Human Enhancement and the Means of Achieving It[*]

HE can be used to augment any number of human functions and features. The means to HE are as diverse as the possible enhancements themselves. Pharmaceutical drugs can be used to treat diseases as well as improve psychosocial and physical performance beyond the norm. Surgical techniques can repair damaged tissues, and can also be used to transform physical identities. Regenerative technologies can be used to extend life in the face of normal aging, or do so in response to unhealthy lifestyle choices. Computer technology may soon be integral to our physical forms, as research progresses that would seamlessly combine organic and non-organic matter. Genetics and nanotechnology are projected to use the very building blocks of life and some of the smallest structures of matter to transform the human experience. This essay summarizes some of the various techniques of human enhancement.

Pharmaceuticals

Many of the HE capable technologies were born out of basic medical research and may not even be recognized as potential HE. Yet, the application of these different technologies in cases other than medical need constitute the first step in moving from therapy to enhancement. Unregulated uses of pharmaceuticals are the most pervasive application of medicine to human enhancement underway today. Viagra, prescribed to treat erectile dysfunction, is used by many without sexual problems to improve sexual performance and stamina. Insulin Growth Factor (IGF) is a biochemical naturally produced in the human body to cue the development of muscle mass. Doctors offer supplemental doses to patients undergoing treatments or suffering from diseases known to deplete muscle mass, such as muscular dystrophy. Yet, in a healthy individual, use of this drug helps individuals develop muscle mass quickly and with less exercise. Erythropoietin (EPO) increases the oxygen carrying capacity of blood, and thus an individual's endurance. Prescribed predominately for patients undergoing chemotherapy, suffering from anemia, and other blood related conditions, the drug has been commandeered to increase athletic endurance. Most visibly, EPO was the source of major scandal at the 1998 Tour de France, when a Festina team trainer was caught smuggling several cases of the drug into the country.[1] Avoiding fatigue is the main impetus for the off-label use of the drug Modafinil, commonly known as Provigil. Modafinil is used to treat the sleeping disorder, narcolepsy, but can enable others to remain continuously awake and functional for up to three days, a feature of particular interest to students, truck drivers, and pilots, among others.[2]

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[*] This document was produced in conjunction with the AAAS invitational workshop on human enhancement held in Washington, DC on June 1-2, 2006.

[1] "Chronology of the 1998 Tour de France Drug Scandal," *Sports Illustrated/ CNN.com*; http://sportsillustrated.cnn.com/cycling/1998/tourdefrance/news/1998/08/02/drug_chronology/ (September 22, 1998).

[2] Moreno, J., "Juicing the Brain," *Scientific American;* http://sciam.com/article.cfm?chanID=sa017&articleID=31373133-E7F2-99DF-3B50B89EA1ADBBFB

Plastic Surgery

Surgical techniques, particularly plastic surgery methods, are another familiar technology providing a route to enhancement. Though many common examples of plastic surgery focus on physical appearance, such as beauty and signs of aging, plastic surgery does have any number of medical uses, including skin grafts for patients suffering from severe burns, reconstructive surgeries after accidents or physical trauma, correcting certain birth defects, etc.[3] Other areas of plastic surgery hover on the border of medical treatment and enhancement. Examples include liposuction for those at risk for disease due to extreme obesity, or even sex change surgeries to bring physical sexual identity more in line with psychological sexual identity. Studies on surgery and sexual identity in children show how perception and experience shape one's understanding of such a surgery as either medical treatment or enhancement.[4] Despite the aforementioned applications, plastic surgery is most commonly associated with beauty enhancement. Breast enlargement or reduction, butt lifts, tummy tucks, nose sculpting, face lifts, and liposuction are just a few procedures readily available.

A recent addition to the plastic surgery repertoire includes the first ever successful face transplant. In November 2005, a French woman received a transplant from a cadaver in order to restore the lower half of her face, damaged in a brutal dog attack. One could easily imagine less noble applications of this procedure – to enable a person to steal another's identity, be it a loyal fan buying the face of a favorite celebrity or an individual hiding from criminal prosecution.

Organ/ Tissue Regeneration[5]

Research is underway based on the naturally regenerative, non-scarring features of the zebrafish. This research illuminates chemical proteins that may play roles in scarring and regeneration. By suppressing proteins associated with scarring, yet promoting ones that encourage regeneration, scientists can help the body fix itself.[6] Dr. Anthony Atala of the Wake Forest Institute for Regenerative Medicine has received a grant from the Department of Defense to research methods of helping injured soldiers regenerate limbs. "A salamander can grow back its leg," says Atala. "Why can't a human do the same?"[7]

There is a number of valuable medical uses for such research, but there are just as many enhancement opportunities. Life extension, sports performance, defense, and beauty are human enhancement areas that could be affected as this technology develops further. Techniques to help patients regenerate heart tissue and kidney function could add years to life expectancy. Though modern medicine can repair many sports injuries, often treatment requires protracted recovery time and leaves scars that impair muscle and joint

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(November 29, 2006).

[3] American Society of Plastic Surgeons; http://www.plasticsurgery.org/public_education/procedures/index.cfm (December 18, 2006).

[4] *Surgically Shaping Children* in E. Parens (ed.), (Baltimore: John Hopkins University Press, 2006).

[5] Stem cell research and nanotechnology are avenues of tissue repair and regeneration discussed in greater detail later in this essay.

[6] Humphries, C., "Broken Hearts May Mend After All," *Focus*; http://focus.hms.harvard.edu/2005/May20_2005/cell_bio.shtml (2005).

[7] Parson, A., "Tissue Replacement May Apply to All Body Parts," *Chicago Tribune* (August 1, 2006).

flexibility.[8] Regenerative techniques may shorten this time, restore full ranges of motion, or enhance joint and muscle response. One study that has immediate implications for sports medicine, but may also lead to gains in life extension, is the use of a "platelet-rich blood plasma" gel to repair the anterior cruciate ligament (ACL) of the knee joints.[9] This study, sponsored in part by the National Football League (NFL), is less invasive than other ACL repair techniques, has a shorter recovery time, and leaves the joint stronger and more flexible then other techniques. Researchers hope to apply these techniques "to other injuries like meniscus and rotator-cuff tears… [and eventually induce] cartilage regeneration to repair joints damaged by osteoarthritis."[10] Should this research prove fruitful, both the young athlete and the elderly person might enhance their physical mobility with the same technology. Finally, skin regeneration technology already available to treat severe wounds and burns,[11] may someday provide another avenue of cosmetic enhancement replacing face-lifts and wrinkle removal.

Synthetic Avenues

Society is very familiar with pharmaceutical and surgical techniques to improve human function. Entire bodies of ethical and social thought have been dedicated to exploring some of the social issues involved.[12] However, with the advent of radically new synthetic means of enhancement, old notions of improved function are quickly being challenged and even discarded. Non-organic means of enhancement, such as quantum computing and synthetic implants, are currently being explored, suggesting paths to enhancement that may be even more challenging to social norms than encountered with the technological developments described previously.

Artificial Organs/Implants

In conjunction with several surgical techniques, a number of artificial implants, everything from internal diagnostics and homeostasis, artificial limbs, muscle stimulators, to microchips implanted directly into the brain, are emerging. Artificial implants currently under development are targeted to accomplish four main goals: increase diagnostic ability and internal drug delivery, replace internal organs/prosthetic limbs, augment tissue function, or improve human interfacing with technical devices.

Diagnostic information coupled with the ability to manipulate body chemistry offers a promising lure to purse research in this area. "Implanted sensors," says Mauro Ferrari, a biomedical engineer at Ohio State University, "will enable doctors to continuously scan our bodies for signs of disease and begin treatment even before

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[8] "Getting ACL tears to repair themselves," Children's Hospital Boston (press release); http://www.childrenshospital.org/newsroom/Site1339/mainpageS1339P1sublevel196.html (March 23, 2006).

[9] *Ibid.*

[10] Patnode, A., "Getting ACL tears to heal themselves"; http://www.childrenshospital.org/newsroom/Site1339/mainpageS1339P1sublevel196.html (March 23, 2006).

[11] "China Succeeds in Skin Regeneration, Duplication"; http://english.people.com.cn/english/200008/09/eng20000809_47688.html (August 9, 2000).

[12] Goering, S., "The Ethics of Making the Body Beautiful: What Cosmetic Genetics Can Learn from Cosmetic Surgery," *Philosophy & Public Policy Quarterly*, (Winter 2001), 21(1):21-27.

symptoms appear. 'They will dissolve the barriers we have between diagnostics and therapeutics,' he says."[13] Sensor technology is quickly being coupled with responsive technologies as these "barriers" dissolve. What if an increase in blood sugar levels prompted the instant release of compensating insulin? That is what Dr. David Gough and his colleagues are working towards at the University of California, San Diego. Gough's team has developed an enzyme-based glucose sensor to be implanted in a major vein of the heart to monitor sugar levels in diabetic patients. Medtronic has built upon this technology by designing an artificial pancreas that uses the glucose readings, communicated through a radio link from the implanted sensor, to deliver insulin dosages via an internal pump.[14] Taking this one step further, if a similar internal sensor recorded chemical reactions associated with stress, instead of life-saving medicine, Prozac might be pumped to a stressed executive, or additional adrenalin and pain-killers delivered to a soldier in a combat zone, or Ritalin released in the blood stream of a college student during an exam. As barriers between diagnostics and treatment crumble, so, too, do the barriers between diagnostics and enhancement.

Implants could be used not only to regulate body chemistry, but serve as entire organs. Replacement organs and tissue under development include artificial eyes, lungs, kidneys, legs, and even hearts, to name a few.[15] The Abiocor heart, first released in 2001, is designed to mimic the capacity of a normal heart. It has an internal motor that circulates blood in manner similar to that of an organic heart and is recharged through an external device placed against the skin. Since heart failure is the leading cause of death in the U.S. and around the world,[16] a replacement heart would offer a number of people vulnerable to such a fate a better alternative.

University of Pittsburgh researchers are developing the first internal artificial lung.[17] The lung consists of a tube with microfibers and a pump that pushes oxygen into the blood stream while expelling carbon dioxide. Utilizing live kidney cells as well as synthetic materials, researchers at Nephros Therapeutics are building an artificial kidney to help the body remove toxins from the blood. Similar work to create artificial spinal disks, knees, and legs are under way in research labs around the world.[18] Technology has even made possible the creation an artificial eye. With a sophisticated combination of brain implants, cameras, and digital processors, a 2002 issue of *Wired*[19] magazine explains how a 39-year old man, blind since the age of twenty, is learning to see again. Despite the practical medical applications, enhancement possibilities in this area are substantial. A person could easily increase endurance beyond the norm with lung and

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[13] Service, R. F., "Can Sensors Make a Home in the Body?", *Science* (August 9, 2002), pp. 962-63.
[14] *Ibid*
[15] Steiner, S., "Will We Merge with Machines?", *Popular Science*; http://www.popsci.com/popsci/futurebody/879d9371b1d75010vgnvcm1000004eecbccdrcrd.html (September 2005); Kotler, S., "Vision Quest," *Wired Magazine* (September 2002), pp. 94-101 and "We Can Rebuild You," *Wired Magazine* (September 2002), pp. 54-55.
[16] http://www.heartpioneers.com/abiocorfaq.html.
[17] Steiner, S., "Will We Merge with Machines?", *Popular Science;* http://www.popsci.com/popsci/futurebody/879d9371b1d75010vgnvcm1000004eecbccdrcrd.html (September 2005).
[18] *Ibid*
[19] Kotler, S., "Vision Quest," *Wired Magazine* (September 2002), pp. 94-101.

heart implants to supplement normal respiration. A scientist or an artist could change her visual field, turning the naked eye into an internal microscope or an optical kaleidoscope.

Increasing one's strength or speed could become a matter of upgrades rather than diet, exercise, or genetic inheritance. A muscle simulator implanted in the body can force muscle to contract or relax on command. The Bion,[20] a device currently used to help arthritis sufferers and stroke victims exercise damage muscles, can be commandeered to force muscle to mimic the motions of exercise, enabling one to work off pounds without breaking a sweat. If this fitness plan does not appeal, there is still the option of replacing or augmenting muscles. Research on artificial muscles[21] capable of mimicking human muscle response is progressing rapidly. "Already engineers are developing artificial-muscle powered devices, including a knee brace that prevents injuries, [and] tiny pumps to deliver drugs …Research has begun on a variety of medical devices that would be implanted in or attached to people's bodies, such as artificial-muscle-powered prosthetics, a pumping device to assist diseased hearts, a urinary sphincter to treat incontinence, and an artificial diaphragm to help people breathe. Further – much further – down the road, scientists talk of plastics that could replace or augment any muscle in the body."[22]

Microchips implanted in the brain may one day help to augment memory and learning in those suffering from brain damage or coping with neurodegenerative diseases. At the University of Southern California, Professor Ted Burger and his team are designing microchips that bridge the gap between damaged tissues, restoring communication across brain cells. This could be an effective treatment alternative for an Alzheimer's patient, or a huge advantage to one interested in augmenting his or her memory.[23]

Interfacing with Computers and Technology

Computer science research is leading the way to more sophisticated interfacing between man and machine, effectively increasing the speed and efficiency with which humans perform computer related tasks. One example of such a technology is the eye-guided mouse. This device follows the movements of one's eye rather than input from a hand-held mouse, touch pad, or keyboard. Professor Guang-Zhong Yang at the Imperial College in London hopes this research will improve understanding of how visual processing occurs in the brain and "believes eye-tracking technology could also help the way we interact with computers." In addition, "other potential applications include

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[20]Steiner, S., "Will We Merge with Machines?", *Popular Science;* http://www.popsci.com/popsci/futurebody/879d9371b1d75010vgnvcm1000004eecbccdrcrd.html (September 2005).

[21] Electroactive polymer fiber, "when stimulated by electricity or chemicals, it moves. It expands and contracts, curls and waves, pushes and pulls. It's also springy, durable, quick, forceful and quiet. Since those properties are shared by human skeletal muscles, electroactive polymers have been dubbed 'artificial muscles,'" Ferber, D., "Will Artificial Muscle Make You Stronger?", *Popular Science;* http://www.popsci.com/popsci/futurebody/822d9371b1d75010vgnvcm1000004eecbccdrcrd.html (September 2005).

[22] *Ibid*

[23] Steiner, S., "Will We Merge with Machines?", *Popular Science;* http://www.popsci.com/popsci/futurebody/879d9371b1d75010vgnvcm1000004eecbccdrcrd.html (September 2005).

installing an eye tracker in a car dash board to warn a driver who is falling asleep, or enable a fighter pilot to aim missiles by simply looking at a target."[24]

Not all interfacing need be external to the body. The movement "toward ultimate mobility"[25] has created a trend in device manufacturing calling for smaller, cheaper, powerful, portable devices. One HE development discussed is that of a cell phone within a tooth implant. In 2002, British design team members James Auger and Jimmy Loizeau designed a protype tooth receiver.[26] Meanwhile, a German design team is developing both a receiver as well as a signal sender by combining a microvibration device and low frequency receiver to send signal along the jaw bone to the ear drum.[27] With this technology, a laboratory created communication device would become a permanent part of the body.

Brain chip implants could allow not only the paralyzed or injured to control devices that improve their mobility and independence, but also allow the average person to change a television channel, or unlock a door with just a thought. Researchers at Brown University and the Cyberkinetics company are working on such an implant. The future may offer a chance not only to manipulate the physical world through brain chips, but could also increase the speed and power with which a human accesses information. Quantum computing is a concept used to describe the exponential increases in speed and capacity of successive generations of computers.[28] If computer power continues to develop rapidly, while physical processors continue to shrink in size, future enhancement might easily allow a person to attain "network enabled telepathy," or the ability to immediately access and manipulate massive amounts of information with a simple thought. Chris Taylor, a futurist with Business 2.0 reported that, "Sony has already patented a game system that beams data directly into the brain without implants,"[29] heralding that the technology in question is well on its way.

Enhancement at the Molecular and Atomic Level

Nanotechnology[30]

Nanotechnology, nanoscale (at the level of one billionth of a meter) manipulation of matter, has the potential to increase our enhancement capabilities. Nanotechnology allows humans to alter matter with a degree of precision previously unavailable to researchers, enabling the creation and manipulation of tiny particles that are integral to human health and performance.

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[24] Hermida, A., "Replace your mouse with your eye," BBC News Online; http://news.bbc.co.uk/1/hi/sci/tech/2098030.stm (July 8, 2002).
[25] Kirkpatrick, D., "Coming soon: Google on your brain," *Fortune;* http://money.cnn.com/2006/07/26/technology/futureoftech_kirkpatrick.fortune/index.htm (July 26, 2006).
[26] See image and summary at http://www.time.com/time/2002/inventions/tra_phone.html (November 2002).
[27] Steiner, S., "Will We Merge with Machines?", *Popular Science*; http://www.popsci.com/popsci/futurebody/879d9371b1d75010vgnvcm1000004eecbccdrcrd.html (September 2005).
[28] Kirkpatrick, D., "Coming soon: Google on your brain," *Fortune;* http://money.cnn.com/2006/07/26/technology/futureoftech_kirkpatrick.fortune/index.htm (July 26, 2006).
[29] *Ibid*
[30] Section written by Arielle Lasky, with added text by Enita Williams.

Take one current therapeutic project being developed at Stanford University: a cancer treatment that selectively targets malignant cells. This treatment "tags" cancer cells with traceable nanoparticles called carbon nanotubes, then employs near-infrared laser technology, usually benign to the body, to heat and destroy the cells. In contrast to traditional chemotherapy, this technique avoids plaguing patients with painful and dangerous side effects, such as nausea, hair loss, and weakened immunity, which occur because of non-targeted treatment. The technique is currently being tailored to treat specific types of cancers.[31] This and other similar nanotechnologies being developed[32] could be extended to enhance human life. For example, an analogous technique that placed targeted nanotubes in fat cells could be used to reduce individual fat levels without need for diet or exercise.

Not all nanotechnology enhancements will be cosmetic. The MIT Institute for Soldier Nanotechnology (ISN) has been charged to engineer nanotechnologies to reduce soldiers' vulnerability during war. Specifically, the ISN is designing a "21st century battlesuit" that provides body armor that weighs very little while significantly bolstering strength. In addition, the suit would contain diagnostic and metabolic regulation features.[33] Talk of introducing this into domestic medical and crime forces has already begun. On the way to the final goal of body armor, spin-offs for police, firefighters, and emergency medical teams are expected to appear.[34]

But these types of enhancements are just the tip of the iceberg for nanotech. K. Eric Drexler, who coined the term "nanotechnology," foresees a complete change in our everyday lives due to nanotech. He believes that everything we use, from roads to medicine, will be positively transformed by this field. Most of these transformations will be due to "nanobots," robots at the nanoscale.[35] One biomedical nanobot application, envisioned by Drexler's colleague Robert A. Freitas Jr., is the "respirocyte," a mechanical replica of a red blood cell. This artificial, superior cell could be used to treat diseases and disorders related to oxygen and/or blood, but could also be used for enhancement purposes. Respirocytes "can deliver 236 times more oxygen … per unit volume than natural red cells," making them extremely attractive to humans in oxygen-poor climates.[36] Freitas, in his vision for these nanobots, discusses the possibility of using respirocytes injected into the blood stream to make an internal underwater breathing apparatus, or "in vivo SCUBA … device." The same technology may be used to facilitate human space exploration in extreme environments.[37] These developments

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[31] "Nanotechnology Kills Cancer Cells," *BBC News*; http://news.bbc.co.uk/go/pr/fr/-/1/hi/health/4734507.stm (August 5, 2005).

[32] Ananthaswamy, A., "Nanotechnology; Can nanopulses heal?", *Proteomics Weekly;* www.eng.odu.edu/interaction/interaction030504/nanopulse.pdf (February 23, 2004), p. 68.

[33] Nordman, A., "Converging Technologies – Shaping the Future of European Societies," European Commission; http://www.ntnu.no/2020/final_report_en.pdf (2004).

[34] Tansey, B., "Molecular Might: Nanotech 'Battle Suits' Could Amplify Soldiers' Powers," *San Francisco Chronicle*; www.sfgate.com/cgibin/article.cgi?file=/chronicle/archive/2003/04/07/BU305865.DTL&type=tech (April 7, 2003).

[35] Atkinson, W.I., *Nanocosm* (New York: Amacon, 2003), pp.125-6.

[36] Freitas, Jr., R., "Respirocytes," *KurzeilAI.net*; http://www.kurzweilai.net/meme/frame.html?main=/articles/art0468.html (May 20, 2002).

[37] Freitas, Jr., R., "A Mechanical Artificial Red Cell: Exploratory Design in Medical Nanotechnology,"

would enhance the capabilities of human exploration and travel well beyond today's possible range.

Genetics[38]

Manipulating the gene itself is both a route to medical progress and to human enhancement. Genes are segments of DNA that correspond to a specific trait overtly or covertly expressed. With the conclusion of the Human Genome Project in 2003, genetic knowledge has increased dramatically, but there are still large gaps in our knowledge of gene expression. Genetic enhancement research works toward identifying and predicting gene expression (genetic screening), using genetically modified tissues to alter body performance (somatic manipulation), and altering patterns of genetic inheritance (germline manipulation).

Genetic Screening

Genetic screening offers another means of enhancement. The common adage "knowledge is power" best describes the application of genetic screening to enhancement. Genetic screening uses a small tissue sample, such as blood or skin, to catalogue a person's DNA sequence. Based on that sequence, a scientist can identify some of the physical or psychological traits a person is more or less likely to express. There is, however, still a large knowledge gap between which chemical DNA sequences correlate to which physical and psychological traits, and an even greater ignorance over how non-genetic factors (exposure to pollutants, diet, etc.) affect the expression of traits. Nonetheless, such information may offer insights into body performance to produce huge health and competitive advantages. According to one HE business consultant,[39] "More than 80 percent [surveyed] want to know if they are at risk for health problems – even if solutions for those health problems don't exist." Beyond health information, genetic screening may offer enhancement options. What if parents could know almost at birth that their child has the qualities to be a successful athlete? A child could start physical training earlier or engage in other enhancement activities that further add advantage (like growth hormones, surgery, and pharmaceuticals). Such foreknowledge might be available sooner than one might expect. An article in the *New England Journal of Medicine* declares that, "The role of mysostatin [highly correlated with strength and muscle] in gene polymorphisms in humans may be used to identify persons who are more likely to become successful athletes. Although the ethics of using such genetic information is questionable, the feasibility of identifying this information should not be doubted."[40] Indeed, there are now companies advertising a ACTN3 Sports Gene Test, a "fast, simple and painless genetic test can identify whether you may be naturally geared toward sprint/power events, or towards endurance sporting ability…. This will assist in tailoring training

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Foresight Nanotech Institute; http://www.foresight.org/Nanomedicine/Respirocytes.html (1996-9).

[38] Section co-authored by Andrea Jolley and Enita Williams.

[39] James Canton, CEO, Institute for Global Futures; http://www.futureguru.com/.

[40] McNally, E.M., "Powerful genes—myostatin regulation of human muscle mass," *New England Journal of Medicine* (June 2004), 350: 2642–2644.

programs and competition tactics, allowing you to realise your full potential within your sport of choice."[41]

Somatic Manipulation – Stem Cells

Stem cells have the potential to become several different cell types. Stem cells are either totipotent, pluripotent, or multipotent. Each of these classifications refers to the level of specialization a stem cell has. Totipotent means that a stem cell has potential to differentiate into any cell of the body, and is found in embryos. As the embryo develops further and specializes into different tissue types, a cell become pluripotent, or capable of become more specific cells types. This specialization continues as a fetus develops until stem cells are so specialized they can only become specific tissue types; these stem cells are considered mutlipotent. One common use of multipotent stem cell research for medical treatment is the bone marrow transplant. Bone marrow contains blood stem cells that can differentiate into all of the body's blood cell types. Because of the rejuvenating features of stem cells and the potential to avoid harmful immune response by harvesting cells from the host patient,[42] researchers hope to use stem cells to further life extension, serve as raw material for organ and tissue replacement, and even restore damaged nerves and brain cells.

One promising line of research relates to life extension. A recent study at Duke University shows that the rate of stem cell division declines with age, and this decline correlates with diminishing cognitive performance generally experienced with aging. By targeting research toward getting neural stem cells to "act younger," i.e. maintain higher rates of division, cognitive function in old age could be improved.[43]

Germline Genetic Manipulation

Germline genetic manipulation involves the modification of inheritable genetic information that is passed on to future generations. Scientists are examining ways to replace defective genes that cause diseases like color-blindness with functional genes. Researchers are also exploring the possibility of enhancing normal genes so that humans have even greater physical abilities, intelligence, and vision.

Scientists have already used this technology to create mice with above-average endurance. These "marathon mice" can run almost twice as far as their non-engineered counterparts before exhaustion. Dr. Ronald Evans of the Salk Institute for Biological Studies altered the promoter sequence, or molecular switch, of a gene that produces the protein PPARdelta. By fixing the promoter to be permanently "on," the mice continuously make this protein, which tells muscles to burn fat instead of sugar and gives the mice the ability to run for long distances. Other scientists have taken a different approach and observed similar results. Dr. Randall Johnson of the University of California at San Diego eliminated the HIF-1alpha gene in mice, and found that they also

[41] Genetic Technologies; http://www.gtg.com.au/HumanDNATesting/index.asp?menuid=070.110.
[42] The Stem Cell Research Foundation; http://www.stemcellresearchfoundation.org/About/FAQ.htm.
[43] "Stem Cell Loss in Aging Brain May Bring Poorer Memory," U.S. Department of Health and Human Services (news release); http://www.healthfinder.gov/news/newsstory.asp?docID=600257 (December 22, 2006).

had superior endurance. These studies show promise for further research examining how our genes are related to endurance, metabolism, and obesity.[44]

Genetic manipulation is not limited to the enhancement of physical abilities – it may also increase cognitive abilities, such as memory recall. In 1999, Dr. Joe Tsien created mice genetically engineered with extra copies of a gene involved in memory function. These mice scored higher than their non-engineered counterparts in basic memory and learning assessments. This type of enhancement could someday be used to restore some memory ability in Alzhemer's patients, or to enhance a normal human's intelligence.[45]

While genetic manipulation appears a promising method of enhancement, most of these biomedical applications are still years away. Researchers at the Medical College of Wisconsin theorize that genetic manipulation will eventually be used to enhance vision. Humans usually have three receptive cones in the retina, but color-blind people only have two functioning cones. Dr. Jay Neitz is working with the genes that determine cone number, located on the X-chromosome. He hopes that someday it will be possible to restore full vision to color-blind individuals by giving them a good copy of the gene responsible for the photoreceptive cone. If that is successful, Dr. Neitz wants to give humans with normal vision a fourth cone – expanding the range of vision to include a new spectrum of colors.[46]

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[44] Pearson, H, "Geneticists engineer marathon mice," *Nature*; http://www.nature.com/news/2004/040823/pf/040823-2_pf.html (August 25, 2004).

[45] Weiss, R., "Study: rodents' higher IQ may come at a higher price," *The Washington Post* (January 29, 2001), p. A2.

[46] Plotz, D., "I spy with my eagle eye: the quest for super-vision," *Slate.com;* http://www.slate.com/id/2079371 (March 5, 2003).