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Short Review

Longevity: A Bird's View from Evolutionary Biology

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Introduction

An old Chinese fable has it that Peng-Tse discovered the secret for longevity. Similar fables exist in most known cultures. They reflect the desire of many humans to perpetuate themselves in time, prolonging our presence in this world for as long as possible. This debate is being revived in recent years in a more academic setting [1,2]. Immortality for humans might or might not be unachievable, but ever longer life spans are a fact of modern life. If humans are to live longer in the future, human society and the human species might feel the effect of such a dramatic change. Some of those effects might be predicted if we use our understanding of the dynamics of evolutionary processes of life history traits in many different animal and plant species. What are the consequences to humanity if longevity is to increase and spread, from the perspective of evolutionary biology? What would be the consequences to humanity if immortality is achieved? Why it is that death exists in the first place? Such questions can be answered with some confidence by modern evolutionary theory and here, I will try to outline some of the basic reasoning behind such answers. Aging or getting old, in physiological terms, has various meanings. Here I will explore three of them

- Active aging: Cells might have inbuilt biochemical processes, triggered by specific genes, that help kill old cells or cells that have completed their physiological function to the organism they serve.
- Passive aging: Cells might get old simply because they accumulate defects and mutations, making it ever more difficult to function properly and thus, they eventually are killed or die.
- Relative aging: Cells might have adapted to combat mutations and biochemical degradation, maintaining themselves pristine over long periods of time, but the environment changes and the surrounding tissue suffers adaptations that make the cells obsolete, making them eventually unable to survive in their ever-changing environment.

These three categories of aging might apply also to organisms in relation to their surrounding environment or the society they belong to. The underlying processes might be just the same ones modulating aging in cells, or additional processes might exist that are working only at the level of the organism. Processes that apply more to populations of organisms than to cells in the tissue forming the organisms include the processes of birth and death. These two are closely related and interdependent in stable populations, modulating biological evolution. Biological evolution is the outcome of variation and natural selection that acts differentially on individuals of a given population favoring individuals with the highest fitness. That is, the highest survival abilities and the highest reproductive output. Variation is achieved through mutations, sex and mate selection. In sexual populations, such as human populations, new combinations of genes in each offspring are achieved. In this way populations are able to explore new phenotypic spaces every time a new human being is born.

Natural selection acts then on these new variants through differential survival. This differential survival is thought to be achieved following strictly the rules of the "Survival of the fittest". Or, if you allow for chaotic processes and large amounts of stochastic events in complex systems, in addition to natural selection, you might prefer to apply the rules of the "Survival of the luckiest". Even if you imagine a world where every new born child will survive to old age, evolution still works. This is because mate choice is not completely random and sex modulated by mate choice will produce changing gene pools in human populations that will produce evolution. Thus, what drives evolution is non-random reproduction with or without natural selection. Regarding human longevity, there has been Irrefutable genetic evidence during the last decades that evolution regulates it [3,4,5]. Any population will then aim at maximizing the survival of the individual and the reproductive output. The reproductive output (fertility) can be increased with increasing birth rates, clutch size, life span and decreasing time separating consecutive births. Yet, natural populations have limited life spans, clutch sizes and birth rates, due to physical biological and chemical constrains on these processes. The life span can be defined as a trait of the life-history of a species and as a physical Dimension of time defining the period between Birth and death. The life span varies among individuals but its average is specific for each species or population. In general, larger organisms have longer life spans than smaller organisms. Organisms with long development period have longer life spans than organisms reaching reproductive maturity fast. Organisms producing few offspring have longer life spans than organisms with large number of them (i.e. large clutch sizes).

Computer simulations help us to explore the effect on evolution of adaptive pressures affecting life-span. So far, they have produced no evidence that evolution favors very long life-spans or even immortality. The reader might design and run its own simulation experiments by running the software Biodynamic [6] Among humans, longer average life spans also correlate with lower fertility, and of course with better health services and in general a with more widespread use of technology. The two last aspects can be estimated through statistical indicators such as infant mortality rates, energy consumption per head, or other indicators of more technology intensive life styles. The data available to us, provided and collected by the United Nations, is presented in (Table 1). The data show that indeed there is a correlation between industrial development and life spans, as industrialized countries in Europe have citizens with longer life spans than poor countries in Africa, for example. The data also shows that as expected, countries with citizens with longer life spans, estimated in the table trough the index "Life expectancy at birth", also show reduced fertility. Broadly speaking, countries with larger life expectancy have lower fertility rates, i.e. females in these countries produce fewer children. This is evidenced from data in the (Table 1). All counties with life expectancy at birth for the cohort of 2000-2005 above 70 years have fertilities of 3 or less children per women; whereas all countries with life expectancies below 50 years for the same cohort have fertility rates of 3.7 children per women or above.

Interestingly, longer average life spans also correlate with longer differences in life expectancy between males and females. Females, with their higher titer in progesterone and lower titer of testosterone than males, seem to live longer, and this difference increases as other factors that limited live spans are controlled. Several reasons might explain this difference, among them, the difference in hormone levels will affect the metabolism of the organism differently, making it more likely that males are more active, suffer more stress, and live shorter lives. Another reason that might affect the odds of survival might be the related to due to cultural and psychological biases, which produce as a consequence much higher frequency of medical attention received by females. The countries with the largest average life expectancy at birth (the first in the list in Table 1) have also very high gender differences in life expectancy. Only former communist countries (Estonia, Latvia, Belarus, Russia, and Kazakhstan in Table 1), which had much higher life expectancies in the recent past, show larger gender differences in life expectancy than the countries with the largest life expectancy at birth. This might be at least partially explained by the much higher stress suffered by males during periods of economic recession, as males are more affected by unemployment, alcoholism and violence, the co-variants of any collapsing society. This was the case of the former communist counties mentioned, where the life expectancy for males dropped in the last two decades. (Table 1) also provides demographic data for a 30-year period that seems to be relevant to our understanding of the effect of increasing the average life span on human populations. The data in the table clearly shows that with few exceptions, humans have changed in the last 30 years their life histories. The common trend in these 30 years, with some exceptions, is for humans to have lower fertility and longer lives. There is no indication that this trend will stop in the near future. Some countries have achieved impressive increases in average life expectancy, showing with dramatic clarity that if the government of a country applies the right policies, it can successfully increase the live spans of its citizens.

Country	(LE) Life Expectancy at birth	Gender difference in LE(Fem-Male)	Expected Change in LE in the last 30 years	children per female (Fertility)	Change in fertility in the last 30 years
Japan	81.6	7	8.3	1.3	-0.8
Sweden	80.1	5	5.4	1.6	-0.3
Hong Kong	79.9	5.5	7.9	1	-1.9
Iceland	79.8	4.3	5.5	2	-0.8
Canada	79.3	5.3	6.1	1.5	-0.5
Spain	79.3	7	6.4	1.2	-1.7
United States	77.1	5.7	5.6	2.1	0.1
Libya	72.8	4.6	20	3	-4.6
Tunisia	72.8	4	17.2	2	-4.2
Oman	72.4	3.3	20.3	5	-2.2
Estonia	71.7	10.6	1.2	1.2	-1
Latvia	71	10.8	0.9	1.1	-0.9
Belarus	70.1	10.7	-1.4	1.2	-1.1
Viet Nam	69.2	4.7	18.9	2.3	-4.4
Maldives	67.4	-1.1	16	5.3	-1.7
Russia	66.8	12.3	-2.9	1.1	-0.9
Kazakh-stan	66.3	11.2	1.9	2	-1.5
Bhutan	63.2	2.5	20	5	-0.9
Pakistan	61	-0.3	12	5.1	-1.2
Yemen	60	2.2	20.2	7	-1.4
Nepal	59.9	-0.5	16.6	4.3	-1.5
Mali	48.6	1.1	10.4	7	-0.1
Niger	46.2	0.6	8	8	-0.1

Uganda	46.2	1.5	-0.1	7.1	0
Guinea	45.3	3.2	8.8	7.1	0
Chad	44.7	2.2	5.7	6.7	0
Kenya	44.6	3	-6.3	4	-4.1
Congo	41.8	2.1	-4	6.7	0.2
Angola	40.1	2.8	2.1	7.2	0.6
Bo-tswana	39.7	2.7	-16.4	3.7	-3
Lesotho	35.1	6.3	-14.4	3.8	-1.9
Swazi-land	34.4	3.4	-12.9	4.5	-2.4
Sierra Leone	34.2	2.6	-0.8	6.5	0
Zimba-bwe	33.1	-0.1	-22.9	3.9	-3.7
Zambia	32.4	0.1	-17.3	5.6	-2.2

Table 1: The data presented in the table were selected so that they include the 10 countries which showed the most extreme values (5 counties for each extreme) for each of the variables presented. Data was taken from the United Nations Statistical Archive for the period 2000-2005.

The data in (Table 1) just discussed strongly suggests that humans suffer from passive aging. Yet interestingly, despite ever longer average life spans, the known maximum life span for humans seem to be less than 120 years. This maximum seems to be constant for the known human history and has certainly not changed in recent years. This would indicate that humans suffer from active aging. Thus, both active and passive aging seem to control human life spans.

Yet, is there an adaptive advantage to active aging in humans?

Has biological evolution weeded out genes that coded for long-living individuals because they had low long-term fitness? Are genes for longevity detrimental to the population or to the chances of their offspring to be successful in their reproductive life? Or: Is active aging just a secondary consequence of other evolutionary forces? Is it just the evolutionary accumulation, by bad luck, of features that do not favor longevity because they would not have increased fitness, as they become active long after the reproductive life of the organism has ended? Theoretical considerations tend to favor the last two of those answers. When evolution is simulated in artificial societies, using the computer model biodynamic a, it can easily have been demonstrated that the dynamics underlying biological evolution does not consider long life spans as advantageous per se. That is, long life spans are not adaptive. Said in simpler terms, the evolutionary dynamics do not favor individuals with longer life spans over individuals that reproduce fast and die earlier. Adaptive pressure on life span ceases as soon as the organism produces brood above the level that guarantees replacement of the old generation. Only if reproductive maturity is delayed does evolution in these artificial societies favor correspondingly longer life spans. That is, reproduction and life spans are linked, not only in artificial worlds but also in the real one, as data from the UN, mentioned above, showed for human populations.

Thus, longevity cannot be achieved through biological evolution. If humans want to live longer they have to reduce passive and active aging. Passive aging can be reduced, as successful demographic policies have shown, by implementing the latest discoveries of modern medicine and hygiene to everyday life. Active aging may also be reduced, as we have evidence that active aging is the outcome of "bad luck" and is not an adaptive feature, necessary for the survival of the species. But active aging can be reduced or controlled only if we gain a better understanding of its working. Research into cancer and cellular control mechanisms will surely help, but Understanding of aging of whole organisms will be essential if longevity is to be increased sustainable in the future. Yet increase in longevity is not the same as immortality. Can immortality be achieved for humans? Evolutionary biology cannot answer this question. Certainly, immortal cells exist and they cause huge damage if they are an integral part of an organism (for example the cancer cells). But immortal, complex organisms living in a changing, chaotic world are less likely to exist. The examples nature offers on very long-life spans among plants and animals are rather exceptions than the rule [7]. This last restriction seems much stronger if viewed in the light of an ever-expanding universe, which will not tolerate a static mechanism challenging the second law of thermodynamics indefinitely. But immortal organisms have been simulated in artificial worlds. Although worlds made only of immortal organisms have little chances of surviving a changing environment, immortal individuals mixed up and interbreeding with plenty of the mortal kind do allow for stable artificial populations, at least in the short term. Yet, as with immortal cells, immortal individuals, when they appear, will certainly affect the health of their society. So, we might now be ready to attempt to answer the questions posed above, in inverse order, if we view immortality just as an extreme case of longevity, and as a useful way to explore, in simplified terms, the effects of longevity.

What is the adaptive value of death?

Life, in order to exist, needs death: There is no death without life. In a dynamic system, death is the tool that weeds out the overhauled, the ancient, the not adapted, the corrupted, and the old. Death provides space for new life and it is new life that produces progress [8]. Human ethics shows us that a person with children will be better prepared to die than a person without children, the more so if her dead will favor her children. This suggests that childless person will be keener in achieving longevity that the child bearing kind. If more and more people remain childless in modern society, and if this trend is to continue in the future, pressure for the achievement of longer life spans will increase.

What would be the consequences for humanity if immortality is achieved?

A short answer to this question is that immortality will stop evolution as longer lives without a corresponding reduction in fertility leads to overpopulation. Immortality will thus require fertility rates of zero. In evolutionary terms, immortality will stop biological evolution as it affects its basic inner working: the interplay between variation and natural selection. Yet this is true only for complete immortality or populations were all individuals are immortal. Populations with a few immortal individuals might be sustainable, although immortal organism, in the long term, will be very much disadvantaged in relation to other organisms that continue to evolve, causing them to suffer from relative aging. Continuing the same argument, we might state that longevity will reduce the speed of evolution. This might be a good opportunity, in the long term, to improve the chances for other animal species to shorten the adaptive gap between them and humans.

What are the consequences to humanity of increased life spans?

What we can deduce from our knowledge of the demography in past century is that reproduction (i.e. fertility) will diminish as life expectancy increases and that differentials between male-female life spans will increase. What we can deduce from the results of computer models simulating long living individuals is that human adaptation will be reduced in future, increasing the need for medical treatments and consumption of medications. Evolution will certainly slow down and might even reverse, due to the "Red Queen" effect, whereby viruses, parasites and other living competitors continue to evolve, causing the human race to have ever more difficulties in maintaining a reasonable quality of life, making it necessary that society expends ever greater amounts of resources for the maintenance of the long living.

Calculating the cost of longevity

As is so often stated: There is no free lunch: There is a cost to longevity. As most human decisions are irrational, I do not believe that the human race will be prepared to aim at a "Rationally" calculated optimal life span. As soon as humans have access to technology that will help them to increase their life span, they will use it. Thus, longer lives are a certainty in the future. It seems thus only wise, accepting our "Bounded Rationality" that we start calculating the costs to ourselves and to society of such longer lives. Some of the increased future cost can be easily imagined. Our expenses in health care will certainly increase as longer living people will demand ever higher quality of life at old age. Other costs might be more cryptic and are invisible to our short sighted habitual thoughts. Humanity has no experience with populations containing a reduced number of young people. But such populations are an inescapable consequence of longer and healthier lives. It should be advisable to start calculating the cost for that.

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