Development of Cognitive enhancement methods

Zhijian Deng*

Shanghai Jiao Tong University, 800 Dongchuan Road, Shanghai, CHN 200240

*Corresponding author: dengzhijian_geralt@sjtu.edu.cn

Abstract. Cognition ability represents a group of cognitive processes, which involves a lot of human's basic cognitive functions, including executive attention, episodic memory, prospective memory, uncertainty monitoring and metacognition, and self-control and delay of gratification, playing an essential role in human's fundamental life. Mainstream cognition enhancing technologies are task based method, drug based method and brain computer interface based method, whose general principles are directly training relative functions, rebuilding nerve interactions in cell or molecular level and giving signals stimulating neurons respectively. In This essay, after introducing these three cognitive enhancement methods and analyzing the advantages and disadvantages of each of them, some advises and expectations are given.

Keywords: Cognition, enhancing, tasks, drugs, brain computer interface.

1. Introduction

Cognition ability is an essential ability for human, which includes a wide range of fundamental functions, such as executive attention(the ability to pay attention, exclude external distractor, focus on certain things, response external stimuli), episodic memory(form self-features: "'what,' 'where,' 'when,' 'who,' etc.", construct human's thinking, planning, communicating, language and so on), prospective memory(consistently put and keep intentions on one thing until a response is needed), uncertainty monitoring and metacognition(administrate cognition to meet different situations and difficulties, foresee potential failure), self-control, and delay of gratification(refuse present gain to get the higher gain after, which is significant to self-management and self-success)[1]. People will face huge difficulty in basic actions and daily life if cognition control is impaired. Cognition enhancing technology is a composite technology combining the knowledge in neuron science, biological and medical science, life science and other topics, aiming to repair and enhance the cognitive ability especially for those patients having cognition deficits because of decease like stroke, Parkinson decease, psychiatric disorder. Recent years scientists put great efforts in developing cognition enhancing technologies to rebuild those functions completely and lots of researches have been taken to state more detailed interpretation of these behaviors, and there were also plenty of studies trying to find ways of enhancing cognition abilities.

There are three mainstream cognition enhancing technologies in the state-of-the-art studies, which includes therapies based on tasks (motor and cognitive exercises, new technologies like VR and computer games), drugs, and technologies based on brain computer interface. In the past, when information technologies, medicine industries and neurology have not been developed yet, the mainstream of approaches improving cognition ability was based on tasks, and this kind is still the most popular direction and been studied nowadays. Instead of deeply analyzing the internal mechanisms of how repeat and particular tasks, scientists mainly focused on the effects on tasks, ignoring the principles behind, and therefore this essay will also put attention on the results rather than reasons. Then, drugs are induced to cure some related diseases (like stroke, Parkinson or psychiatric disorders, whose one prominent symptom is cognitive impairment) at cell or molecular level. The areas of those drugs work would mostly be the neurons in the brain, which are the most basic and important cells constructing the brain. The functions of the brain are mainly achieved by the interactions between neurons, so some deceases leading to the loss of those interactions will cause the cognition abilities going wrong. To fix those functions, some drugs are used to rebuild those connections.

As mentioned before, cognition ability is mental processes in brain, so neurology studying the mechanisms in brain will help most in the improvement of cognition ability and with brain-computer interfaces (BCI), which can directly stimulate corresponding cortex in brain responsible for memory or information processing. BCI can provide a time-based data of decoding brain signals, which allows us to analyze patients' brain activities and stimulate certain neurons by providing control signals. Using BCI, machines can decode patients intentions and response them, building the lost connection between cognition and motor.

This study mainly introduces and concludes the basic principles and development of these three kinds of cognition improving technologies by giving some current research about these field, and simply by analyzing and comparing to show the advantages and disadvantages of each of them. The analysis of this paper might provide references to future direction of the development of cognition impairment treatment.

2. Cognition Enhancing Approaches

Cognition ability, or cognition control, is one of human's internal mental abilities, which is responsible for fundamental and regular cognitive behaviors and executive functions (like distributing attention to analyze necessary external information with excluding distractions and then store useful messages into brains or forming memories of future plans (what is needed to be done later), evaluating existing memories and required information, and self-control. Studies related to cognition control are these several areas: "executive attention, episodic memory, prospective memory, metacognition, and self-control" [1]. Those behaviors are essential to human, so those people who facing the cognition deficiency due to deceases or age will face huge problems in daily life, and also better cognition ability benefits broad aspects of people's life in all aspects.

There are three main methods applied in the enhancement of cognitive abilities, including methods based on task, drugs and a newly developed Brain Computer Interface-based method.

2.1. Tasks based method

The general principle of the tasks-based method is repeating simple and basic training which represents the functions of cognition. By going to several 60-120 minutes sessions per week continually, those functions can be re-built based on the self-healing function of human body.

Lots of researches combine physical training with cognition training (CT), and the type of physical training is mostly aerobic exercise. Edgardo found that through regular walking on the plane, aged women in high air pollution not only showed better resistance ability against air pollution, but also improved performance on EF, mainly because of better brain integrity and oxygen transport [2]. Jon-Frederick has concluded that physical exercises, especially aerobic exercises, had positive effects on EF and working memory (WM) [3]. Also, Sandra analyzed participants' (who went to the training sessions every week and it lasted for 12 weeks) cognition abilities' changes and concluded that short-term and isolated exercises could slow down the speed of cognition loss when aging [4]. When the idea that physical training is beneficial to cognition ability is widely accepted, some further studies focused on the relationship between physical training and CT. They compared isolated physical exercises and CT with sequential "motor-cognitive" training (finish CT first and then do physical exercises) and simultaneous exercise-cognitive training (do some tasks that require both mental and motor works), and found evidence that simultaneous training may be more significant than sequential tasks and single fitness training with explaining the possible reasons that those two training both increase "cerebral blood flow", "induce angiogenesis in the cortex and cerebellum" [5][6].

However, although this combination is always proposed to enhance elderly people's cognition ability, some researches indicates that these exercises show no obvious impact on the cognition ability. There is a report showed that no strong evidence showed that short-term cognitive training for the elderly people was effective, which conflicts with previous study [7]. In addition to cardiopulmonary exercises, some other elements are added into the tests, like traditional puzzle games or music. One

essay investigated the internal relationship between musical training (musical perception, production and learning) and EF, and finally implied a generally positive result for the improvement of cognition ability by musical training, which are affiliated with working memory updating [8]. Besides, with the development of information technologies, scientists are allowed to add more advanced electronic devices into tasks. Some experiments introduced video games or virtual reality (VR) (which can be flexibly customized by researchers to meet the goal of brain training) into cognition training. In one experiment, participants were asked to play online brain-training games, and then researchers measured their improvement by getting EEG data, which indicated that "targeted cognitive training using online games" showed both short term and long-term impact on cognitive flexibility [9]. Moreover, a study was taken with "non-action video games" training for older adults, showing a significant improvement over all periods [10] Besides, research analyzed the effects of "VR-based therapies" on patients having stroke (who face high levels of cognitive impairment and mental health problem), and the outcomes were positive and displayed the improvements on EF, memory and visuospatial function [11].

It's obvious that those aerobic exercises or other tasks are mostly designed for elderly people who are capable to do fundamental regular exercises, but for those patients facing more serious cognition impairment, they have difficulties in finishing those tasks or the effects are not so significant to fully cure the deceases, so some other more effective and direct therapies need to be introduced.

2.2. Drugs based method

Drugs can bring external stimuli to more directly rebuild those functions. By introducing specialized compounds, neurons' rehabilitation is supported and accelerated. The main type of drugs is antioxidant. One certain type of antioxidants was introduced in one report, called "grape seed proanthocyanidin" (GSPA), which may be able to interfere the accumulation of synthetic Aβ peptides, which plays an essential role in the Alzheimer decease (AD) [12]. At the same time, "atypical antipsychotic drugs" (AAPDs), was proved to have close relationship with 5-HT1A receptor, which has huge contribution to cognition improvements (especially for EF and verbal memory) by "diminishing the activity of gamma-aminobutyric acid (GABA) neurons, leading to dis-inhibition of Glu neurons" [13].

2.3. Brain computer interfaces method

The mechanisms of BCI work are similar to the drugs, which both concentrate on the repair of basic functions of neurons, but this has more straight and effective effects. What is worth mentioning is a typical technique in BCI, named deep brain stimulation (DBS), which a process that after using electrodes detecting neuron signals in the deep areas of the brain and decode, optimize them, stimulating those neurons with particular signals, which to some extent simulate the functions of neurons.

Ravikiran demonstrated two BCI strategies for stroke rehabilitation: one is assistive BCI, which means avoiding broken neuronal pathways by providing a consistent communication with external devices; another one is called rehabilitative BCI, aims to recover those damaged neuron links and corresponding functions by a series of treatment (among them the key step is stimulating, building and enhancing neuronal circuits) [14]. Also, one paper systematically concludes the applications of BCI technologies in stroke, Parkinson decease psychiatric disorders and others, listing lots of rehabilitation paradigms, like "Neurofeedback", "EEG-based imagery enhancement", "Close sensorimotor loop", "Train motor preparation" and "State-dependent training", and analyzing their curative effects on those deceases correspondingly, which got a positive result and bright future of further studies [15].

The key of whether we can get enough curative effects is the percentage of successfully detecting and decoding neuron signals, and to what extent the stimulated signals can be optimized, and the DBS has been consistently evolving due to the efforts of a majority of researchers. A laboratory delivered a new DBS technology, called "AlphaDBS system", which was able to collect signal data, manage

the interface with deep brain neuron system, and generally gave a reliable system for decoding, modulating [16].

3. Discussion

This essay mainly analyzes part of the main features of several categories of cognition enhancing technologies, which are technologies based on tasks (motor exercise, music, information technologies), drugs and neuron engineering (BCI), and systematically state the development of cognition enhancing therapies. The following discussion will be the detailed analysis on those technologies, the comparison between them to get the advantages and disadvantages of each of them, and finally a expectation to the future of this field.

Therapies based on tasks have the longest history in the treatment of cognition disease, and the most obvious reason and advantage is of course is the cost. The cost is not just about the money, but also about the limitation of the difficulties of those therapies and relative technologies. Compared with expensive drugs and devices of BCI, these motor tasks only require aerobic exercises (normally are running) or resistance exercises (e.g., use "resistance bands, machines or free weights"), which nearly need no extra money for devices [3]. In addition, those physical works are just the repeating of some simple physical movement, requiring no budget for learning, both for the patients and doctors. In contrast, when applying drugs or BCI, professors, even a team all in master's degree or PHD in corresponding topic are often needed to design and manage the whole process of treatment, while any doctor experiencing short time training can perform motor treatment. Similarly, these advantages are also shown in the tasks about music and information technologies.

However, the simplicity of tasks has also their side effects. The first disadvantage is high time cost. Although other cost is low, the time cost cannot be ignored. Usually, patients need only less than 8 weeks of treatment using BCI technologies [14], but as for motor exercises, they often require more than 6 month, 3 sessions per week, 60-120 minutes per session [2]. Because those exercises are not fierce, meaning that few months of training will not have profound influence [7]. Besides, even having adequately long training, the curative effect is not so effective. Also, for those having serious cognition impairment, who have difficulties in daily life, they cannot finish those tasks, so tasks are not applicable in any situation for any group of people.

Nowadays, approaches based on tasks are often considered as a support basis and recover in the treatment, mixed with drugs and BCI technologies. The occurrence of BCI makes the role of drugs a little bit embarrassing. The complexity of analyzing drugs and BCI is roughly at the same level, but as a new cutting-edge technology, BCI have experienced great progress these years. Meanwhile, the development of drugs is limited by lack of experiment subjects (the experiment must be seriously cautious) and unknown side effects. But that is not to say that the research on drugs is totally abandoned, for those patients who only can lie on the bed, medicine is still needed and plays an essential role.

As the most popular technology in this area, BCI has its undoubtedly unique benefits. The improvement brought by BCI is all-round. EEG which can monitor neuron signals firstly allows scientists to study and analyze the mechanisms and actions of brain, letting researchers have a deeper understanding about cognition deficits. Meanwhile, BCI can also be combined with other technologies. Researchers have found that with BCI-based therapies, motor and cognitive training have better effect in shorter time, perfectly solve the problems that the technologies based on tasks are facing [14][15]. Besides, advanced BCI technologies can precisely and continually get the neuron signal data and directly stimulate certain area in brain, strongly improve the functions of BCI. But BCI also has problem which must be solved, that is, too invasive. Unlike regular EEG, which only requires some electrodes put on patients' head, DBS need to dig out patients' head to jab thick and a large number of electrodes into the internal areas of the brain, which is too invasive for those conservative and old people, who are the greatest group having cognition deficits.

Table 1. Principles, advantages, disadvantages of three methods.

Types	Principles	Advantages	Disadvantages
Task based	Function training	Low cost	Time-consuming, not effective
Drug based	Rebuilding interactions in cell or molecular level	Available for all groups	Unknown side effects
BCI based	Signal stimulating neurons	Can mixing other methods, monitoring	Invasive

Unlike studying the effect of each therapy separately, the present and future treatment for cognition deficits will be the combination of all those cognition enhancing technologies, so the development of any of them cannot be left behind. But BCI must be paid the most attention to, due to its functions in the whole treatment. Furthermore, the strengthening effect of BCI on other cognition improving technologies should be studied more, which can not only develop BCI technologies, but also take more advantages of other therapies. Instead of just the repairing cognition deficits, the enhancement of cognition ability for ordinary people should be studied, which can be beneficial to all humanities.

4. Conclusion

This essay introduces the main functions of cognition ability and analyzing the principles, advantages, disadvantages of three cognition enhancing methods: task based method, drug-based method and brain computer interface method, and pointing out that the present and future treatment of cognition deficits should be the combination of three methods, with putting the most attention to the development of brain computer interface technologies.

References

[1] Beran, Michael J, Audrey E Parrish, J. David Smith, David A Washburn, Charles R Menzel, Ken Sayers, and Bonnie M Perdue. "Primate Cognition: Attention, Episodic Memory, Prospective Memory, Self-control, and Metacognition as Examples of Cognitive Control in Nonhuman Primates." Wiley Interdisciplinary Reviews. Cognitive Science 7.5 (2016): 294-316.

[2] Molina-Sotomayor, Edgardo, Marcelo González Orb, Francisco Pradas De La Fuente, Giovanni Carozzi Figueroa, Antonio Jesús Sánchez-Oliver, and José Antonio González-Jurado. "Effects of Cardiorespiratory Exercise on Cognition in Older Women Exposed to Air Pollution." International Journal of Environmental Research and Public Health 16.2 (2019): 245.

[3] Landrigan, Jon-Frederick, Tyler Bell, Michael Crowe, Olivio J Clay, and Daniel Mirman. "Lifting Cognition: A Meta-analysis of Effects of Resistance Exercise on Cognition." Psychological Research 84.5 (2019): 1167-183.

[4] Chapman, Sandra B, Sina Aslan, Jeffrey S Spence, Laura F DeFina, Molly W Keebler, Nyaz Didehbani, and Hanzhang Lu. "Shorter Term Aerobic Exercise Improves Brain, Cognition, and Cardiovascular Fitness in Aging." Frontiers in Aging Neuroscience 5.NOV (2013): 75.

[5] Tait, Jamie L, Rachel L Duckham, Catherine M Milte, Luana C Main, and Robin M Daly. "Influence of Sequential vs. Simultaneous Dual-task Exercise Training on Cognitive Function in Older Adults." Frontiers in Aging Neuroscience 9.NOV (2017): 368.

[6] Herold, Fabian, Notger G Müller, Dennis Hamacher, and Lutz Schega. "Thinking While Moving or Moving While Thinking - Concepts of Motor-cognitive Training for Cognitive Performance Enhancement." Frontiers in Aging Neuroscience 10.AUG (2018): 228.

[7] Souders, Dustin J, Walter R Boot, Kenneth Blocker, Thomas Vitale, Nelson A Roque, and Neil Charness. "Evidence for Narrow Transfer after Short-term Cognitive Training in Older Adults." Frontiers in Aging Neuroscience 9.FEB (2017): 41.

[8] Okada, Brooke M, and L. Robert Slevc. "Individual Differences in Musical Training and Executive Functions: A Latent Variable Approach." Memory & Cognition 46.7 (2018): 1076-092.

[9] Olfers, Kerwin J.F, and Guido P.H Band. "Game-based Training of Flexibility and Attention Improves Task-switch Performance: Near and Far Transfer of Cognitive Training in an EEG Study." Psychological Research 82.1 (2018): 186-202.

[10] Ballesteros, Soledad, Antonio Prieto, Julia Mayas, Pilar Toril, Carmen Pita, Laura Ponce De León, José M Reales, and John Waterworth. "Corrigendum: Brain Training with Non-action Video Games Enhances Aspects of Cognition in Older Adults: A Randomized Controlled Trial." Frontiers in Aging Neuroscience 7 (2015): 82.

[11] Zhang, Qi, Yu Fu, Yanhui Lu, Yating Zhang, Qifang Huang, Yajie Yang, Ke Zhang, and Mingzi Li. "Impact of Virtual Reality-Based Therapies on Cognition and Mental Health of Stroke Patients: Systematic Review and Meta-analysis." Journal of Medical Internet Research 23.11 (2021): E31007.

[12] Lian, Qingwang, Yongsheng Nie, Xiaoyou Zhang, Bo Tan, Hongying Cao, Wenling Chen, Weiming Gao, Jiayi Chen, Zhijian Liang, Huangling Lai, Siming Huang, Yifei Xu, Weiwen Jiang, and Ping Huang. "Effects of Grape Seed Proanthocyanidin on Alzheimer's Disease in Vitro and in Vivo." Experimental and Therapeutic Medicine 12.3 (2016): 1681-692.

[13] Sumiyoshi, Tomiki, Yuko Higuchi, and Takashi Uehara. "Neural Basis for the Ability of Atypical Antipsychotic Drugs to Improve Cognition in Schizophrenia." Frontiers in Behavioral Neuroscience 7.OCT (2013): 140.

[14] Mane, Ravikiran, Tushar Chouhan, and Cuntai Guan. "BCI for Stroke Rehabilitation: Motor and beyond." Journal of Neural Engineering 17.4 (2020): 41001.

[15] McFarland, Dennis J, Janis Daly, Chadwick Boulay, and Muhammad A Parvaz. "Therapeutic Applications of BCI Technologies." Brain Computer Interfaces (Abingdon, England) 4.1-2 (2017): 37-52.

[16] Arlotti, Mattia, Matteo Colombo, Anea Bonfanti, Tomasz Mandat, Michele Maria Lanotte, Elena Pirola, Linda Borellini, Paolo Rampini, Roberto Eleopra, Sara Rinaldo, Luigi Romito, Marcus L F Janssen, Alberto Priori, and Sara Marceglia. "A New Implantable Closed-Loop Clinical Neural Interface: First Application in Parkinson's Disease." Frontiers in Neuroscience 15 (2021): 763235.