

Diy Biology and Biohacking: A New Research Journey

Varsha Sorout and Kakoli Dutt*

Department of Bioscience and Biotechnology, Banasthali Vidyapith, India

ARTICLE INFO

Received Date: July 03, 2019
Accepted Date: April 10, 2020
Published Date: April 15, 2020

KEYWORDS

Biohack
DIYbio
Implants
Bulletproof coffee
Keto diet
Brain hack

Copyright: © 2020 Kakoli Dutt et al., Journal Of Case Reports: Clinical & Medical. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Citation for this article: Varsha Sorout and Kakoli Dutt. Diy Biology and Biohacking: A New Research Journey. Journal Of Case Reports: Clinical & Medical. 2020; 3(2):150

Corresponding author:

Kakoli Dutt,
Department of Bioscience and
Biotechnology, Banasthali Vidyapith,
P.O. Banasthali Vidyapith, Rajasthan-
304022, India,
Email: kakoli_dutt@rediffmail.com

ABSTRACT

Scientific curiosity is generating new ventures in form of DIY Biology and biohacking which opens up an alternative route to structured and organized research. People even without traditional degrees are exploring various hacks to augment and enhance the quality of their lives. The applications range from dietary modifications to implants, open source medicine and gene manipulation. This is leading to result oriented science with higher rate of innovations. DIY bio also bridges the gap between classical trained users and amateurs generating a whole new scope of innovation and discovery with significant social impact. DIYers are challenging the boundaries of human existence and generating methods to overcome physical disabilities and linking neural networks to computer networks. But such unrestricted access and unregulated functioning may have new ethical conflicts and biosafety concerns associated with it.

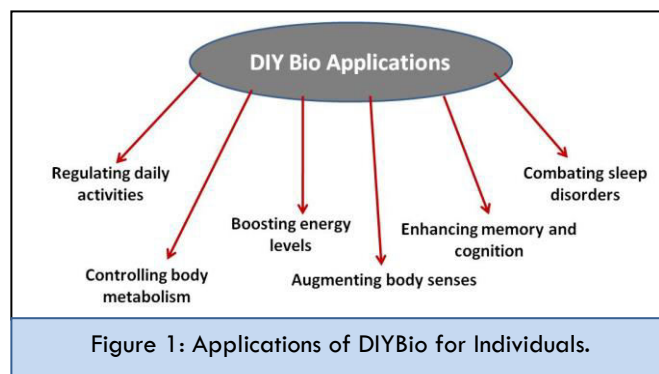
INTRODUCTION

Do-it-yourself biology or garage biology is slowly introducing itself as a tool and technique for self-improvisation by increasing Action Research (AR) which is an open revolution against the academic institutionalization of science and its categorization as fundamental or applied [1]. Called as citizen science, it aims at openness in perusing science leading to an upsurge in various scientific pursuits independent of the conventional scientific think tanks including universities. People with knowledge and specializations in biomedical, nutrition, microbiology, synthetic biology try to generate innovations which can greatly increase quality of life outside the purview of regulated science [2]. This Do-it-yourself (DIY) movement is changing the approach towards science and technology since 2008 [3]. It is leading to a massive democratization of science in which people do not need any degree to pursue their hobby of DIY or biohacking [4].

These biohackers or DIYers support the generation and spread of knowledge without the boundaries regulating any academic pursuit where only few people with degrees from the structured educational setup. Their motivation stems from various goals some which are merely, self-augmentation or self-diagnosis of genetic disorders or acquisition of self-data or cybernetic exploration and open source medicine [5]. The approach of biohackers follows the idea of proliferation of knowledge free of any boundaries while the academic investigation traditionally relies on the disciplinary expertise of isolated individuals and small teams operating from a top-down expert model [6].

DIYbio practitioners take a holistic view by acknowledging the complexity of real-life situations to build collaborations in order to deliver innovations which are specific and augment one's self in a sustainable environment [1,2,7]. DIYers range from amateurs to scientists working independently in their own home-made labs or forming community lab spaces for joint ventures [8,9]. These amateurs are not dependent on using high end instruments. They procure freely available equipment and tools from eBay or any such online stores to experiment. Genspace was the first community lab space formed in 2009 where the enthusiasts learnt about various biohacks to make biology more personal [10]. This has truly revolutionized the access of science taking it from the domain of few and bringing it to masses in form [11] which is most required. Some of the prominent biohacks featured are estimation of blood sugar at home [12], improved night vision [13], increasing resilience towards stress [14], bio-accessorizing one's body by implantation of various microchips or biomagents [15], wearing smart watches, shoes, VR headsets [16] and biohacking sleep [17]. DIY bio aims to improve significant participation of stakeholders as a way of not only enriching the research process, but also empowering iterative research processes leading to a gradual, but potentially profound, societal transformation [1,18].

Biohacking aims at improving and augmenting our physical self (Figure 1) for improved state of being. Several DIYbio users communicate via blogs, magazine content and journals to talk about their experiences while extrapolating on future uses. This paves the way for setting up of a global DIYbio community creating opportunities for participation in open science, thus bridging the gap between reality and virtuality. DIYbio movement which started in 2000 [19] has today gained enough momentum and participants to make conferences, open projects providing amateurs about the basic knowhow a regular feature. In this journey, DIYbio.org was founded in 2008 with the aim to set up a flourishing community of DIY biologists [20]. DEF CON is a very well-known conference held every year since 1992 in Las Vegas, Nevada, USA [21] aiming at informing public about the technique of implants, disease curing and healthy hacks. Thus, biohacking is providing the public with opportunities to explore themselves across the globe.



BULLETPROOF- THE STRONGEST BEVERAGE

Coffee, a globally consumed beverage which has taken different forms like the black, hot and sweet Turkish coffee, Filter coffee from the southern states of India, café au lait, cappuccino and many more. Globally, there are many coffee serving chains that provide this beverage in its many forms to the people. Coffee from antiquity has been recognized to be a stimulant as it increases mental alertness by inhibiting adenosine binding with brain receptors [22] and also reduces the chances of Alzheimer's due to its antioxidant capacity and insulin sensitivity [23]. Coffee stands out to be best antioxidant contributing 11.1 mmol of total antioxidant intake [24].

Thus, even coffee has experienced biohacking in form of Bulletproof Coffee which according to a well-known biohacker Dave Asprey (CEO of bulletproof coffee) suppresses hunger, burn fats and increases alertness. It includes three ingredients, Arabica coffee beans grown in Colombia without herbicides and pesticides, grass fed butter and brain octane oil [25]. Despite this peculiar combination, it has been shown that bulletproof coffee is a trendsetter with outstanding results. The butter obtained from grass fed cow's milk is enriched with vitamins such as vitamin A, D, E and K, along with omega -3 fatty acids, Conjugated Lineoleic Acid (CLA) and butyrate [26]. Omega-3 fatty acid is a complex polyunsaturated fatty acid which prevents from hyperlipidemia and cardiovascular diseases [27] which also serves as anti-inflammatory [28]. Continuous intake of CLA helps in losing body fat while increasing lean body mass [29] along with fighting cancer [30]. Brain octane oil is a pure form of saturated fatty acids called Medium Chain Triglycerides (MCT) derived from 100% coconut oil. Researches shows that not only MCT has satiety effects, it induces greater energy expenditure in comparison to Low Chain Triglycerides (LCT) thereby contributing to efficient

weight loss [31]. Moreover, it switches its role to ketone bodies by inducing production of more Cholecystokinin (CCK) which leads to hunger suppression [32]. Thus, one cup of Bulletproof not only satiates but eliminates the need for breakfast as it is not merely coffee but an amalgamation of all nutrients to kick the body energy level to maximum proving it to be an innovative, healthy and utilitarian biohack for people with long and busy schedules.

KETO DIET- BIOHACK FOR WEIGHT LOSS

Obesity is a problem faced by all generations and society has generally been unflattering towards people with high weight. This creates a need for weight loss and apart from physical exercise, dieting or altering food habit and intake is also in vogue. One of the biggest reason for obesity is unhealthy eating habits apart from lack of exercise, diseases such as thyroid dysfunctioning. However, due to obesity, other diseases can be induced like high blood pressure, coronary diseases, diabetes, cardiovascular diseases, gall bladder stones which may in some cases lead to mortality [33]. According to WHO over 2.8 million people die every year due to obesity. However, this lifestyle disease can be controlled by exercise, proper diet and even some extreme measures like bariatric surgery. Recently, keto diet a low carbohydrate, high fat, average protein diet has gained immense popularity through blogs, newspapers and TV. This diet first emerged as the treatment for epilepsies in 20th century but it went on to become a potent weight controlling diet as compared to low fat diets [34]. The keto diet increases gluconeogenesis, lipolysis along with enhanced satiety effects of proteins [35]. The production of ketone bodies (β -hydroxybutyrate, acetoacetate and acetone) is a hall mark feature of keto diet [36]. These ketone bodies can serve as alternative substrate for energy utilization resulting in minimal insulin level [37]. Ketone bodies are able to cross blood brain barrier and serve as fuel for brain but since liver can't use acetoacetate, it is then hydroxylated to beta hydroxyl butyrate [38]. Moreover, due to decarboxylation of acetoacetate, acetone is produced which is volatile and has a fruity smell indicating ketosis [39].

Beside weight reducing effects keto diet contributes as therapeutic for amyotrophic lateral sclerosis [40], polycystic ovary syndrome [41], epilepsies [42], alzheimer's (AD) and Parkinson diseases [43] along with anti-inflammatory effects

[44]. Due to these diverse applications, this diet becomes a very innovative biohack making it an ideal diet plan or health management for noticeable weight loss.

DIY FOR BRAIN HACKS

Improvement of cognitive skills along with memory and learning form a cornerstone of any developing society. Infact, the ability to observe and convert it to utilitarian skills or technology has propelled human civilization through the ages. Thus, it is no wonder that in the current era, where research is going on various types of genetic manipulation and generating artificial intelligence to improve human computational skills, biohacks are also being sought to improve brain cognition and decrease incidence of neurodegenerative disorders. DIY bio makes it easier to enhance IQ level by influencing the ability of brain for learning, emotion and memory.

a) Polyphenols as brain food: Polyphenols are plant based secondary metabolites which are broadly divided into flavonoids and non-flavonoids [45]. Fruits (grapes, blueberry, citrus), vegetables (onions, leek, broccoli, celery, parsley tomatoes), cloves, cereals, legumes, red wine, tea, coffee and cocoa powder are rich in polyphenols and form a regular part of diet with a recommended dietary intake of 1193 mg/d for healthy brain [46]. Studies have shown that polyphenols are potent neuroprotector and help in reducing the chance to develop dementia and AD [47]. Oxidative stress coupled with neuronal death in AD patients can be reduced by intake of flavonoids which work as antioxidants which neutralize free radicals by free radical scavenging and metal chelation [48]. Polyphenols (majorly flavonoids) play significant role in upgrading memory and cognition due to their ability of neuroprotection which prevents the degeneration of neurons and improves their function. Their mechanism of action may involve modulation of intracellular signaling cascades controlling neuronal survival, death and differentiation. Other mechanisms include gene expression and mitochondrial interactions.

Consumption of flavonoids enhances cortical blood flow which with increased cerebrovascular function, especially in the hippocampus, may facilitate adult neurogenesis. The clustering of hippocampal cells near blood vessels leads to proliferation due to vascular growth factors is vital for learning and memory. Polyphenols including flavonoids may exert cellular

effects via direct modulation of protein and lipid kinase signalling pathway and induces both ERK1/2 and cAMP-Response Element-Binding protein (CREB) activation in cortical neurons and subsequently increases CREB regulated gene expression. CREB is a transcription factor which binds to the promoter regions of many genes associated with memory and synaptic plasticity [49].

Beside this, polyphenols work in helping reverse age related spatial memory. Several plant sources like berries, soy have been found to have positive effect on working memory and cognition while cocoa not only positively affects cognition but also lessens mental fatigue during continued mental exertion [50-52]. Even coffee rich in polyphenols is reported to preventive approach to chronic diseases [53].

b) Role of fats: Brain structure and functioning is closely associated with fats more than 60% of it is made of fats [54]. Human body cannot synthesize Essential Fatty Acids (Omega-3 and Omega-6) which need to be supplied via diet. Omega 3 fatty acids include α -linolenic acid (ALA), eicosapentaenoic acid (EPA) and docosahexaenoic acid [55]. Foods such as walnut, flax seed, soya bean are rich in ALA while fish oil is a major source of EPA and DHA. Omega-6 fatty acid include linoleic acid (found in sunflower, corn, safflower, almonds) and γ -linolenic acid essentially found in borage and black current. ALA gets metabolized enzymatically to EPA and DHA, the latter being predominantly present in human brain. It increases oxygen delivery by enhancing levels of prostacyclin (vasodilator) and decreasing thromboxane. Moreover, by acting on acetylcholine it boosts memory [56] DHA prevents plaque formation in AD patients and in combination with EPA reduces inflammation [57]. Omega-6 fatty acid are also reported to have pro anti-inflammatory roles [58]. Cholesterol present in brain is around one fourth of the total amount of cholesterol in a body. CNS cholesterol is present in neuronal myelin sheath in highest amount where it works as an insulator as well as the glial and neuronal membranes. Schreurs (2010) has discussed various reports of cholesterol effects on learning and memory. Low HDL cholesterol has been associated with loss of memory in middle aged people while increased cholesterol values correlate to higher cognition proving a distinct correlation between adult memory-learning and cholesterol levels [59].

c) Role Of Nootropics and Nutraceuticals: Nootropics better known as smart drugs are substances that help in improving mental performance leading to better focus, memory and cognition. Methylphenidate (MPH) used to treat Attention Deficit Hyperactivity Disorder (ADHD), is the most commonly used nootropic. Low levels of MPH are related with increased level of dopamine in prefrontal cortex resulting in weak signal to noise ratio. It inhibits the reuptake of non-epinephrine and dopamine by transporters resulting in improved long term memory and attention. Ampakines enhances the activity of AMPA receptors thus increasing long term potential and maintaining cortical plasticity. They are proved to be cognitive enhancers [60]. Modaphinil, another notropic, helps in enhancing wakefulness and attention is also efficacious in ADHD, Schizophrenia, Parkinson disease etc. It affects hypothalamic anterior nucleus and elevates serotonin, glutamate level while lowering the level of Gamma-aminobutyric Acid (GABA) [61].

Prominent nutraceuticals include green tea, omega-3, folic acid, lutein, glucosamine, ginseng, cod liver oil, polyphenones, PUFAs (Polyunsaturated Fatty Acids), vitamins and Echinacea. They show numerous therapeutic effects and are in atherosclerosis, cardiovascular diseases, alzheimer, neurological disorders and cancer primarily due to their antioxidant properties. Not only do nutraceuticals help the body in normal physiological functioning, they provide aid in treating chronic diseases, inflammation, obesity and eye disorders [62]. Vitamin C has been reported to protect the brain from hemorrhage [63] while vitamin B increases homocysteine level and preventing brain atrophy [64].

Nutraceuticals such as curcumin, lycopene, beta-carotene and turmerin show favorable effects in treatment of AD [65] Daidzein, biochanin, genistein and lycopene are shown to have protective effects against cancer. Quercetin is used to treat allergies as it can scavenge free radicals. Lipoic Acid and dietary fibers from psyllium are beneficial for diabetic patients. Flavonoids from in fruits and vegetables block cyclooxygenase enzyme thereby inactivating the angiotensin converting enzyme and preventing platelet aggregation. Thus, they work as good therapeutic agents for CVD diseases [65].

d) Hacking Depression for Mental Peace: Increased work life pressure, unhealthy lifestyle brings about not only physical

discomforts but mental stress, insomnia and despondency. Though, there are drugs suggested by physicians as nerve soothers, sleeping pills and tranquilizers. However, this therapy is avoided or not preferred by many due to myriad of side effects like addiction, drowsiness and lethargy. Thus, people search for alternative therapy like meditation. This is a very old concept which is considered as a form of mental exercise and helps not only in overcoming stress but also makes one feel relaxed and filled with positivity. It is hypothesized that meditation involves neural networks of frontal cortex, cingulate gyrus and parietal lobe [66], and enhances brain efficiency as a consequence of continued attention and impulse control [67]. There are many forms such as yoga, mantra, tai chi, breath exercises etc. Another form of meditation known as Mindful meditation is of Buddhist origin has been described as “the non-judgemental attention to experiences in the present moment”. This meditation effects multiple regions of brain such as hippocampus, sensory corticals and insula, corpus callosum and superior longitudinal fasciculus, anterior cingulate cortex, mid-cingulate cortex and orbitofrontal cortex thereby showing positive effects on executive functioning [68]. Meditation reduces stress, depression [69], and improves memory [70]. The habitual meditators also reported to have structural changes in brain including cortical thickness which promotes cortical plasticity [71]. According to the SHY hypothesis, the synaptic plasticity need to be recovered which occurs during the time of sleep ensuring proper functioning of brain [72]. Acute lack of sleep may result in impaired cognitive functions and reduced activation of prefrontal region. Short term sleep deprivation is linked with curtailment in prefrontal, parietal cortex and thalamus [73], while deep sleep results in better cognitive efficiency [74]. Meditation helps relaxing the body which leads to better sleep. One of the effective techniques introduced more than half a century ago to the western world by Mahirishi Mahesh Yogi is Transcendental Meditation which results in significant decline in psychological troubles, depression, anxiety and emotional distress while building up positivity in patients suffering from illness [69].

BIOHACKS FOR GENETIC MANIPULATION

With the advent of CRISPR Cas9 genome editing technology, it is much easier to modify and bring optimum changes in genes. “This is for the first time in the history of earth that humans are

no longer the slaves of genetics they are born with” said Josiah Zayner, the CEO of Odin who owns a company which sells CRISPR kits [75]. The curiosity seekers are participating actively and getting started because the cost of sequencing DNA is one tenth of a cent per base pair, reducing expense [76]. This biohack made this possible to carry out experiments which were first limited to scientific labs in homemade labs. There are many communities bringing all the researchers, enthusiastic students and entrepreneurs to try their hand in biology by providing basic knowhow which includes Biocurious, the first hackerspace located in California (USA) [77], followed by Genspace (New York), with the primary motive to make biotechnology available to all [78]. Biohackers play with plasmids, bacteria and yeasts. Josiah Zayner a famous biohacker wants to see humans editing their genome themselves injected himself to grow stronger muscle in Synbiobeta Conference [79]. He also made a musical instrument called chromochord which works on plant proteins known as LOV (Light,Oxygen,Voltage sensing) proteins and produce tones when hit by light [80]. Meredith Peterson, a computer programmer is working on yoghurt bacteria to glow green showing presence of melamine [81] Many experiments are being done by DIYers every day. The peoples around the globe participating in open science and trying to bring some significant changes in lifestyles by closely working on genomes.

BIOHACKS FOR HUMAN ENHANCEMENT

Globally, digitilization and electronics have made their way. An innovative biohack which is a modification of the tracking technology using implanted microchip has been devised. This technology aims at using the implanting microchip in ones hand to open doors, car and even laptop. With the advent of technologies, human augmentation has increased to the use of various implants and prosthetics. Developments in biomedical engineering have further revolutionized biohacking by developing highly efficient tools like pacemakers, cochlear implants, retinal implants, prosthetic limbs etc. Some of the currently used implants are pacemakers used for continuous rythmation of heart, cochlear implants which reinstate the function of hearing, retinal implants to restore lost sight, glucose sensors for checking blood glucose level etc. Besides these, wearables like smart watches, smart shoes, VR headsets are also available for public to use which can help collect health

related data such as body temperature, fatigue, calories burnt and many more. These biohacks aim at connecting two worlds of artificial intelligence and neural network to improve the lives of people with various physical disabilities.

RFID (Radio Frequency Identification) and NFC (Near Field Communication) chips are vital tools for security and safety purposes. These microchips use radio waves and require no power. Kelvin Warwick a professor at Coventry University underwent a RFID chip implant in his forearm in year 1998 under cyborg project 1.0. The signal from the chip permitted the computer to control where he is moving. The implants allowed him to monitor a number of appliances such as heaters, lights and other computers(74) [82]. Another project cyborg 2.0 was performed in 2002 which allowed the communication between Kelvin and his wife who also went through a less complex nervous implant. A microelectrode array inside a guiding tube was implanted below Kelvin's elbow. This allowed them to communicate via sending signals to one another [83]. These projects by Warwick have brought a new wave towards telepathy. He is considered as world's first cyborg. Later on the implants are used for several purposes by public and companies. Dangerous Things sell microchip kits costing just \$100 is an affordable for many and allows the general public to embed themselves with microchips for managing diverse activities thus becoming transhuman [84]. Amal Graafstra, CEO of Dangerous Things says that "The awareness of implants of this nature, especially over a decade now from the first coverage, has seeped into people's general consciousness" [85].

Another interesting biohack which eliminates the need for carrying wallets or cards are NFC chips. Meow Ludo, the founder of Biofoundry implanted a NFC chip in his thumb to store information about credit card and bitcoin keys. Another entrepreneur Martin Wismeijer known as "Bitcoin Man" implanted the NFC chips in both hands as an experiment to store bit coins using sub dermal implants as it would simplify contactless payments" [86]. The implants help to keep the cryptocurrency secure which can be used by everyone to protect money from theft and robbery and provides a more secure and healthy way of making payments.

Improving on the technologies available to counteract physical disabilities, implant technology focusing on human enhancement

is being rapidly developed. Developments in biomedical engineering have further revolutionized biohacking by developing highly efficient tools like pacemakers, cochlear implants, retinal implants, prosthetic limbs etc. These sensors help to have a closer look over body's metabolism and how we interact with ourselves digitally [87]. The wearable technology is now very common in public and serves the purpose of communication with the body [88]. Besides these hacks, the biohackers are developing different prostheses and incorporating these technologies in their body to evolve and generate a whole new concept of cyborgism. The human enhancement technology emerged in a few years and it is thus serving to therapeutics and humanity. The rise of epidermal science and prostheses provide favorable modifications allowing a better way to communicate with our body and making it self-regulatory [5]. One of the finest examples is Filmmaker Rob Spence who lost his eye accidentally. He underwent a project named Eyeborg project carried out by several highly talented engineers where a wireless camera was embedded in his eye which can record a 30 minute footage. This was for the first time a prosthesis eye camera was used which was replaced later with a newer version [89]. Another interesting biohack was carried out for a color blind man Neil Harbisson, who suffered from achromatopsia i.e. vision in grey scale. An Eyeborg was developed by Adam Montan, a cybernetic expert to help Neil hear colors. This device has the ability to convert light into sound frequencies which produce different notes in the audible frequency range and every color. Neil Harbisson is thus considered as a cyborg due to his ability to perceive more colors than human eyes can visualize [90].

The magnet implants to increase sensory vision are very common among implantable hacks which cause no harm to skin. The magnet senses magnetic fields and picks up small metallic things. Bodyhacker Rich Lee implanted magnets in his ears which he uses as earphones to listen to music. North Sense is an external device which need not to be implanted thus no tear to skin and produces vibrations in response to magnetic north thereby adding one more sense [91].

ETHICAL IMPACTS OF DIYBIO SOCIETY

The DIY bio practitioners generally utilize different strategies as compared to the traditional researchers as they intend to

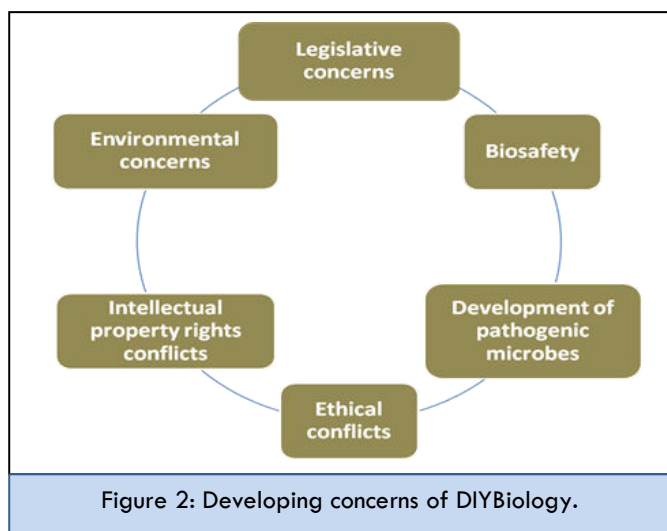
provide technological solution to several societal issues (Table 1).

Biohack	Feature	Impact	Reference
Bulletproof coffee	A modified version of coffee with ingredients including Arabica coffee beans, grass fed butter and brain octane oil.	Suppress hunger, boost energy level, Increase alertness.	Dave Asprey [27]
Keto diet	High fat, low sugar, average protein diet.	Increase metabolism of glycogen, Ketosis, increase in lean body mass, anti-inflammatory effects.	Dr. Peter Huttenlocher [34,36]
Mindful meditation	Non-judgmental attention to experiences in the present moment.	Positive effect on executive functioning.	Buddhists [68]
CRISPR Cas9	A unique Genome editing tool.	Helps in altering, deleting and introducing new sections of DNA.	Yoshizumi Ishino [75-77]
RFID implant	Subdermal implant	Allows switching on lights, doors and communication within a building.	Kelvin Warwick [82]
Polyphenols	Organic compounds obtained from plants.	Act as neuroprotector, have free radical scavenging activity, anti-oxidant activity, and enhance memory and cognition.	[45-53]
Fatty acids	Carboxylic acids with long saturated or unsaturated aliphatic chains.	Increase oxygen delivery to brain, reduce plaque formation in AD patients, improves memory, anti-inflammatory.	[54-59]
Nootropics	Smart drugs	Serve the purpose of excellent mental performance.	[60,61]
Nutraceuticals	Natural bioactive compounds.	Prevent from neurodegenerative, cardiovascular diseases.	[62-65]

In the current era, the world of biotechnology and other related technologies are subject to legislative control in form of various acts and regulations which discuss, describe or prohibit certain experiments. The qualifiers for identifying the practices that are acceptable are generally listed as ethical, moral, human rights and environmental. Of these, in the last couple of decades, many researchers and people associated with biotechnology research are identifying potential hazards which have the capacity to alter an ecosystem by inducing misbalances. Also associated are the fears of people that uncontrolled research and experimentation may have an

unseen side effect with disastrous consequences. There are numerous examples of how anthropogenic activities have impacted the ecosystem mostly in a negative manner culminating with the introduction of transgenic plants like Bt cotton etc [92]. All these have led to the formation of various regulatory agencies where principles of substantial equivalence, precautionary principle, risk assessment and management have become the foundation [93]. A DIY bio researcher does not follow any such restriction or the acceptable pathway of pursuing research which normally is subject to conditions particularly physical and biological containment (Figure 2). Currently, the DIY biology community is self-regulated [94,95] According to Jonathan Tucker, a Senior Fellow at the James Martin Center for Nonproliferation Studies at the Monterey Institute of International Studies (Washington, DC, USA), DIY Bio developments are moving faster than the regulators and legislators and it is necessary to understand how this garage biology be regulated so no unintended harm may come to them or other practitioners or the environment. Of even bigger concern is the development of synthetic biology as a part of DIY Biology as it has the potential of doing immense good for the society but any wrong handling can lead to disastrous efforts [94]. In an interesting case study of Glowing Plant project, the DIYbio researchers evaded the legal and regulatory oversight of the Animal and Plant Health Inspection Service (APHIS), an agency of the US Department of Agriculture (USDA) by using a gene gun rather than a live plant pathogen to transfect foreign genes. But such oversight may lead to potentially dangerous situations. Evans and Segelid [96] have discussed various emerging issues with respect to DIY Biology where they highlight potential generation and misuse of pathogens through affordable molecular biology DIY kits which also poses significant challenges to ensure biosafety. This is currently the most important aspect of biotechnological advances. Also, there is an emerging fear of “Black Hat Biologists” [97] who may use the openness and innovativeness of DIY biology for mischievous or nefarious reasons causing harm to society or state. Hence, it is of utmost importance that the DIYbio researchers understand the complexity of the living system and continue to carry out their innovations keeping “safety for all” clause in their work methodology. This will enhance the ethical and moral viewing of the research, making

it more acceptable to public and traditional researchers. Thus, the DIYBio.org website contains within itself forums addressing biosafety and “ask a biosafety expert” column to assist the biohackers with novel biosafety issues [96].



CONCLUSION

DIYbio is focused on the democratization of science which allows everyone to explore various methods which possibly can lead to self enhancement beyond the existing norm. Innovative methods result in improving body’s metabolism and results in better life quality. These biohacks have also influenced the field of medical bioengineering giving rise to new concepts like eyeborg where in the innovation helps in removing the physical disability and augment self for various activities. DIY biology is bringing the world of science and technology to the public in a very simple result oriented manner and breaking the boundaries of conventional science. However, it is imperative that safety measures and ethical decisions are taken to ensure that while carrying out free science no societal or environmental hazards are generated.

CONFLICT OF INTEREST

The authors declare no conflict of interest with respect to publication of this review.

REFERENCES

1. Greenwood DJ, Levin M. (2007). Introduction to Action Research . Thousand Oaks, CA: SAGE Publications.
2. Golinelli S, Ruivenkamp G. (2015). Do-it-yourself biology: Action research within the life sciences? *Action Research*. 14: 151-167.

3. Keulartz J, van den Belt H. (2016). DIY-Bio - economic, epistemological and ethical implications and ambivalences. *Life SciSoc Policy*. 12: 7.
4. Meyer M. (2013). Domesticating and democratizing science: A geography of do-it-yourself biology. *Journal Of Material Culture*. 18: 117-134.
5. Yetisen AK. (2018). Biohacking. *Trends in Biotechnology*. 36: 744-747.
6. Gustavsen B. (2003). New forms of knowledge production and the role of action research. *Action Research*, 1: 153-164.
7. Da Costa B, Kavita C. (2008). *Tactical biopolitics. Art, activism and technoscience*. London, UK: MIT Press.
8. Keltly MC. (2010). Outlaw, hackers, victorian amateurs: diagnosing public participation in the life sciences today. *Journal Of Science Communication*.
9. Merton RK. (1973). The normative structure of science. In R. K. Merton (Ed.), *The sociology of science: Theoretical and empirical investigations*. Chicago, IL: University of Chicago Press.
10. <https://www.genspace.org/>
11. Delfanti A. (2013). *Biohackers. The Politics of Open Science*. London: Pluto Press.
12. <https://www.quantifiedbob.com/hacking-tracking-glucose/>
13. This biohacker used eyedrops to give himself temporary night vision.
14. Hormesis: how to use stress to boost your resilience.
15. <https://jenova-rain.com/magnet-implant-uk/>
16. Three garmin smartwatch apps for biohacking health.
17. Biohacking sleep and chronotypes with ben greenfield.
18. Zoeteman B. et al. (2005). *Biotechnologie en de Dialoog der Doven. Dertigjaargenetische modificatie in Nederland (Biotechnology and the Dialogue of the Deaf. Thirty years of genetic modification in the Netherlands)* (p. 120). Bilthoven, The Netherlands: Commissie Genetische Modificatie.
19. https://www.wilsoncenter.org/sites/default/files/7_myths_final.pdf
20. <https://diybio.org>
21. <https://www.defconbiohackingvillage.org>

22. Kaster MP, Machado NJ, Silva HB, Ana Nunes, Ana Paula Ardais, et al. (2015). Caffeine acts through neuronal adenosine A2A receptors to prevent mood and memory dysfunction triggered by chronic stress. *Proc Natl Acad Sci U S A*. 112: 7833-7838.
23. Eskelinen MH, Kivipelto M. (2010). Caffeine as a protective factor in dementia and Alzheimer's disease. *Journal of Alzheimer's disease : JAD*. 20: S167-74 .
24. Svilaas A, Sakhi AK, Andersen LF, Tone Svilaas, Ellen C Ström, et al. (2004). Intakes of Antioxidants in Coffee, Wine, and Vegetables Are Correlated with Plasma Carotenoids in Humans, *The Journal of Nutrition*. 134: 562-567.
25. <https://blog.bullectproof.com/bullectproof-coffee-benefits/>
26. Daley CA, Abbott A, Doyle PS, Nader GA, Larson S. (2010). A review of fatty acid profiles and antioxidant content in grass-fed and grain-fed beef. *Nutrition Journal*.
27. Hebeisen DF, Hoeflin F, Reusch HP, Junker E, Lauterberg BH. (1993). Increased concentrations of omega-3 fatty acids in milk and platelet rich plasma of grass-fed cows. *Int J Vitam Nutr Res*. 63: 229-233.
28. Calder PC. (2010). Omega-3 fatty acids and inflammatory processes. *Nutrients*. 2: 355-374.
29. Blankson H, Stakkestad JA, Fagertun H, Thom E, Wadstein J, et al. (2000). Conjugated Linoleic Acid Reduces Body Fat Mass in Overweight and Obese Humans. *The Journal of Nutrition*. 130: 2943-2948.
30. Lee KW, Lee HJ, Cho HY, Kim YJ. (2005). Role of the conjugated linoleic acid in the prevention of cancer. *Critical Reviews In Food Science And Nutrition*.
31. St-Onge MP, Jones PJH. (2002). Physiological Effects of Medium-Chain Triglycerides: Potential Agents in the Prevention of Obesity. *The Journal of Nutrition*. 132: 329-332.
32. Raybould HE. (2007). Mechanisms of CCK signaling from gut to brain. *Current opinion in pharmacology*. 7: 570-574.
33. Djalalinia S, Qorbani M, Peykari N, Kelishadi R. (2015). Health impacts of Obesity. *Pakistan journal of medical sciences*. 31: 239-242.
34. Bueno N, De Melo I, De Oliveira S, Da Rocha Ataíde T. (2013). Very-low-carbohydrate ketogenic diet v. low-fat diet for long-term weight loss: A meta-analysis of randomised controlled trials. *British Journal of Nutrition*. 110: 1178-1187.
35. Paoli A, Cenci L, Grimaldi KA. (2011). Effect of ketogenic Mediterranean diet with phytoextracts and low carbohydrates/high-protein meals on weight, cardiovascular risk factors, body composition and diet compliance in Italian council employees. *Nutrition journal*.
36. Johnstone AM, Horgan GW, Murison SD, Bremner DM, Lobley G.E. (2008). Effects of a high-protein ketogenic diet on hunger, appetite, and weight loss in obese men feeding ad libitum. *The American Journal of Clinical Nutrition*. 87: 44-55.
37. Masood W, Uppaluri KR. (2019). *Ketogenic Diet*. Treasure Island: StatPearls publishing.
38. Paoli A, Rubini A, Volek JS, Grimaldi KA. (2013). Beyond weight loss: a review of the therapeutic uses of very-low-carbohydrate (ketogenic) diets. *European journal of clinical nutrition*. 67: 789-796.
39. Musa-Veloso K, Likhodi SS, Cunname SC. (2002). Breath acetone is a reliable indicator of ketosis in adults consuming ketogenic meals, *The American Journal of Clinical Nutrition*. 76: 65-70.
40. Zhao Z, Lange DJ, Voustianiouk A, Donal MacGrogan, Lap Ho, et al. (2006). A ketogenic diet as a potential novel therapeutic intervention in amyotrophic lateral sclerosis. *BMC neuroscience*.
41. Mavropoulos JC, Yancy WS, Hepburn J, Westman EC. (2005). The effects of a low-carbohydrate, ketogenic diet on the polycystic ovary syndrome: a pilot study. *Nutrition & metabolism*.
42. Rogovik AL, Goldman RD. (2010). Ketogenic diet for treatment of epilepsy. *Canadian family physician Medecin de famille canadien*. 56: 540-542.
43. Gasior M, Rogawski MA, Hartman AL. (2006). Neuroprotective and disease-modifying effects of the ketogenic diet. *Behavioural pharmacology*. 17: 431-439.
44. Masino SA, Ruskin DN. (2013). Ketogenic Diets and Pain. *Journal of Child Neurology*. 28: 993-1001.
45. Vazour D, Camprubi-Robles M, Miquel-Kergoat S, Andres-Lacueva C, Bánáti D, et al. (2015). *Nutrition for the ageing*

- brain: Towards evidence for an optimal diet. *Aging Research Reviews*. 35: 222-240.
46. Lamport D, Dye L, Wightman JD, Lawton CL. (2012). The effects of flavonoid and other polyphenol consumption on cognitive function: A systematic review of human experimental and epidemiological studies. *Nutrition and aging*. 1: 5-25.
 47. Beking K, Vieira A. (2010). Flavonoid intake and disability-adjusted life years due to Alzheimer's and related dementias: a population-based study involving twenty-three developed countries. *Public Health Nutrition*. 13: 1403-1409.
 48. Aliev G, Obrenovich ME, Reddy VP, Shenk JC, Moreira PI, et al. (2008). Antioxidant therapy in Alzheimer's disease: theory and practice. *Mini Rev. Med. Chem*. 8: 1395-1406.
 49. Spencer J. (2008). Flavonoids: Modulators of brain function? *British Journal of Nutrition*. 99: ES60-ES77.
 50. Shukitt-Hale B, Bielinski D, Lau F, Willis L, Carey A, Joseph J. (2015). The beneficial effects of berries on cognition, motor behaviour and neuronal function in ageing. *British Journal of Nutrition*. 114: 1542-1549.
 51. Scholey AB, French SJ, Morris PJ, Kennedy DO, Milne AL, et al. (2010). Consumption of cocoa flavanols results in acute improvements in mood and cognitive performance during sustained mental effort. *Journal of Psychopharmacology*. 24: 1505-1514.
 52. Lee YB, Lee HJ, Sohn HS. (2005). Soy isoflavones and cognitive function. *The Journal of Nutritional Biochemistry*. 16: 641-649.
 53. Higdon JV, Frei B. (2006). Coffee and Health: A review of Recent Human Research. *Critical Reviews in Food Science and Nutrition*. 46: 101-123.
 54. Chang CY, Ke DS, Chen JY. (2009). Essential fatty acids and human brain. *Actaneurologica Taiwanica*. 18: 231-241.
 55. Dyal SC. (2015). Long-chain omega-3 fatty acids and the brain: a review of the independent and shared effects of EPA, DPA and DHA. *Frontiers in aging neuroscience*.
 56. Singh M. (2005). Essential fatty acids, DHA and human brain. *The Indian Journal of Pediatrics*. 72: 239-242.
 57. Swanson D, Block R, Mousa SA. (2012). Omega-3 fatty acids EPA and DHA: health benefits throughout life. *Advances in nutrition (Bethesda, Md.)*. 3: 1-7.
 58. Bentsen H, Landro NI. (2018). Neurocognitive effects of an omega-3 fatty acid and vitamins E+C in schizophrenia: A randomised controlled trial. *Prostaglandins, Leukotrienes and Essential Fatty Acids*. 136: 57-66.
 59. Schreurs BG. (2010). The effects of cholesterol on learning and memory. *Neuroscience and biobehavioral reviews*. 34: 1366-1379.
 60. Urban KR, Gao WJ. (2014). Performance enhancement at the cost of potential brain plasticity: neural ramifications of nootropic drugs in the healthy developing brain. *Frontiers in systems neuroscience*.
 61. Shuman T, Wood SC, Anagnostaras SG. (2009). Modafinil and memory: effects of modafinil on Morris water maze learning and Pavlovian fear conditioning. *Behavioral neuroscience*. 123: 257-266.
 62. Nasri H, Baradaran A, Shirzad H, Rafieian-Kopaei M. (2014). New concepts in nutraceuticals as alternative for pharmaceuticals. *International journal of preventive medicine*. 5: 1487-1499.
 63. Sotoriou S, Gispert S, Cheng J, Wang Y, Chen A, et al. (2002). Ascorbic-acid transporter Slc23a1 is essential for vitamin C transport into the brain and for perinatal survival. *Nature Medicine*. 8: 514-517.
 64. Smith AD, Smith SM, de Jager CA, Whitbread P, Johnston C, et al (2010). Homocysteine-lowering by B vitamins slows the rate of accelerated brain atrophy in mild cognitive impairment: a randomized controlled trial. *PloSone*.
 65. Mirmosayyeb O, Tanhaei A, Sohrabi HR, Martins RN, Tanhaei M, et al. (2017). Possible Role of Common Spices as a Preventive and Therapeutic Agent for Alzheimer's Disease. *Int. J. Prev. Med*. 8: 5.
 66. Chan D, Woolacot M. (2007). Effects of Level of Meditation Experience on Attentional Focus: Is the Efficiency of Executive or Orientation Networks Improved? *The Journal of Alternative and Complementary Medicine*. 13: 651-658.
 67. Kozasa EH, Sato JR, Lacerda SS, Barreiros MA, Radvany J, et al. (2012). Meditation training increases brain efficiency in an attention task. *Neuroimage*. 59: 745-749.

68. Teper R, Segal ZV, Inzlicht M. (2013). Inside the Mindful Mind: How Mindfulness Enhances Emotion Regulation Through Improvements in Executive Control. *Current Directions in Psychological Science*. 22: 449-454.
69. Elder C, Nidich S, Moriarty F, Nidich R. (2014). Effect of transcendental meditation on employee stress, depression, and burnout: a randomized controlled study. *The Permanente journal*. 18: 19-23.
70. Khalsa DS. (2015). Stress, Meditation, and Alzheimer's Disease Prevention: Where The Evidence Stands. *Journal of Alzheimer's disease : JAD*. 48: 1-12.
71. Lazar SW, Kerr CE, Wasserman RH, Gray JR, Greve DN, et al. (2005). Meditation experience is associated with increased cortical thickness. *Neuroreport*. 16: 1893-1897.
72. Cirelli C, Tononi G. (2017). The Sleeping Brain. *Cerebrum:cer-07-17*.
73. Ma N, Dinges DF, Basner M, Rao H. (2015). How acute total sleep loss affects the attending brain: a meta-analysis of neuroimaging studies. *Sleep*. 38: 233-240.
74. Fattinger S, de Beukelaar TT, Ruddy KL, Volk C, Heyse NC, et al. (2017). Deep sleep maintains learning efficiency of the human brain. *Nature Communications*. 8: 15405.
76. Nash DB. (2010). Beware biohacking?. *Biotechnology healthcare*. 7: 7.
77. <https://www.risingtidebio.com/diy-biohacking-crispr/>
78. <https://www.pcworld.com/article/2044761/diy-biohackers-play-with-bacteria-at-genspace-a-community-biology-lab.html>
79. <https://www.livemint.com/Leisure/FVPrvuBYMtyzHHNpdG2QgN/Josiah-Zayner-The-man-who-hacked-his-own-DNA.html>
80. <https://www.labcritics.com/chromochord-proteins-play-tunes-1794/>
81. http://www.nbcnews.com/id/28390773/ns/technology_and_science-innovation/t/hobbyists-try-genetic-engineering-home/
82. <http://www.kevinwarwick.com/project-cyborg-1-0/>
83. <http://www.kevinwarwick.com/project-cyborg-2-0/>
84. <https://www.dangerousthings.com/>
85. Michael K. (2016). RFID/NFC Implants for Bitcoin Transactions. *IEEE Consumer Electronics Magazine*.
86. <https://medium.com/novamining/alternative-wallets-subdermal-nfc-chip-a9bcf84cb3b9>
87. Catherwood PA., Finaley DD., McLaughin JAD. (2016). Intelligent Subcutaneous Body Area Networks: Anticipating Implantable Devices. *IEEE Technology and Society Magazine*.
88. Swan M. (2013). The Quantified Self: Fundamental Disruption in Big Data Science and Biological Discovery. *Big data*.
89. <http://eyborgproject.tv/>
90. <https://cyborgproject.com/pdf/Neil-Harbisson-A-cyborg-artist.pdf>
91. <https://www.geek.com/tech/north-sense-implant-turns-you-into-a-human-compass-1656462/>
92. Robinson J (1999). Ethics and transgenic crops: A review. *Electronic Journal of Biotechnology*.
93. Prakash D, Verma S, Bhatia R, Tiwary BN. (2011). Risks and Precautions of Genetically Modified Organisms. *ISRN Ecology*.
94. Wolinsky H. (2009). Kitchen Biology. *EMBO reports*. 10: 683-685.
95. Landrain T, Meyer M, Perez AM, Sussan R. (2013). Do-it-yourself biology: challenges and promises for an open science and technology movement. *Syst Synth Biol*. 7: 1115-1126.
96. Evans NG, Selgelid MJ. (2014) Biosecurity and Open-Source Biology: The Promise and Peril of Distributed Synthetic Biological Technologies. *Sci Eng Ethics*. 21: 1065-1083.
97. Carlson, R. (2012). Causes and consequences of bioeconomic proliferation: Implications for U.S. Physical and Economic Security. Department of Homeland Security Science and Technology Directorate. United States Department of Homeland Security.