Are humans still evolving?

Technological advances and unique biological characteristics allow us to adapt to environmental stress. Has this stopped genetic evolution?

Jay T. Stock

Much of the beauty of the concept of evolution lies in its elegant simplicity. According to Charles Darwin's grand theory, the characteristics of populations or species can change over time if heritable variation exists, and if there are differences in reproductive success or survival rates. Therefore, in response to environmental pressures, the frequency of heritable characteristics will change from one generation to the next, and evolution by natural selection will take place.

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The modern theory of evolution—built on a vast array of supporting evidence from diverse scientific fields—is now widely accepted. However, it has been far more controversial in a social context, particularly when it is applied to our own species. When Darwin published *On the Origin of Species* in 1859, he was aware that applying the concept of natural selection to humans would create controversy in a religious Europe, and therefore only briefly mentioned that, “[i]n the distant future I see open fields for far more important researches [...] light will be thrown on the origin of man and his history” (Darwin, 1859). He waited another 12 years to revisit the issue of human evolution in *The Descent of Man* (Darwin, 1871), in which he noted that humans have both a unique place in nature and are part of the natural world, such that man, with a “god-like intellect which has

penetrated into the movements and constitution of the solar system [...] still bears in his bodily frame the indelible stamp of his lowly origin” (Darwin, 1871).

The theory of evolution has since been applied to the understanding of human variation in several ways. The most infamous uses of evolutionary theory, which were most common until the first half of the last century, used it to justify social prejudice and racism. However, biological anthropology and the study of human diversity have been central to deconstructing the myth of ‘races’. Biological characteristics are common components of how humans socially define races; human populations display variation in features such as stature, hair and skin colour, which corresponds with environmental conditions. This variation can be used to identify trends in the population structure and history of our species, and patterns of environmental adaptation. However, there is no scientific basis for subdividing the human species into unique biological subsets; the range of observable variation in these features is continuous. This has led to a widespread acceptance in the scientific community that there is no consistent biological basis for the identification of discrete races within our species (American Association of Physical Anthropologists, 1996).

Genetic, fossil and archaeological evidence have now demonstrated that all humans share a common ancestor who lived approximately 200,000 years ago in Eastern Africa. As a result, humans display greater genetic unity than most other species, which has led many to assume that human evolution ended with the origin of modern humans. However,

the diversity that we see within our species remains to be explained. Is evolution still a factor that drives human variation? Is there evidence for natural selection acting on our species? Is human variation the result of random processes, such as genetic drift, rather than natural selection? The past decade has seen an increasing interest in answering these questions, and in understanding whether and how evolution has influenced our species. This research has moved beyond attaching value to biological characteristics, and instead seeks to understand the underlying adaptive and biological mechanisms that control diversity.

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Reports in the media and the popular writings of academics commonly claim that evolution is no longer relevant to humans, and that, as a species, we now depend on culture and technology for survival, rather than the random mechanisms of variation and selection (Dyson, 2007; Ward, 2001). The concept of culture is central to this argument. Culture is often defined as human achievements—artistic expression, science, technology, morals and laws, for example—but it can be defined more simply as shared, learned social behaviour, or a non-biological means of adaptation that extends beyond the body (White, 1959). In this respect, humans have been regarded as a species so dependent on culture and technology that cultural adaptation has replaced

Fig 1 | Model of the relationship between the environment and human adaptation.

biological adaptation. During the past 12,000 years, humans have increasingly used culture and technology—built upon agriculture and animal domestication—to control and modify the natural environment. Therefore, culture has an important role in understanding whether evolution is still influencing the biology of our species.

Adaptation, in the simplest sense, is a mechanism that allows organisms to mediate the stresses of their environment to ensure survival and reproduction. We often think that adaptation takes place through direct genetic modifications in response to environmental stress. However, many animal species are able to accommodate environmental stress simply by changing their behaviour in response to environmental conditions, without the need to resort to genetic adaptation. This could involve modifications as simple as moving to another area, changing annual or daily activities, or changing strategies for food procurement.

If behavioural flexibility cannot accommodate environmental stress, animals also have a range of physiological mechanisms that help them to respond—again, without the need for genetic adaptation. Examples include adaptive changes in heart rate, respiration and the accumulation of body fat. In combination, behavioural and physiological

flexibility form a two-tiered defence against environmental stress (Fig 1). These mechanisms might be linked to the regulation of genes, but their variability might be mediated by environmental conditions without changes in gene frequency. If these defences fail or only partly buffer against environmental stress, then survivorship or reproductive rates might vary. In this case, changes in gene frequencies will occur over time and evolution will take place.

How do humans fit into this two-tiered system of defence against environmental stress? Most importantly, we have developed an extensive dependence on culture and technology that has allowed us to populate the most extreme environments worldwide. There is also evidence that other complex social species such as chimpanzees show cultural variability that is important for their survival (McGrew, 2004). However, our dependence on technology can be seen as different to that of other species in our capacity for cumulative cultural change, which provides greater potential to remove humans from a direct relationship with the natural world.

In combination, behavioural and physiological flexibility form a two-tiered defence against environmental stress

The earliest direct evidence of this trend might have been the first use of fire roughly 700,000 years ago, which probably allowed the early human species *Homo heidelbergensis* to spread into and occupy northern latitudes. We know from the fossil record that anatomically modern humans, *Homo sapiens*, originated in Africa between 150,000 and 200,000 years ago, but did not migrate to other parts of the world until between 50,000 and 70,000 years ago. Evidence of what we can call ‘modern human behaviour’ appears in the archaeological record over a long period of time, from 300,000 to 50,000 years ago. It was not until early humans had developed a complete range of behaviour that we consider to be ‘modern’—including artistic expression and symbolism—that they colonized all habitable regions of the world.

Culture and technology were clearly crucial to the successful colonization of the world by our species. They allowed us to occupy most regions of the planet through the use of fire, housing, watercraft, versatile tools and cognition, which enormously improved our ability to hunt and forage for food in markedly different environments—and, in the process, to occupy more environmental niches than most other species.

Since the origins of agriculture, the rate of technological progress has increased exponentially. Agriculture originated independently within the past 12,000 years in various parts of the world, and the surplus of food resulting from agriculture has allowed people to specialize in different tasks, and has provided greater scope for innovation and cultural transmission. The technological achievements of our contemporary and industrialized society still rest on our agricultural production system, and the effective distribution of food resources. In turn, these technologies allow us to modify our environment so effectively that many have argued that we have removed our species from nature. Gene frequencies might still change over time through random factors such as genetic drift, but if our culture effectively removes us from environmental stress, then natural selection will no longer occur. However, it is important to remember that our ability to adapt to environmental stress is contingent on the availability and distribution of resources and energy.

Regarding the second tier of environmental buffering, there is evidence that humans have physiological characteristics that allow them to adapt efficiently to different or changing environments (Wells &

Stock, 2007). The ability to cook food provides humans with a greater dietary flexibility than chimpanzees, gorillas or orang-utans. This dietary flexibility and the extensive use of meat has allowed humans to converge on a common adaptive niche, and to survive in a greater range of environments. Humans also show greater flexibility in growth and have larger stores of body fat than many other species, both of which increase our ability to survive short-term environmental fluctuations. We have greater variation in fertility and birth spacing, which allows populations to bounce back quickly after periods of high mortality, and there is increasing evidence that environmental conditions can alter the regulation of specific genes. All of these physiological features allow us to respond to environmental stress without the need for genetic adaptation by natural selection.

Diseases are environmental stressors that can easily break through the technological and physiological defences of the human genome

Considering the strong evidence that our species has a greater range of both technological and physiological mechanisms for buffering the effects of environmental stress, one could argue that genetic evolution is no longer influencing our species. However, it is clear that most of our non-genetic methods for mediating environmental stress depend on our access to the resources provided by agriculture. As a result, these means of environmental buffering might not be sufficient in all circumstances.

From the discussion above, it would be easy to conclude that humans have stopped evolving. But is this really the case? Is there any evidence that evolution is still acting on our species? Are there any conceivable circumstances in which evolution might influence our species again in the future?

There are a few points to bear in mind. First, many of the classic studies to demonstrate natural selection have been conducted under experimental conditions on short-lived and fast-reproducing species, such as the fruit fly. Humans, by contrast, are a long-lived and slow-reproducing species with generation times of about 20 years or more. It is therefore difficult to observe

intergenerational genetic change—only two reproductive generations have passed since the discovery of the structure of DNA. Clearly, we need a different approach to study evolution within our species.

Second, much of the genetic variation that we see in human populations today developed within the past 50,000 to 70,000 years, after the dispersal of *Homo sapiens* out of Africa. Much of this variation could have been caused by genetic drift resulting from random genetic differences in small populations of hunter-gatherers who were migrating to various parts of the world. In this respect, the variability that we see in our species might be non-adaptive, and could actually be the result of historical processes and random chance relating to the pattern of human dispersal. However, the spatial distribution of some biological characteristics of our species is not random. For example, variation in skin pigmentation is under genetic regulation, and corresponds with variability in latitude and light exposure (Parra, 2007). This genetic and phenotypic variability evolved after the origin of modern humans. Yet, one might argue that the evolution of this variation occurred before the advent of agriculture, and that subsequent technological developments have effectively insulated humans against environmental stresses.

There are, however, examples of human evolution that occurred subsequent to the invention of agriculture, and that involve the co-evolution of cultural and genetic systems with changes in subsistence strategies. The example that is most often cited is the natural selection of heterozygous carriers of the sickle-cell gene to maintain sickle-cell anaemia in populations that are exposed to malaria. This natural selection is particularly visible in regions of central Africa where tropical forests have been cleared for agriculture, which, in turn, has caused the proliferation of mosquitoes that transfer the malaria-causing *Plasmodium* parasite.

Another example of more recent evolution within the human genome is provided by evidence for strong natural selection on the gene that controls lactase production (Bersaglieri *et al*, 2004). Among populations with a long history of cattle herding and milk consumption, the ability to metabolize lactose is maintained into adulthood. These are clear examples that natural selection has recently acted upon our species after

the origin of agriculture and the domestication of animals, and independently among different populations.

Our current technological society is therefore built on climatic and environmental stability, which might well change in the future

Diseases are environmental stressors that can easily break through the technological and physiological defences of the human genome. Indeed, there is growing evidence that epidemics are exerting selective pressure on our species. New methods for studying genetic variability—which can be used to study long-lived species with long generation times—have demonstrated directional natural selection on human genes by looking for signatures of selection in the genes of present populations (Quintana-Murci *et al*, 2007). These include the glucose-6-phosphate dehydrogenase (*G6PD*) gene, which confers resistance to malaria (Tishkoff *et al*, 2001), and the chemokine receptor 5 (*CCR5*) among Europeans, which confers resistance to the human immunodeficiency virus (HIV). The latter is likely to have evolved within the past 2,000 years, in response to an infectious agent that uses the *CCR5* receptor to infect host cells (Stephens *et al*, 1998). Numerous other studies have also provided evidence for recent natural selection on the human genome through comparisons of large sections of DNA (Sabeti *et al*, 2007; Frazer *et al*, 2007; Hawks *et al*, 2007).

These studies provide clear evidence that natural selection has been influencing human populations since the origins of agriculture. Yet, the evidence is still historical and relies on detecting markers for recent evolution in contemporary genetic diversity. One could therefore argue that future technological developments will provide an increasingly efficient buffer to shield the human genome from natural selection. However, the recent studies show that disease epidemics, which have the potential to bypass our cultural and physiological mechanisms of adaptation, are likely to continue to exert selective pressure on our species in the future. This is particularly the case when resources are insufficient to provide human populations with the necessary means of cultural or physiological adaptation.

Another argument against evolution within our species at present, is that the evidence within our species represents recent history, and not the present or future. Still, there are several good reasons to believe that our species has not stopped evolving biologically and will face natural selective pressures in the future. First, our cultural and technological abilities to respond to environmental stress depend on an economic system based on the effective distribution of agricultural resources. Agriculture originated and spread within the past 12,000 years, which has been the most climatically stable period in the course of human evolution (Richerson *et al*, 2001). Our current technological society is therefore built on climatic and environmental stability, which might well change in the future. Another lesson from the archaeological record is that those regions of our planet that are agriculturally most productive today will not necessarily remain so in the future.

A critic might also argue that the evidence for recent human evolution is nothing more than examples of microevolution or minor changes in gene frequencies, and not major adaptive shifts. However, microevolution is precisely what we would expect to see under current conditions. As the past 12,000 years of human history have been characterized by demographic growth, gene flow and environmental stability, we would not expect major adaptive shifts in the absence of the isolation of some human populations, major extinction events or dramatic environmental instability.

It is clear that the future stability of global agricultural production is not guaranteed given the projected climate change (Schmidhuber & Tubiello, 2007), and that some parts of the world—and some populations—will feel the greatest impact (Morton, 2007). The most productive agricultural regions of the world today have the potential to produce enough food for the entire population of our planet, but global politics and economic factors stand in the way of a more efficient distribution of agricultural resources. The economic and technological mechanisms to mediate environmental stress might therefore not be universally available.

So, does the distribution of resources and the ability to culturally mediate our environment influence the evolution of our species? Recent evidence indicates that it does. A high rate of mortality among living pygmies of the Philippines has been linked to the evolution of faster development, smaller body size and earlier reproduction (Migliano *et al*, 2007).

This implies that human life-history and body size are still under selection pressures in circumstances of high mortality, which is related to economic and technological marginalization.

There is now sufficient evidence to predict that our period of climatic stability is coming to an end. Will the agricultural system that supports our technological development be sustainable? Will we be able to find a technological solution to the environmental problems that face humanity? The answer to both questions at present is, possibly, yes. Our ability to respond to future environmental stress effectively depends not only on the development of the technology to do so, but also on economic and technological equality.

In recent years, scientists have accumulated intriguing evidence that humans continue to evolve despite cultural and behavioural buffers against environmental stress. However, predicting the future course of human evolution is futile because we cannot accurately predict the environmental stresses that we will face. On the basis of the current state of our species, we can at least answer several questions. Will humans continue to evolve? The answer depends on whether the two mechanisms outlined at the beginning of this paper still apply to our species. Is there inheritable variation? Yes, variations between individuals are inherited genetically, and humans and the populations in which they live are still variable. Are there differences in reproduction or survivorship between individuals? Yes, and they depend on access to resources.

In fact, resources are crucial to both our means of mediating the environment and our biological mechanisms of adaptation, reproduction and survival. Our future evolution will depend on whether we are able to adapt successfully to future environmental stress through technological and physiological means. Natural selection occurs in response to environments—and our environment is changing. The relative importance of natural selection in shaping our species might be weak at present, but it has the potential to become stronger again in the future.

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Jay T. Stock is at the Leverhulme Centre for Human Evolutionary Studies, University of Cambridge, UK. E-mail: j.stock@human-evol.cam.ac.uk

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