Computerized Training for Neuroplasticity and Cognitive Improvement

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Abstract—The research area of brain plasticity studies indicates that individuals can train and improve their cognitive abilities throughout life. In addition, more and more computerized training tools are presented in recent studies. The purpose of this study is to review studies of the last decade in the field of cognitive training using Information and Communication Technologies, to record the cognitive improvement techniques used, as well as to evaluate the effectiveness of these intervention programs. As indicated by the literature review, computer-based tools, mobile training apps and video games could be used in intervention studies for cognitive improvement. In addition, cognitive training techniques seem to be significantly effective for the cognitive improvement of healthy or cognitive impaired individuals.

Keywords—Cognitive improvement, neuroplasticity, neurodevelopment, cognitive training

1 Introduction

Neuroimaging studies have shown that the human brain develops throughout life, especially from birth through adulthood [1]. High plasticity of the human brain indicates that perceptual-cognitive abilities are trainable [2]. Brain plasticity could be considered a memory function that affects the capacity of information processing and the ability to acquire skills [3,4].

Brain plasticity is the basis for the functional recovery on individuals after brain damage, as well as for the reduction of the effects caused by Parkinson's disease, aphasia, Alzheimer's disease, etc. [5, 6, 7, 8]. There is evidence that music making, as well as learning how to play a musical instrument could influence brain plasticity across the life span [9, 10]. In addition, recent studies show that physical activity and especially aerobic training, as well as resistance training, could promote cognitive brain plasticity in seniors [11, 12]. Pareja-Galeano et al (2013) emphasized the significant effect of exercise training on the increase of neuroplasticity-related proteins on healthy adolescents [13]. Furthermore, meditation-based training displays neuroplasticity in the attentional networks and is also considered an effective technique for the improvement of cognitive skills [14].

Most parents believe that television viewing could enhance cognitive development of their children. Studies show that this is not true for very young children. The study of Zimmerman & Christakis (2005) showed that television viewing before age 3 years could act negatively to the cognitive outcomes at the age of 6 and 7 years [15]. On the other hand, television viewing from 3 to 5 years old children, could enhance their reading recognition and short-term memory. In addition, a study with 1,008 parents of children under the age of 2 years in Washington and Minnesota, revealed that there is strong negative correlation between viewing baby videos and vocabulary acquisition [16]. According to Mar, Tackett & Moore (2010) exposure to children's movies is a reliable predictor of children's theory of mind (i.e. the ability of understanding mental stages of others). However, based on their study, the same could not be said for children's television shows [17]. Analyzing data from 678 New York families, Johnson, Cohen, Kasen & Brook (2007) showed that extensive television viewing (more than 3 hours per day) during adolescence, could increase the risk for attention and learning difficulties [18].

During the last decade, various digital cognitive training tools have been developed, incorporating traditional training techniques. The purpose of this study is to evaluate the effectiveness of the use of Information and Communication Technologies, such as computer-based intervention tools, mobile apps and video games, on intervention programs for cognitive improvement. In addition, this study aims to analyze the cognitive training techniques which are considered, based on the literature, as the most effective for cognitive improvement. For this reason, we analyze the most representative studies on this topic, published during the last decade.

2 State-of-the-Art

2.1 Computerized cognitive training

CALM Tools for Living is a set of web-based innovative tools, which use cognitive behavioral therapy (CBT) principles for anxiety disorders. Its eight modules are designed to enhance self-monitoring, fear hierarchy, breathing, cognitive restructuring, exposure to external cues, exposure to stimuli and relapse prevention. This computer assisted program was positively rated by clinicians and patients, as intervention resulted significant reduction in anxiety symptoms [19].

Mishra, Sagar, Joseph, Gazzaley & Merzenich (2016) applied online neuroplasticity-based cognitive training on children with Attention Deficit Hyperactivity Disorder (ADHD). Intervention, which was based on 25 online cognitive exercise modules, led to reduction of distractor-based errors for the participants, as well as to improvement of their scores on response inhibition and Stroop interference tests [20].

A study with thirty older adults revealed that non-action video games could enhance cognitive their skills. Specifically, results of the study showed that training for 20 one-hour sessions with ten cognitive-based video games from the online platform *Lumosity*, improved participants processing speed, sustained attention, immediate and

delayed visual memory and wellbeing dimensions. However, the training did not improve spatial working memory and executive control [21].

In a study with 42 older adults (mean age = 67.38 years), members of the experimental group participated in a digital inclusion workshop, containing training on the basics of computing and Internet browsing. Training on computers and Internet searching resulted significant improvement on participants' executive functions, as well as on their language and memory skills [22].

Ball, Edwards & Ross (2007) examined the impact of speed of processing training, which involves computer-based nonverbal exercises, on cognitive and everyday abilities of seniors [23]. Exercises that are included in the speed of processing training are based on target detection, identification, discrimination and localization in limited time. According to the results, this training protocol could improve speed of processing, as well as executive function and memory of adults from 55 to 95 years old.

Smith et al (2009) proposed a computer-based cognitive training program containing auditory information processing exercises for the improvement of untrained measures of memory and attention [24]. Discrimination, recognition, matching and reconstruction of auditory stimuli could lead to plastic changes in brain systems and thus result in improvement of memory and attention, as revealed by delayed recall, digits backwards and letter-number sequencing tasks.

Fisher, Holland, Merzenich & Vinogradov (2009) used a neuroplasticity-based, computerized auditory training program in order to enhance memory and cognitive skills of people with schizophrenia [25]. Results revealed significant improvement of participants' verbal working memory and global cognition.

Voelbel, Ceceli, Georgieva, Tortarolo & Lindsey (2014) evaluated the effect of computerized neuroplasticity-based training on adults with traumatic brain injury (TBI). According to the results, there was significant improvement of participants' processing speed and task switching ability [26].

In a study with 31 schizophrenia patients, Subramaniam et al (2012) evaluated the impact of intensive computerized training on patients' neural activity [27]. Patients who trained for 10 weeks with computerized auditory/verbal, visual and social processing exercises, showed significant improvement in reality monitoring, as well as an increase in medial prefrontal cortex (mPFC) activation.

2.2 Video games

The study of Clemenson and Stark (2015) indicated that playing complex 3D video games like Super Mario 3D World, improves hippocampal-associated memory [28]. On the other hand, training in a 2D game, Angry Birds, did not result in such improvement. Developmental psychologists, during the last years, claim that digital game play contributes to children's and adolescents' cognitive development [29]. A study with 48 participants (mean age 24.1 years) in Berlin, Germany, used *Super Mario 64*, a 3D platformer game for training, in order to measure plasticity effects on specific brain regions. Results of the study revealed significant increase of gray matter in the right hippocampal formation [30]. In addition, multitasking training with *NeuroRacer*, a 3D computer-based video game, had significantly positive effect on sus-

tained attention and working memory of older adults (mean age = 67.5 years) [31]. In addition, 54 older adults (mean age = 67.8 years) were trained with five cognitive online video games for seven weeks. Results showed that seniors playing video games can improve their inhibition and inductive reasoning [32]. Finally, the study of Li, Ngo, Nguyen & Levi (2011) revealed that playing action video-games, in which players should track fast moving objects, could result visual plasticity in adults with amblyopia, most known as "lazy eye" [33].

2.3 Mobile training apps

Mobile apps are considered as effective, low-cost tools for behavioral improvement [34]. Engaging mobile apps (interactive e-books, games, or creating apps) could enhance awareness and goal accomplishment in 4 to 6 years old children [35]. 3125 US citizens (mean age 32.4 years) participated in an online survey regarding their perceptions on brain training mobile apps. Participants claimed that cognitive training apps could improve their thinking, memory, attention, or even their mood [36].

Oiva, an Android mental wellness training app, designed using acceptance and commitment (ACT) principles, seems to improve users' mental wellness, reducing stress levels [37]. Two hundred twenty-seven eighth-grade students in Chile participated in an experimental study. Three mobile serious games were used for students' training: *Evolution*, a strategy game using 3D graphics and *BuinZoo* & *Museum*, which are trivia games. According to the results, playing mobile serious games benefits problem solving skills and especially plan execution capacities [38]. *HealtheBrain* is an innovative mobile application, compatible with iPhone and iPad (available on Apple Store), which is based on evidence that physical activity is correlated with cognitive improvement. In particular, *HealtheBrain* offers square-stepping exercise, a visuospatial working memory task which improves cognitive and executive functioning in older adults [39]. Chittaro & Sioni (2014) used three versions of a mobile app for breathing training, offering visual and auditory instructions for users, in order to adapt their breathing frequency [40]. During the procedure, researchers collected data about the skin conductance level, the heart rate, the power of frequency band, the respiratory signal to noise ratio, the perceived effectiveness, as well as the relaxation effectiveness. Wave-based visualization provided from the app offered the opportunity for participants to track over time their breathing training and thus enhance their relaxation and reduce their stress levels.

2.4 Neurofeedback training

Several studies reveal that neurofeedback training (NFT) has positive effect on individuals with behavioral or neurological disorders, such as attention deficit hyperactivity disorder (ADHD), Parkinson's disease, autism, etc. [41, 42, 43, 44]. Electroencephalogram (EEG) alpha activity seems to be highly related to memory performance. In the experiment of Nan et al (2012), consisting 32 participants (mean age = 23.28 years), neurofeedback training of the upper alpha frequency band, enhanced self-regulation of brain activity, as well as short-term memory performance [45]. In addi-

tion, the study of Wang and Hsieh (2013) revealed that frontal-midline theta (fmθ) training improves attention and working memory performance in the elderly [46]. In addition, the fmθ training protocol benefited orienting and executive control of the participants (mean age = 65 years).

Magnetic resonance imaging (MRI) studies have shown that NFT can lead to changes in white and gray matter [47]. Structural changes in white and gray matter volume, as well as functional reorganization after neurofeedback sessions are indicators of neural plasticity [48]. Furthermore, mental rotation tests have indicated that training with neurofeedback on the upper alpha frequency, could significantly improve cognitive performance [49].

3 Methodology

The present paper targets to answer the following research questions: –Can ICT-based training be used for cognitive improvement? –Which training techniques can be used for cognitive improvement? –Which technologies can be used for cognitive intervention? This review presents research studies from 2007 to 2018, which contain ICT-based cognitive training for cognitive improvement of the participants. In order to collect published studies from peer-reviewed journals, we searched on the following databases: Academic Search, ERIC, PubMED Central, PsycINFO, CiteSeerX, dblp and Scopus. Search terms used were: neuroplasticity, neuroplasticity training, cognitive improvement, mobile training app, computerized cognitive training, neurofeedback training. The following inclusion criteria were used in order to identify eligible studies:

- Study population consisted of healthy or cognitive impaired individuals
- Any type of computerized cognitive intervention
- Use of subjective outcome measures after the intervention. Furthermore, studies based on the same study population were excluded. After the final selection we extracted data from each study in terms of the purpose, the study population, the intervention design, the cognitive training, as well as the training outcomes.

4 Results

Figure 1 presents the studies selected for this review. Twenty-two studies were finally included. There were twenty experimental studies and two field studies. Of the selected studies, sixteen studies included a sample of healthy individuals and six studies included a sample of cognitive impaired individuals. The number of healthy participants in the experimental groups varied from 15 [37] to 242 [24], while the number of participants with cognitive impairment varied from 13 [19] to 31 [20]. The mean age of the participants ranged from 5 years [35] to 75.6 years [24]. Nine studies aimed at the improvement of working memory, while four studies aimed at the improvement of participants' attentional skills. In addition, four studies aimed at the reduction of anxiety symptoms, as well as of stress levels, while eight studies aimed

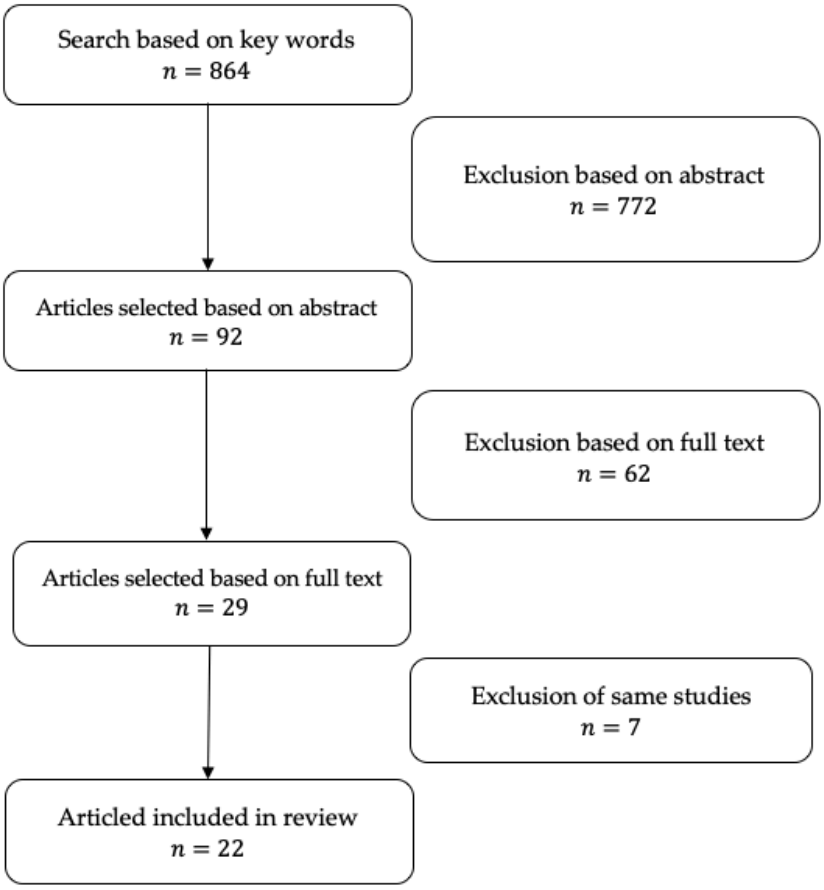

Fig. 1. Selection process for the review.

at the improvement of participants' metacognitive skills such as inhibition, task switching, executive function, inductive reasoning and self-regulation.

Results have shown that the techniques which could enhance cognitive improvement were cognitive behavioral therapy, speed of processing training, auditory training, eye tracking, acceptance and commitment, physical activity, breathing training, visualization and neurofeedback training. Intervention studies for cognitive improvement utilized computerized training tolls, commercial video games, serious games, training mobile apps, as well as neurofeedback equipment.

Table 1. Study characteristics of selected studies for cognitive improvement.

Study	Purpose	Sample	Intervention	Cognitive Training Protocol	Results
Ahtinen et al (2013)	Effect of mobile mental wellness training apps on stress management	15 working age participants	Mental wellness training mobile app (*Oiva*)	Acceptance and commitment	Improvement of mental wellness and reduction of stress levels
Anguera et al (2013)	Effects of video game training on cognitive control of older adults	46 older adults M = 67.5 years	3D Video game (*NeuroRacer*)	Multitasking training	Improvement of sustained attention and working memory
Ball, Edwards & Ross (2007)	Effect of speed processing training on cognitive and everyday functions	2,039 older adults M = 73.94 years	Computer-based non-verbal exercises	Speed of processing training	Improvement on executive function and memory
Ballestros et al (2014)	Effect of training older adults with cognitive-based video games	30 older adults M = 28.8 years	Web-based tools	Cognitive-based games	Improvement in processing speed, attention and visual memory
Chittaro & Sioni (2014)	Evaluation of mobile breathing training apps	68 adults M = 24.73 years	Adaptation of breathing frequency via mobile app	Breathing training	Reduction of stress levels and possible improvement of well-being
Clemenson and Stark (2015)	Effect of environmental enrichment via video games on memory	68 university students	Video games	Environmental enrichment	3D video games improved hippocampal-associated memory
Craske et al, 2009	Effect of web-assisted cognitive behavioral therapy on anxiety disorders	13 clinics with anxiety disorders 25 to 59 years	Web-based tools	Cognitive behavioral therapy	Reduction of anxiety symptoms
Fisher, Holland, Merzenich & Vinogradov (2009)	Effect of computerized cognitive training on patients with schizophrenia	29 adults with schizophrenia M = 42.86 years	Computer-based treatment	Auditory training	Improvement of verbal working memory and global cognition
Kühn, Gleich, Lorenz, Lindenberger & Gallinat (2014)	Effect of 3D video game training on structural brain plasticity	48 healthy adults M = 24.1 years	Commercial video game (*Super Mario*)	3D video game with orientation and strategic demands	Increase of gray matter on crucial brain regions
Li, Ngo, Nguyen & Levi (2011)	Effect of playing video-games on spatial vision of adults with amblyopia	20 adults with amblyopia M = 31.4 years	Playing action video games	Tracking fast moving objects	Plasticity in the visual system
Mishra,	Effect of online	31 children	Online cog-	Signal-to-	Improvement of

Sagar, Joseph, Gazzaley & Merzenich (2016)	cognitive training on cognitive measures of children with ADHD	with ADHD M = 12 years	nitive exercise modules	noise resolution training	response inhibition and executive function
Noorhidawati, Ghalebandi & Hajar (2015)	Effect of children's engagement with mobile apps on the learning process	18 children 4-6 years	e-storybooks, gaming and creating apps	Children's engagement	Enhancement of awareness and goal accomplishment
Ordonez, Yassuda & Cachioni (2011)	Digital inclusion of older adults	42 older adults M = 67.38 years	Computer training workshops	Digital inclusion classes	Improvement in language and memory domain
Sánchez & Olivares (2011)	Impact of mobile serious games on problem solving skills	227 8th grade students	Educational video games	Mobile serious games	Improvement of problem solving and plan execution skills
Smith et al (2009)	Efficacy of a brain plasticity–based computerized training program in older adults	242 older adults M = 75.6 years	Computerized training with auditory information processing	Brain plasticity	Improvement of memory and attention
Van Muijden, Band & Hommel (2012)	Effect of online cognitive training games on healthy older adults	54 older adults M = 67.8 years	Online cognitive training games	Brain training game intervention	Improvement of inhibition and inductive reasoning
Zimmerman & Christakis (2005)	Evaluation of the cognitive outcomes from television viewing	1,979 children & young adults	Television viewing		Television viewing had positive effect on 3 to 5 year-old children
Shellington, Felfeli, Shigematsu, Gill & Petrella (2017)	Effect of square-stepping exercise via mobile app on older adults cognitive function	19 older adults M = 68.3 years	Smartphone app (*HealtheBrain*)	Physical exercise	Improvement of executive functioning
Nan et al (2012)	Effect of neurofeedback training on short-term memory	32 students M = 23.28 years	Electroencephalogram (EEG)	Alpha neurofeedback training	Enhancement of self-regulation and short-term memory performance
Wang and Hsieh (2013)	Effect of neurofeedback training on older adults cognitive performance	32 older adults M = 65 years	Electroencephalogram (EEG)	fmθ uptraining	Improvement of attention and working memory
Voelbel, Ceceli, Georgieva, Tortarolo & Lindsey (2014)	Effect of computerized cognitive training on adults with traumatic brain injury (TBI)	20 adults with TBI M = 43.33 years	Structured computerized modules	Cognitive training	Improvement of processing speed and task switching

Subramaniam et al (2012)	Effect of computerized training on schizophrenia's neural activity	31 schizophrenia patients M = 40 years	Computerized training	Auditory/verbal, visual and social processing exercises	Improvement of reality monitoring and increase in mPFC activation

5 Discussion

This review aimed to evaluate the impact of computerized training on cognitive improvement of healthy or cognitive impaired individuals. Literature review of the decade indicated that Information and Communication Technologies, such as computer-based or web-based training tools, commercial or serious games, training mobile apps, as well as neurofeedback devices could be used for intervention programs including cognitive training [50]. In addition, there is evidence that cognitive training techniques such as cognitive behavioural therapy, speed of processing training and neurofeedback training, as well as traditional techniques as physical activity, breathing training and eye tracking could significantly enhance cognitive improvement both for healthy as for cognitive impaired individuals. Furthermore, neuroimaging studies provide evidence of brain plasticity from birth to late adulthood, indicating that cognitive skills are trainable throughout life [51]. However, most Information and Communication training tools are still at an experimental level, indicating that further research is required before the universal application of these tools for reliable cognitive improvement.

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