider whether social cognition as a cognitive gadget would be more or less like (i) or (ii), ultimately arguing that with respect to evolvability it would be far more similar to (i). In other words, at least in terms of the properties relevant to the speed and flexibility of evolution, cognitive gadgets are more like genetically inherited traits than culturally inherited ones. In Section 4, I conclude the paper with a consideration of the implications of this for CGH and for related theories of cognitive evolution that couple biology and culture in a similar fashion.

1. Some Background – Heyes' Cognitive Gadgets Hypothesis

1.1 The basic picture

The central claim of Heyes' CGH (2018) is that the transmission of various forms of "distinctly human" social cognition (including mindreading, language and imitation) within populations is largely via cultural, rather than genetic, inheritance.[2] On Heyes' view, like tools or gadgets, the characteristic elements of human social cognition are constructed during development at each generation through the presence of a genetically specified, domain-general learning start-up-kit alongside a suite of culturally inherited, specialised developmental resources for social cognition (i.e., knowledge, information, practices and the like). It is, Heyes contends, a culturally inherited suite of specialised resources that carries the particular information necessary for the development of the cognitive "gadgets" of human social cognition. In this sense, the persistence of social cognition in human populations is (to the extent that any trait can be said to be due to one specific route of inheritance) the product of cultural inheritance.

In presenting her thesis, Heyes (2018) distinguishes between two sorts of inherited material. First, those features typically considered to be cultural, such as the contents of our thoughts (e.g., language systems, mathematical and scientific beliefs). These, she describes as the "grist" of the mind. And second, what she dubs the "mills" of the mind—the mechanisms that underly how our minds actually work. As Heyes (2019) describes it, these are "the computational mechanisms that enable us to read print, learn selectively from others, imitate, read minds and speak to one another". Heyes' cognitive gadgets are culturally inherited mechanisms of the second type. They are "the mills" through which the first type of thing— the contents of our thoughts ("the grist")—are processed.[3]

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[2] Note my use of "largely" here. No one is arguing for a "culture-only" or "genes-only" picture, there is a clearly important role for genes, learning and culture on all-sides. The debate surrounding the inheritance and nature of social cognition (and the CGH within that) concerns the middle ground, rather than polar opposites. In the case of the CGH, cultural inheritance is given the greatest weight in explaining the features of human social cognition, rather than solely attributing causal responsibility to cultural factors.

[3] Although intuitively appealing, Heyes' "grist" and "mills" analogy can be misleading (Baggs et al., 2019; C. Heyes, 2019a; Smaldino & Spivey, 2019; Whiten, 2019). For example, it implies that there is a clear boundary

Given this, the picture of the development and evolution of human social cognition offered by Heyes lies in stark contrast with more traditional approaches (such as a modularity-based account or dual systems model). Unlike the CGH, these emphasise the genetic inheritance of domain-specific cognitive mechanisms for social cognition. They postulate the existence of a set of specialised, genetically inherited cognitive mechanisms which are largely causally responsible for both the development, and mature activity, of the mechanisms of human social cognition. Heyes denies the existence of such specialisations for social cognition beyond some "tweaks" to the domain-general start-up-kit. Any specialisations specifically for social cognition are culturally inherited on her account and the product of the accumulation of cultural capital over evolutionary time. Put simply, the CGH model thus places the special causal "difference makers" for social cognition largely in the heritable cultural, or external, realm, whilst traditional pictures emphasise the role of internal, or biologically heritable, elements. To illustrate, let us turn to the most well-developed account of any of Heyes' gadgets—that for imitation.

1.2 An illustration: Imitation as a Gadget

One of the striking capacities of even very young infants is their apparent capacity to imitate others (Meltzoff & Moore, 1983)[4]. As anyone who has taken a dance or aerobics class knows, however, successfully imitating the movements of others is no mean feat. It is all too easy to move your right arm when the model is moving their left; or step to the right when they are stepping left. Even for quite simple gross body movements it can be challenging to work out which of your own actions correspond appropriately to the actions of the model. This is because imitation requires that the imitator translates

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between cognitive mechanisms and the contents they process (much like a mill processes the grain to make flour). The contents of our thoughts (the grist), however, both build and shape our cognitive mechanisms (the mills) as well as being processed by them. This is not at all like the relationship between the grist and mills of the agricultural variety. Similarly, the cultural inheritance of cognition plays a role in the transmission of the content of thoughts and the mechanisms of thought themselves (C. Heyes, 2012, 2018a, 2019b), which again doesn't clearly work for the grain and flour mill case. Thus, whilst I have used the analogy here in outlining Heyes' view, I have tried to avoid using it where possible in the later discussion because I suspect it confuses more than clarifies once we move away from the big picture and into the weeds.

[4] It is worth prefacing this discussion with acknowledgement of the depth of controversy surrounding imitation, and more particularly neonatal imitation. Although explaining the phenomena has played a central role in much theorising in developmental psychology, its very existence is debated (e.g. Beisert et al., 2017; Kennedy-Costantini et al., 2017; A. N. Meltzoff et al., 2018; Ray & Heyes, 2011; Simpson et al., 2017; Vincini et al., 2017). A recent meta-analysis of a large number of independent studies of neonatal imitation did not find clear positive evidence for the phenomena. It did not rule out the possibility that this was due to methodological factors, however, rather than there being no observable feature of neonatal development (Davis et al., 2021).

visual information (i.e., the observed movements of the demonstrator or model) into a motor program for their own use, despite the fact that the information about actions they observe is in a different frame of reference and modality to how they must be performed. Imitation researchers call this the "correspondence problem" (Catmur et al., 2009b).

Given the apparent precocious development of the ability to solve this problem in humans, traditional models of imitation (such as Meltzoff & Moore's (1997) active intermodal matching (AIM) model) postulate the existence of genetically inherited cognitive mechanisms specifically for imitation found only in humans and their close relatives (Meltzoff & Moore, 1977; Meltzoff & Decety, 2003; Nagy, 2006). On such accounts experience plays relatively little role in explaining our imitative capacities, rather it is an inherited genetic endowment that does the heavy lifting.

In contrast, the associative sequence learning (ASL) model of imitation developed by Heyes and others over the better part of the last 30 years postulates that our imitative capacities are acquired during development as a consequence of particular sorts of sensorimotor experiences (Brass & Heyes, 2005; Heyes, 2016a, 2016b; Heyes, 2001; Heyes & Ray, 2000; Ray & Heyes, 2011). Specifically, a new cognitive mechanism ("cognitive gadget") for imitation is built during development through the association of perceptual and motor sequences via cultural experiences that have evolved (at least in part) because they strengthen these associative links. Such cultural experiences include synchronous dances and exercise, being imitated by others, and experience with optical mirrors. The ASL model rejects the idea of specialised, genetically inherited cognitive processes or mechanisms specially adapted for imitation, depending instead on straightforward associative learning in the development of a culturally acquired gadget for imitation (Catmur et al., 2015; Cooper et al., 2013; Dickinson, 2012; Heyes, 2016a). Essentially, the reliable development of this imitation gadget is the product of a set of tweaks to a start-up developmental kit over evolutionary time coupled with a suite of specialised cultural resources and general associative learning capacities (Catmur et al., 2015; Cooper et al., 2013; Heyes, 2018a). I will say more about this example in Section 3, but for now let us return to the dialectic around gadgets and their evolvability.

1.3 Faster and nimbler gadgets

In *Cognitive Gadgets* (2018), Heyes draws on the Social Intelligence Hypothesis (Byrne & Whiten, 1988; Humphrey, 1976; Jolly, 1966) and other theories which tie complex cognition with environmental variability more broadly (Godfrey-Smith, 1996, 2001), arguing that the heterogenous and rapidly changing nature of human social environments would favour those individuals better able to modify their behaviour rapidly. Culturally inherited mechanisms of social cognition (i.e., cognitive gadgets), she claims, would be far more capable of undergoing rapid change (i.e., more evolvable), than any analogous specialised genetically inherited system(s) could be. Given this, we should expect culturally inherited social cognition to evolve and have significant selective advantages over any genetically determined mechanism that could arise.[5]

We see the case for this idea most clearly stated in Heyes' discussion of genetic assimilation in *Cognitive Gadgets* (2018, Chapter 9). There, Heyes responds to the following hypothetical objection to her view—why, so the possible objection goes, would the inheritance of such important (and clearly fitness enhancing) traits like mindreading, language and imitation remain reliant on something so unreliable and changeable as culture? Why, in short, wouldn't cognitive gadgets just be genetically assimilated over time? Heyes replies to this objection by claiming that it rests on the unfounded assumption that lability is a "bug" of culturally inherited systems, rather than a feature. She states that,

> "…distinctively human cognitive mechanisms need to be nimble, to be capable of changing faster than genetic evolution allows, because their job is to track specific, labile features of the environment….in short, distinctively human cognitive mechanisms are tracking targets that move too fast for genetic evolution. In a stable phase, "assimilative alleles"—genes that reduce the experience dependence of a cognitive gadget's development—may increase in frequency. But when the environment shifts, there will be selection against assimilate alleles because their bearers will be slower to adjust to the new conditions…" (Heyes, 2018, p. 208)

Heyes goes on to say that, while we expect genetic assimilation of elements of the start-up-kit for cognitive gadgets, the gadgets themselves are not assimilated[6],

> "Changes to the cognitive mechanisms that increase the supply of information from social sources, and the efficiency of problem-solving across domains, are good targets for genetic assimilation because they remain adaptive as long as the developmental environment contains knowledgeable agents and tricky problems to be solved. But changes to cognitive mechanisms that tune human development to specific features of the culture-soaked environment—cognitive gadgets— are poor targets for assimilation because they remain captive only until those features change." (C. Heyes, 2018a, p. 209).

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[5] It is worth noting that, although Heyes says she expects that her cognitive gadgets would be more evolvable than genetically inherited cognitive systems, and that such evolvability would be a good thing, she is not offering this as a bald reason to think that cognitive gadgets exist. The foundation of her defence of the CGH is empirical, not theoretical and does not rest on evolvability.

[6] Heyes adds further reasons to reject the idea that cognitive gadgets could be partially genetically assimilated in a later response (Heyes, 2019b) to a criticisms by Dor et al. (2019). Whilst interesting, I don't elaborate on these reasons here, as Heyes' views regarding the evolutionary lability of cognitive gadgets (which is our focus) appear unchanged.

As stated in the introduction, this type of claim is common in discussions of cultural evolution and has significant intuitive appeal. In the case of cognitive gadgets, however, it rests on a mistake—the assumption that the evolvability of cognitive gadgets (i.e., their capacity to undergo cumulative and lasting evolutionary change[7]) would be akin to that exhibited by other technological gadgets given that both are culturally inherited and the product of the accumulation of cognitive capital. As I show, rather than being able to undergo rapid adaptive change like a tool or other cultural element that is not integrated with the body, cognitive gadgets would be much more akin to genetic traits in their evolvability. In making my case, I begin by comparing and contrasting two classic cases—(i) the genetic evolution of the tetrapod limb and (ii) the paradigmatic cultural evolution of the bow-and-arrow. This exercise serves to bring out the features that underwrite the relative lability of paradigmatic cases of cultural evolution over paradigmatic cases of genetic evolution which is assumed by Heyes. With that in place, we can then turn to the question of whether it is plausible to claim that cognitive gadgets would be able to undergo rapid adaptive evolutionary change.

2. Bows and Arrows and Limbs: Getting to grips with the drivers of adaptive cultural flexibility

2.1 Two paradigmatic traits: One "biologically" and one "culturally" inherited

The key features of paradigmatically cultural evolution that make it so powerful can be neatly illustrated by comparing the evolvability of two complex human "traits"—one, the clear product of biological evolution, the other, the clear product of cultural evolution. In comparing and contrasting these traits, the features which make the latter more capable of undergoing rapid evolution are easily identified. The human forelimb and bow-and-arrow offer straightforward traits for this purpose.

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[7] The term evolvability is a fraught one with multiple definitions in the literature (Brown, 2014). In this context, I am using it to refer to the extent to which a trait can undergo evolutionary change which is specifically related to the supply of heritable variation to selection. Not all traits are equal in this light. A highly canalised trait and is relatively robust to both genetic and environmental change is not particularly evolvable as, even if in a population under strong selection, the variation upon which selection can act, would not arise. In contrast, a trait underwritten by a highly variable area of the genome without such canalisation may be comparably quite evolvable, as there would be significant phenotypic variation for selection to act upon within populations carrying it. We would see this differential evolvability borne out by (on average) faster rates of evolution in highly evolvable traits as compared to less evolvable traits. I flesh this out further in Section 2.3 but for other discussions of evolvability in this sense see Kirschner & Gerhart (2005), Wagner and Altenberg (1996) and West-Eberhard (2003).

Like social cognition, the human forelimb has been described as a hallmark feature of our species. The opposable thumb, highly dexterous digits, and other elements of the forelimb are central to many features of human behaviour allowing us to manipulate our worlds in all sorts of fine-grained ways that are difficult for other species. For our purposes here, the forelimb is also a paradigmatic example of a genetically inherited trait that is the product of straightforward "biological" evolution (at least to the extent that we could say that any trait is). It is a biological "gadget" built by "biological" evolution.

In contrast, although it too could be described as being hallmark trait of our species, the bow-and-arrow is a paradigmatic culturally evolved trait. One of the oldest composite tools, the bow-and-arrow is a key cultural innovation within the hominin lineage, allowing hunting on a scale previously unimaginable and without the danger that earlier technologies, such as throwing spears, carried with them[8] (Lombard & Haidle, 2012). This is a paradigmatically cultural "gadget".[9] With both of these paradigmatic examples now in place, let me turn to their similarities and differences from an evolutionary perspective.

2.2 Comparing the paradigmatic cases: Similarities

The bow-and-arrow and forelimb share many evolutionarily relevant features. For one, they are both complex traits—they have a number of differentiated parts that are organised in a very specific way, as well as being both functionally and developmentally integrated.

In the case of the forelimb, for example, the proper functioning of the hand is dependent on the presence of a multitude of tendons, bones, muscles, blood vessels etc… in the rest of the forelimb which work in concert. The development of the various parts of the limb is also interdependent. The arrangement of the nerves in the arm, for example, are set during development by the placement of the musculature (Kirschner & Gerhart, 2005). Changes in one aspect of this architecture often has downstream effects on others.

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[8] Throwing spears (the antecedents of bows-and-arrows) are not subtle or particularly efficient hunting tools. The spear thrower, for example, must be standing, and have sufficient room to move in order to throw the weapon, making stealthy use difficult. This, and the limited number of spears any one person can carry or use (generally one only), make spear hunting both inefficient and costly with many individuals required to cooperate in the hunt. In contrast, bow-and-arrows can be used from a crouching position. Up to a dozen or more arrows can be carried by any one individual. And, with a poison tipped dart, one or two individuals can successfully bring down large game while incurring limited personal risk (at least as compared to spear hunting which involves getting close to the wounded animal (Villa & Soriano, 2010)).

[9] Of course, there are cognitive traits required for generating tools, such as technical competence or causal reasoning which co-arose or preceded bow-and-arrow making. These are not my interest here. They are best understood as part of the developmental resources for building the cultural gadget in this context, just as the developmental architecture for the arm is required for building it.

Turning now to the bow-and-arrow. Even the simplest bow, and unfletched, stone-tipped arrow is made up of a bow, string, arrow-shaft and arrowhead. Each of these elements have features of their own, plus the binding used to connect them and the glue or mastic used (Lombard & Haidle, 2012). The proper functioning of the bow is contingent on the correct fashioning of these elements, along with their appropriate arrangement and integration during construction. Tension in the string, for example, is the product of a combination of the flexibility of the bow itself and the amount of give in the string material. The final structure displays a high degree of functional integration—the proper functioning of the various elements of the bow-and-arrow (and ultimate good function of the entire structure) require that each element is working properly. Not all tools are like this. Take a swiss army knife, for example, the scissor functions independently of the screwdriver, and the knife independent of the scissors or screwdriver. Failure of one or the other is likely to have relatively little impact on the other, and thus the overall good functioning of the tool could be said to be more robust than that of a bow-and-arrow. If one element of the swiss army knife fails, the tool is still functional, whereas the failure of the string or arrow-shaft etc… is lethal to the functionality of the whole in the case of the bow-and-arrow.

We also see a high degree of path dependence and integration in the "development" of bow-and-arrows. Construction of a working bow-and-arrow, from gathering the elements through to the final firing of the first arrow, involves numerous interrelated steps, pieces of knowledge and expertise (Lombard & Haidle 2012). These steps are not the same for every particular bow either. For pre-modern bows at very least, the natural materials they are built from vary in their flexibility, uniformity and weight, meaning that no two bows will ever be exactly the same. Consequently, constructing a fully functioning bow requires that the maker balances the unique affordances of the different elements of each particular weapon. This is an intricate job. The complexity of both the forelimb and bow-and-arrow is a sign of a certain type of evolutionary history and has implications for how these traits could evolve in the future (as discussed in Section 2.3).

As well as being complex and displaying a high degree of functional and developmental integration, both the bow-and-arrow and human forelimb share being the product of selective evolutionary processes. In so far as anything can said to be, the human forelimb is the straightforward product of evolution by natural selection acting upon populations. In the case of the bow-and-arrow, things are less straightforward, but nonetheless it is undeniably the product of an evolutionary process of some nature. Contemporary bows and arrows and their designs are the product of the accumulation of many cultural innovations[10] over multiple generations and the testing of those innovations in a combination of intelligent design and cultural selection. On the whole, this testing process has seen those bow-and-arrow designs that fail to improve functionality fall by the wayside, and the propagation

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[10] Where "innovation" is used loosely to include both intentional and unintentional (or accidental) novelties in design.

and persistence of those good-making properties of bow-and-arrows. In that sense we can say that bow-and-arrow evolution has been selective, although the exact nature of the dynamics of the change is of course going to be complex. How much, if any, of that dynamic could be said to be evolution by natural selection is not of particular relevance here. Importantly for our purposes, just like in the evolution of the forelimb, the evolution of the bow-and-arrow has involved something like an iterated process of innovation and selection ultimately leading to the accumulation of design represented in bow-and-arrows today.

2.3 Comparing the paradigmatic cases: Differences

Whilst bows and arrows and forelimbs are similar in many evolutionarily significant ways, it is the differences between the two cases which are illustrative of why cultural evolution is typically understood to be nimbler than genetic evolution. One obvious difference concerns the way that the traits are inherited.

Inheritance

The features of your forelimb are largely inherited from your parents via their germline DNA. In this sense forelimbs are inherited simply and vertically across generations. This, in itself, makes the spread of any novelty in forearms that might arise (even novelties which are highly fitness enhancing) slow, as it takes many generations for novel phenotypic elements to spread within in human populations via genetic inheritance (particularly modern human societies with low fecundity and mortality). In contrast, a novel bow-and-arrow variant, is transmitted between individuals via social learning which allows for both vertical and horizontal inheritance. This could see a novel bow-and-arrow form or innovation in design or construction sweep through a population in a single generation, just like a dress or dance style. Inheritance of this form also means that cultural innovations and wholesale cultural traits like dances or dress styles can be lost entirely within single generations. For example, bow-and-arrow technology was likely lost and reintroduced in Northern Europe during the late paleolithic period (Riede, 2009).

Even if we hold fixed the size and adaptive value of the phenotypic innovations we are likely to see, there is clear difference in the evolutionary potential of populations (i.e., evolvability) with respect to these two traits purely as a consequence of the channel of inheritance that they are reliant on. In the case of the limb, any novelties are most likely going to be very slow to filter through the population over many generations. In the case of the bow-and-arrow, change is potentially very rapid and within a single generation though there is no guarantee such change will be fitness enhancing[11]. Whilst the rapid

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[11] There is no guarantee that what is selected for in a cultural context is actually going to be fitness enhancing. Even if agents are trying to build tools which will improve their own survival and reproduction (i.e., adapted to their circumstances) the complexity of the trade-offs between tool efficiency, tool production and other factors in

spread of traits in populations that cultural inheritance can afford is one driver of the "rapid and nimble" moniker of cultural evolution, and that most often discussed, it is not the only driver. The other driver rests in the differences between the supply of heritable phenotypic variation typically produced in populations with respect to their cultural versus biological traits.

The supply of heritable phenotypic variation

It is widely accepted that for any selective evolutionary process (whether it be artificial, cultural or natural selection) to take place there must be heritable variation in the trait under selection (Lewontin, 1970). Without heritable variation there is nothing for selection to act upon, and no way for the effects of selection to accrue over generations. Not only is heritable phenotypic variation necessary for natural selection to take place, but the nature of the supply of variation within populations influences how fast they can change over time and how likely that change is to be adaptive.

Assuming for simplicity's sake that phenotypic variation straightforwardly reflects genetic variation[12], phenotypic traits exhibiting relatively low rates of variation within a population provide little for selection to act upon, and, consequently, evolution in them is likely to be slow (i.e., low evolvability). In contrast, high levels of phenotypic variation within populations can provide the basic material for there to be relatively rapid evolution (i.e., high evolvability). Consider, for example, a population of a short-lived species which tends to produce relatively large numbers of offspring, such as *Drosophila melanogaster*. It will (all else being equal) evolve faster than a population of a longer-lived, less fecund species, such as our own. This is because, whilst every reproductive event in human and drosophila populations represents an opportunity for novel heritable traits to arise via straightforward recombination during meiosis and mutation, in drosophila populations, there are many more of these events in any given period than for a human population of a similar size. The consequence is that the supply of heritable phenotypic variation in drosophila populations is effectively much larger for any given time period than for a human population of a similar absolute population size. More

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these contexts make accurate assessments of actual fitness value difficult and thus what is directly selected may not actually improve fitness.

[12] Obviously, this is an idealisation (though not an unusual one to make). There is no simple one-to-one mapping of genotypes to phenotypes and naturally occurring phenotypic homogeneity is often accompanied by cryptic genetic variation. Similarly, genetic homogeneity does not imply phenotypic homogeneity due to the important influence of the environment and gene interactions on the expression of traits. What is important to note here is simply that without a supply of heritable variation that is also visible to selection (i.e., variation that makes a difference to fitness) populations cannot undergo natural selection. How this plays out is often complex, but the requirements of natural selection remain the same.

variation means that there are more chances for beneficial mutants to arise, and thus, all else being equal, evolution should be on the whole faster for a drosophila than the human population.

The supply of phenotypic variation in populations can vary beyond merely the rate at which novel forms arise. The size of the shifts in phenotype that can occur in any given generation, and the extent to which those shifts are produced by a blind or directed process, all also impact upon a population's capacity to evolve (its evolvability). For example, a population of organisms in which mutation is biased towards adaptive benefit, will (all else being equal) be liable to evolve adaptations faster than a population of organisms in which mutation is random or insensitive to adaptive value. In a similar vein, of those populations in which mutation is biased towards adaptive benefit, those in which bigger mutations tend to occur, are (in at least some circumstances) going to be able to evolve adaptations faster merely in virtue of each adaptive shift they make being larger in size. It is in this sense that the supply of phenotypic variation to selection is of great importance when making assessments of the relative rate at which populations can undergo evolution. Selection can only act on the material available to it in populations, and that material is the direct product of the mechanisms generating phenotypic variation. Let us now return to the forelimb and bow-and-arrow and see how they compare in this regard.

In the case of the forelimb, heritable variation within human populations is straightforwardly generated by mutation and recombination during reproduction. As per above, humans are a long-lived and not particularly fecund species which means our absolute rate of phenotypic innovation is low, and the pace of biological or genetic evolution is also relatively slow as compared to other animals. In addition, the processes of mutation and recombination during reproduction are insensitive to adaptive value i.e., traits that improve the fit between the organism and the environment are no more likely to arise than those that do not improve that fit. Indeed, the complexity of the forelimb, makes adaptive mutations even less likely than if it were a very simple trait.

When we make random changes to the genes underwriting a complex, functionally and developmentally integrated trait such as the forelimb their phenotypic impact is far more likely to be deleterious or neutral than adaptive. This is because, even small changes to the instructions for building a complex integrated mechanism, such as the forelimb, are likely to have many downstream effects. This is because there are, to put it simply, many more ways to build a poorly functioning or non-functional machine, than there are to build a well-functioning one. To illustrate, it helps to draw an analogy between the human body and a complex machine such as a car. What if we were to randomly alter the size of just one component of a car? We would be highly unlikely to improve its handling. Furthermore, whilst some of the possible changes we could make would make no difference to the car's function (e.g., changing the size of the headrest or drink cup holders), many of the random changes (even quite small ones) would actually have multiple negative downstream effects (e.g., if we made one wheel larger, or an axle longer, the car would be more difficult to drive, if it would go at all). Very few random changes are likely to improve the functioning of the car. Returning to the forelimb, we are in a similar predicament.

Random mutations to the genes for the forelimb are much more likely to be neutral or deleterious than adaptive in nature because we are talking about a complex and integrated trait. A mutation, for example, that makes the ulna (one of the long bones of the forearm) shorter would have numerous negative effects on the good functioning on the limb unless there are concomitant changes in other parts of the system to compensate. Although developmental systems typically have features that are able to reduce the likelihood of mutations having negative downstream consequences (e.g., modular organisation and phenotypic plasticity, see Kirschner & Gerhart (2005) for useful discussion of this), the fact remains that the randomness of the supply of genetic mutations in biological systems places a constraint on the rate of evolutionary change in those systems.[13]

This alone would be sufficient to suggest that the evolvability of the human forelimb is extremely low (i.e., any large-scale evolutionary changes are likely to take many, many generations) but the functional and developmental integration of the forelimb also make adaptive mutations of large phenotypic effect particularly unlikely further constraining evolvability. To return to the car analogy, when making random changes to a complex machine, you are far less likely to damage the functioning of that machine if you stick to jiggles and tweaks to the machine, rather than wholesale changes to organisation or structure. Similarly, mutations which result in small variations in the length of the forelimb are less likely to be deleterious than those resulting in large shifts in length. Consequently, we expect the supply of adaptive variation in the case of the forelimb to be both relatively small and relatively modest in the degree of novelty that those variants display. This is quite different to what we would expect to see for bow-and-arrows.

Heritable variation in bow-and-arrow designs can be sensitive to both immediate adaptive benefit (and more indirectly, overall fitness value). Variation in tools of this nature is generated by a combination of accident and intelligent design. New bow-and-arrow designs may be intentionally "thought up", generated by trial-and-error tweaking of existing designs, produced by accidental error in either copying or execution of a design, and even by an entirely *de novo* innovation through necessity when typical materials are unavailable. Although, as a complex entity, small changes to the bow-and-arrow are (like the forelimb) going to have many downstream effects, the nature of the bow-and-arrow as external to the body along with their status as designed tools affords us with a number of not available in the forelimb case which counter this fragility.

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[13] Importantly, many of the features that are pointed to as buffering developmental systems from the potential impacts of random mutation also reduce the supply of phenotypic variation by effectively canalising the development of particular robust phenotypes (West-Eberhard, 2003).

First, unlike the forelimb for which both development and the inner workings are reasonably opaque to the organism, those building and using bow-and-arrows carry (imperfect) knowledge about their mechanics, their construction, and the good and bad making properties of bows and arrows by observing skilled makers and using the tools themselves. Whilst this knowledge is often hard won through many years of training (Hiscock, 2014; Sterelny, 2011, 2015), it means that, rather than being insensitive to fitness value as in the forelimb case, the sources of novel bow-and-arrow designs can be sensitive to immediate adaptive value (and indirectly, overall fitness value). For example, a bowyer may tinker with the shape of an arrowhead and materials used in an intentional effort to make it more effective at penetrating the hide of prey, and very often the adaptive modifications made will also be fitness enhancing to those using such arrows. In addition, deleterious variation is unlikely to arise or propagate past a very small community as individuals are selective in who they copy, preferring to copy those with successful designs. Together, makes the drift of populations into poor design improbable. [14].

Second, in virtue of this epistemic transparency and the directedness in the process of innovation, large adaptive shifts in bow-and-arrow design are possible in a manner unthinkable in the forelimb case. Although large changes in elements of the bow-and-arrow are going to have knock-on effects to other elements, they are less likely to be deleterious because the agent constructing the tool can accommodate them into those elements (i.e., they can use their technical competence to compensate for the deleterious effects of innovation). Indeed, even error in construction (a source of innovation in itself) can be accommodated during construction in the case of bows and arrows quite easily (in at least some cases). Whilst there are some forms of developmental architecture that can do this too for more straightforward biological traits (again see Kirchner & Gerhart's (2005) discussion of "exploratory behaviour" in development), it is fair to say that the capacity is much less robust and sensitive to error than that in the bow-and-arrow case.

Third, the supply of variation in bow-and-arrows is potentially far larger than in the forelimb case. A person may have two or three children in their lifetime, making a relatively small contribution to the genetic variation in forelimbs in their population in that time. In the same timeframe, they can feasibly generate many, many novel bow-and-arrow forms and propagate them to many others for testing. This extra fuel can drive faster evolution.[15]

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[14] Again, whilst it seems reasonable to expect that locally adaptive modifications will track fitness, they will not always simply because of the complexity of the interactions involved in fitness calculations. For example, a more penetrative arrowhead may be selected for culturally but nonetheless not be fitness enhancing to individuals that use that arrowhead because it requires more costly or difficult to source materials than other designs despite being "better" at doing the job of bringing down prey.

[15] Although rapid evolution is not at all guaranteed. The "s-shaped" curve often cited in discussions of innovation includes a flattening or tapering off of change as new techniques are adopted and no better ones arise. This is

Fourth, another important difference between innovation in bow-and-arrows and human forelimbs is that whilst mutation events are relatively independent in nature, each new bow-and-arrow design innovation need not be. Errors or failures can inform future innovations such that the capacity to generate adaptive variation improves over time as more and more is learned about good bow-and-arrow design and the related physics etc… For example, in trying a different fibre for the string of the bow, a bow-and-arrow designer may find that while the fibre is not good for that job, it would be good for another purpose (say as binding on the arrow shaft). This knowledge then forms another adaptive constraint on future bow-and-arrow variants.

Overall, these different factors make the supply of variation in bows and arrows far more powerful than in the case of forelimbs. We would expect there to be more brute variation in bows and arrows over time and also that the variation that arises is far more likely to be useful (and indirectly fitness enhancing), than not.

2.4 Comparing the paradigmatic cases: Verdict

In conclusion, having compared and contrasted these paradigmatic "biological" and "cultural" human traits we can now see clearly what drives the common intuition that cultural evolution is faster and more labile than genetic or biological evolution. Cultural traits, like the bow-and-arrow, are far more capable of undergoing rapid adaptive evolutionary shifts than biological traits, like the forelimb, because we are far more likely to see beneficial innovations in cultural traits infiltrate populations. Three key differences drive this:

(i) *The relative functional and developmental transparency of cultural, versus biological traits*. We are better placed to learn about the affordances of cultural tools and their construction than we are about biological traits and thus make adaptive interventions upon them and their development. Many of these interventions will also be fitness enhancing to those bearing these tools.

(ii) *Our ability to modify cultural traits and innovate adaptive new forms and construction methods within short timescales (i.e., the nature of the supply of phenotypic variation)*. Without modern technology like genetic engineering, the heritable modification of biological traits like forelimbs is outside of our capacity. This is not the case for cultural tools. Multiple large-scale adaptive innovations on tool form and construction are feasible within single generations.

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reflected in the significant periods of stasis in the evolutionary history of human toolmaking such as the absence of incremental change in stone tool technology between 1.6-2.6 mya (Stout et al., 2010).

(iii) *The rapidity with which cultural innovations can spread within populations*. Social learning allows a rate of spread of adaptive cultural innovations within populations which is unheard of for innovations in biological traits.

These sorts of differences between cultural and biological systems can "supercharge" evolution resulting in the rapid evolutionary shifts within single generations that characterise human culture. Whilst these features are seen in culturally constructed, culturally inherited gadgets that exist outside the body (i.e., artefacts) like bows and arrows, to what degree (if at all) can we see them in *cognitive* gadgets? Are cognitive gadgets likely to undergo this type of "supercharged" evolution? As I show in the next section of the article, the answer to this question is unfortunately, no.

3. Cognitive Gadgets, more like limbs than tools

With the features of culturally inherited systems that can make them more evolvable than biological systems now clear, we can now turn to whether cognitive gadgets have those features. First, however, I want to make clear how I am viewing cognitive gadgets as traits.

Although Heyes has sketched out general computational models for some of her cognitive gadgets[16], their detailed computational structure, algorithmic or neurological realisation remain unclear. This is, however, as Heyes notes herself (for example in her discussion of mirror neurons (Heyes, 2018, p. 121), a step further than many approaches which do not address this computational issue at all. For our purposes here, what is important to note that, despite their simple associative origins, Heyes' gadgets are expected to be made up of multiple, non-identical, interacting parts that form causal networks which feature complex relationships such as feedback loops in their general structure. To illustrate, the ASL model of imitation involves networks of associations between perceptual and motor representations which we can imagine being mutually reinforcing and interrelated rather than clearly delineated and modular in nature. Given this sort of organisational complexity, it is not unreasonable to expect that they will display a level of developmental and functional integration. These are systems with multiple elements that are interdependent with respect to their origins and their day-to-day activity. Given this, I assume in what follows that cognitive gadgets would not differ relevantly from bows and arrows or human forelimbs. Turning now to my analysis.

3.1 Divergence I: Functional and Developmental Translucency

As discussed in the previous section, the workings of a bow-and-arrow and its construction are relatively transparent to the agent (if not perfectly so), thus allowing for directed modification and acting as an

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[16] For example, the ASL model of imitation outlined in Chapter 6 of *Cognitive Gadgets* and the model of metacognition presented in Heyes et al. (2020).

important driver of evolvability (as noted in (i) in Section 2.4). The same, however, cannot be straightforwardly said for a cognitive gadget. Cognitive gadgets look far more like human limbs than bow-and-arrows in this respect. They are functionally and developmentally translucent; their workings are not entirely hidden from the agent, but they are far from transparent. This has obvious impacts on the nature of the supply of variation we might expect to see in relation to cognitive gadgets as we are less capable of deliberate and directed innovation. Before I turn to that, why consider them functionally and developmentally translucent?

Cognitive gadgets like those proposed by the CGH would be located entirely within the body and entirely within a little understood organ, the brain.[17] To illustrate, the ASL model of imitation sees our imitative capacity as being the product of a set of "matching vertical associations" (bidirectional excitatory links between sensory representations and motor representations) which are built out of standard processes of associative learning (Catmur et al., 2015; Cooper et al., 2013; Dickinson, 2012; Heyes, 2016a). This set of associations is, like any computational feature of our cognitive systems, not directly observable. Nor is it directly accessible introspectively. We are reliant on behaviour, neurology and other evidence in theorising about its nature. This means that unlike for bow-and-arrow where the process of construction is in full view of the maker and the impact of any changes to that process are relatively easy to track, the causal "levers" that underwrite the construction of a functioning cognitive gadget and the workings of the final product itself would be less clear to us as agents. Not only would the mechanism of the gadget be hidden from us, but the protracted nature of human development would also likely make identifying the different causal influences on that development difficult.

This expectation is reflected in the progress of modern psychology. Though we are not entirely in the dark regarding the causal levers of social cognition, our knowledge of what contributes to both the normal development of social cognition and its maintenance over time is far from complete. Because of this, it is very difficult to imagine that pre-modern science humans are likely to have detailed knowledge of the computational, algorithmic and physical structure of cognitive gadgets, let alone how to tweak the cultural inputs to those systems to alter them to our own ends in a targeted or direct fashion.

That is not to say that some understanding of the causal levers of both development and the workings of cognitive gadgets would be impossible however, nor that a detailed understanding is required for adaptive innovation of any sort to occur—hence my description of them as being translucent rather than opaque. Cognitive psychology is a field built on making inferences regarding the computational and mechanistic structures of the mind on the basis of externally measurable behaviours and our capacity to predict the behaviour of others suggests our folk psychological

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[17] That is assuming a non-embodied or extended approach to cognition. We can imagine on such accounts that gadgets could extend beyond the brain and into the body or even the world (Baggs et al., 2019). I will set this possibility aside here as Heyes does not offer this type of picture in her book. It does, however, suggest an interesting approach for another discussion elsewhere.

understanding of our minds has some accuracy (Sterelny, 2003). Indeed, just as the cricketer does not need a detailed understanding of the workings of their sensorimotor system to know what sorts of practice make their batting better, we have an array of cultural and folk practices that indirectly influence the development of our social cognition and, in at least some cases, we have inferential knowledge of the causal role of these practices even if it is at a coarse grain. To draw on imitation again, it is no coincidence on the ASL model that dancing is taught in mirrored studios. Access to mirrors is a part of our cultural knowledge of our own imitative cognition and what can improve it (Heyes, 2018, Chapter 6).

Whilst this sort of coarse grain knowledge is important, it remains less likely to allow for targeted adaptive innovations. Whilst the cricketer knows what practice works to make their batting better, without a knowledge of why that is the case, it is hard for them to intervene and improve on that approach. Similarly, whilst there are many cultural practices which scaffold the learning of imitation on the ASL model, such as synchronous dance, which modifications of these are likely to "break" the system or improve it are not necessarily obvious to the agent. This is particularly true when the value of the practices is multifaceted and not always accurate. Synchronous dances, for example, are typically viewed culturally as a source of social cohesion, leisure and symbolic practice rather than as an essential developmental resource for building our imitative capacities. Consequently, the positive and negative impacts of changes to such practices on the development of innovation are far less likely to be detected by cultural agents and thus responded to appropriately.

It is worth noting that none of this is in conflict with Heyes' presentation of the CGH. She is clear that she expects intelligent design to have played a limited role in the evolution of our cognitive gadgets as mechanisms with blind cultural evolution doing the heavy lifting (Heyes, 2019b). For our purposes here, however, the relative epistemic transparency of cognitive gadgets has particular significance that becomes apparent when we consider the nature of the supply of phenotypic variation we would expect for cognitive gadgets as opposed to a culturally inherited tool such the bow-and-arrow.

3.2 Divergence II: Supply of Phenotypic Variation

The developmental and functional translucency of cognitive gadgets has important consequences for the nature of the supply of variation we would expect to see in such gadgets as compared to classically cultural "gadgets" like bows and arrows. As discussed in Section 2, our ability to make directed adaptive innovations in a culturally inherited trait like a bow-and-arrow rests heavily on our functional understanding of bow-and-arrow technology. This understanding makes it possible for us to modify the construction processes and design of the technology towards our own adaptive ends. Whilst, of course, this is not a perfect process, errors and mistakes are likely, this allows rapid adaptive shifts in bow-and-arrow technology that are not likely in the case of genetically inherited traits.

In the case of cognitive gadgets we would have, if anything, less understanding of the development and causal structure of the mechanism in question than even in the forearm case (I can at very least know a little of the working of the arm just by examination of the limb) and although, theoretically more capacity to intervene on development and function, no clear capacity to do so in a directed manner. Consequently, the supply of phenotypic variation in cognitive gadgets is likely to be (akin to what we see in the case of forelimbs) insensitive to adaptive value. Although accidental innovation is of course possible, large, accidental adaptive shifts are unlikely (for the general reasons discussed in Section 2. 3).

This poses a major challenge for Heyes' view that having a cognitive gadget driven cognitive architecture would give individuals some kind of selective advantage on the grounds of greater flexibility and capacity for rapid evolutionary change. The lack of transparency for agents on the workings and nature of cognitive gadgets and their complexity (and thus potential for fragility) make it difficult for individual agents to identify the developmental resources that are causally relevant to any particular shift in order to copy them (and thus gain the relevant adaptive benefit). Given the above concerns, if a cognitive gadget were to undergo rapid evolutionary change, any such change would be highly unlikely to be adaptive. When we couple this with a plausible account of the inheritance of gadgets we can see the true extent to which cognitive gadgets fail to be akin to other cultural tools, and thus not comparable with respect to evolvability.

3.3 Divergence III: Inheritance

In the case of the forelimb and the bow-and-arrow we had a relatively straightforward difference in inheritance—the forelimb is (in so far as we can say anything is) inherited via vertical genetic transmission, whilst there is both vertical and horizontal cultural inheritance of bows and arrows via social learning. As discussed in Section 2.3, this difference in inheritance contributes significantly to the different evolvability of cultural tools versus biological traits. Whilst we can see the developmental resources required to build a cognitive gadget coming from both vertical and horizontal cultural channels in a manner akin to technological gadgets, again it looks like there are ways in which this inheritance would differ significantly from that we see in traditional cultural tools and that these differences impact upon evolvability.

Most significantly, unlike in the case of a bow-and-arrow, it seems reasonable to expect that once a cognitive gadget has been built wholesale changes to the gadget will be difficult (though to not their contents). Whilst a bowyer cannot turn a regular bow into a long bow (you can't just add more wood, it wouldn't be strong enough), they can learn the long bow innovation at any time in their life and then simply build a new bow with that design. In contrast, we cannot not simply build our cognitive gadgets, any changes have to happen against and within the context of the existing trait. Returning again to the ASL model, whilst matching vertical associations between incoming stimuli and particular motor patterns built in development could be replaced or overridden with enough countervailing stimuli, modification of well-established and heavily reinforced associations (as in any associative learning system) is likely to be a slow.[18] In this sense innovation in cognitive gadgets (at least in the lifetime of the organism) would be more like updates to a software system, than wholesale rebuilds of the computational architecture of the computer[19]. Just like a bowyer cannot simply add more wood to a short bow to make a long bow, there would be changes to cognitive gadgets that are simply not possible (or at very least improbable) after early childhood. Rather, in a manner akin to how a software designer might add a new feature such as the capacity to insert references to a word processing program, the computational architecture of cognitive gadgets is more likely to be tweaked and added to during the lifetime of the organism, but not wholesale rewritten.[20]

This is something, again, which constrains the extent to which cognitive gadgets are likely to be nimble or capable of rapid evolution. Whilst bow-and-arrow designs can theoretically go through multiple iterations in a generation[21], it seems highly implausible that such a thing could happen to cognitive gadgets[22]. We cannot do trial and error on our cognitive gadget design during our lifetimes. Whilst some tweaks and changes seem possible (I could, for example, learn new norms or information or encounter significant countervailing reinforcement which a gadget might ultimately change to incorporate via ontogenetic construction (Heyes, 2003)), it seems that the majority of heritable variation of significance in constructing the gadget would need to be transmitted relatively early in the life of the individual. Ultimately this means both the rate of innovation for cognitive gadgets and their spread could never have the same potential as we see for traditional culturally inherited tools or gadgets.

In summary, in Section 2 we saw that cultural traits, like the bow-and-arrow, are far more capable of undergoing rapid adaptive evolutionary shifts than biological traits, like the forelimb, because we are far more likely to see adaptive innovations in cultural traits infiltrate populations. Three key differences drove this:

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[18] Heyes' (2003) discussion of the role of self-perpetuating stimuli in the establishment of imprinting associations is informative on how associative systems can be developmentally "canalised" in this way.

[19] This comparison is due to Calcott (2009).

[20] There are complications that I have glossed over here for the sake of brevity which are important for anyone seeking to develop this point further. Specifically, I have focused on Heyes' "mills" or the gadgets themselves without looking at the "grist" or contents that the gadgets process here. This, however, is overly simplistic as the "grist" is both processed by the gadgets but also transformed by them. See Heyes (2018, pp. 181–183) for some discussion of this in relation to critical periods and language.

[21] This is not to say that bow-and-arrow designs or cultural designs more broadly are unconstrained or limited but that *in general* we would expect them to be far less so than cognitive gadgets.

[22] Again, remembering we are talking about the gadgets themselves here, not the contents which they process.

(i) The relative functional and developmental transparency of cultural, versus biological traits.

(ii) Our ability to modify cultural traits and innovate adaptive new forms and construction methods within short timescales (i.e., the nature of the supply of phenotypic variation).

(iii) The rapidity with which cultural innovations can spread within populations.

In this section of the paper, we have seen that none of these drivers are in place for cognitive gadgets. (a) Cognitive gadgets are as functionally and developmentally translucent (if not more) than we see for biological traits. This has the consequence that, (b) we are constrained in our ability to modify cognitive gadgets or innovative adaptive new forms within short timescales. In short, the rate at which we would see adaptive innovations in the form of cognitive gadgets is likely to be far lower than what we could expect to see for culturally inherited tools and similar cultural traits. Furthermore, although culturally inherited, the construction of cognitive gadgets as physical elements of a biological system means that any adaptive innovations that do arise (c) are highly unlikely to spread through populations at anything like the rate that innovations in tools like bows and arrows can spread.

4. Where does this leave us? Some concluding thoughts

In this article, I have made clear a number of key differences between culturally inherited artefacts or gadgets and biologically inherited traits that I take to underpin the assumption that culturally inherited cognitive mechanisms (such as Heyes' cognitive gadgets) would be more labile and flexible than biologically inherited mechanisms for social cognition (Sections 1 & 2). I have also shown that when we examine cognitive gadgets in light of this analysis, we see a divergence from what we might expect given the bow-and-arrow as a paradigmatic culturally inherited trait. They are unlikely to be fast or nimble in their evolution.

The question of why we don't see genetic accommodation of gadgets becomes more pressing in light of my analysis, and furthermore, the question of how gadgets are constructed in development (something Heyes only talks about in a general manner) becomes more significant. One way, for example, for Heyes to push back on my analysis is to reject my assumption that cognitive gadgets would be complex or functionally integrated though this, to my mind at least, would be a significant cost. At very least, the next steps in the development of the CGH have to be in building greater clarity on what cognitive gadgets and how they are instantiated. What exactly is constructed during development? How is that entity structured? How flexible is that architecture?

My analysis shows that we cannot take for granted that simply because cognitive gadgets are largely the product of cultural inheritance that they will be as labile or flexible as other culturally inherited traits. In order to understand their lability and evolvability in turn, we need to know more about how they are internally organised and how that permits variation. One place to look for guidance on such a project is the existing literature in developmental systems theory and evolutionary developmental biology concerning the ways in which novelty is generated in complex systems, particularly notions like “facilitated variation” (Kirschner & Gerhart, 2005). This is, of course, an entire project in of itself but it is one that is necessary if we are to build a plausible theory of social cognition in which cultural inheritance is to play a significant role in the construction of not just “grist”, but “mills” too.

Whilst my discussion has focused on Heyes’ Cognitive Gadgets Hypothesis, it highlights the importance of thinking about the supply of variation when considering cultural evolution and its relative speed when compared to biological evolution more broadly. Mere horizontal inheritance is not enough for rapid adaptive evolution. Two factors are also important. First, the nature of the supply of adaptive variation. Without a supply of adaptative innovations the rate of evolution has no impact on adaptation of a population. Second, at least where we are talking about complex systems, generating adaptive variation is not a free ride even in the case of cultural traits. Rapid cultural evolution is frequently due to the transparency of the developmental and functional integration of cultural traits which then allows agents to make targeted changes to them. Without this transparency, cultural evolution is unlikely to be rapid (or at least, not rapid *and* adaptive!).

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