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EFECTOS DEL ENTRENAMIENTO CON VIDEOJUEGOS EN ATENCIÓN Y MEMORIA EN ADULTOS JÓVENES Y MAYORES. MEDIDAS CONDUCTUALES

VIDEO-GAME TRAINING EFFECTS ON ATTENTION AND MEMORY IN YOUNG AND OLDER ADULTS. BEHAVIORAL RESULTS

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ORGANIZATION

The present work seeks to investigate the cognitive benefits derived from non-action video games in young and older adults. The thesis is organized in seven Chapters.

Chapter 1 sets out the theoretical framework. It describes the general features of video games as neurocognitive stimulation programs, the methodological approaches to the field, and the principles of neuroplasticity and learning in relation to video-game training.

Chapter 2 describes the cognitive changes associated with normal and pathological aging and how video games could help to prevent cognitive decline during aging.

Chapter 3 reviews the main contributions of these training programs in young adults' cognition.

Chapter 4 presents the results of a clinical trial conducted with older adults to investigate the results derived from training a group of healthy older adults with non-action video games. Results were published in 2017 in the Journal *Frontiers in Aging Neuroscience*

Chapter 5 presents the results of a study conducted with two groups of young adults: an experimental group trained with non-action adaptive video games, and an active control group trained with simulation games. Results will be published in *Games for Health*. The manuscript has already been accepted.

Chapter 6 presents the main conclusions of the studies, the general conclusions, the limitations of the current thesis, and future directions.

Finally, Chapter 7 presents a summary of the Thesis in Spanish.

CHAPTER 1

VIDEO GAMES FOR COGNITIVE STIMULATION

1.1. Introduction

The number of publications related to the effects of video-game training has increased substantially in recent decades, from 15 papers per year during the 90s, to 350 papers in 2015 (Palaus, Marron, Viejo-Sobera, & Redolar-Ripoll, 2017). Many studies focused on the positive effects of video games: learning in educational contexts, neuromotor rehabilitation in clinical contexts, or the improvement of cognitive functions such as memory, attention and language with clinical, personal or professional purposes (Barnes & Prescott, 2018; Best, 2013; Neri et al., 2017).

These studies have been conducted at different developmental stages, from children to older adults (Belchior et al., 2013; Franceschini et al., 2013) and have led to the growth of commercial video games for cognitive stimulation (Simons et al., 2016). Moreover, these programs have many advantages over traditional cognitive stimulation programs, in terms of resources, space, time, qualified personnel and availability; they also improve motivation, concentration and positive emotions, facilitating adherence to the training intervention (Belchior, Marsiske, Sisco, Yam, & Mann, 2012; Brown, Johnson, Sohl, & Dumas, 2015; Burgers, Eden, Van Engelenburg, & Buningh, 2015; Eseryel, Law, Ifenthaler, Ge, & Miller, 2013; Fu, Su, & Yu, 2009; Johnson, Gardner, & Sweetser, 2016; Procci, Singer, Levy, & Bowers, 2012).

It is also important to mention that the possibility of playing video games using smartphones or tablets makes them cheaper and easier to use anywhere by people with reduced mobility or without previous computing experience (Joddrell & Astell, 2016). Moreover, brain games or mental games are adaptive, in other words, the game adapts the difficulty level and game duration to previous performance, which encourages learning without frustration (Gilleade & Dix, 2004). In addition to being user-friendly, enjoyable and adaptable, other aspects, such as players' preferences, are being studied by game developers to improve engagement and performance. Some studies have shown that preferences vary with age; older adults prefer casual games, like puzzles, that are intellectually demanding but easy to play, while young adults favor action and strategy games with a lot of variety (Chesham, Wyss, Müri, Mosimann, & Nef, 2017; Salmon et al., 2017).

Video games have many advantages, but their neurocognitive benefits are still subject to debate. Many cross-sectional studies have compared the perceptive-cognitive abilities of experienced action video-game players and non-players (Latham, Patston, & Tippett, 2013). These studies have found that experienced players are faster than non-players and perform better on tasks assessing visuo-spatial abilities, attention, working memory and executive functions (Cain, Landau, & Shimamura, 2012; Shawn Green & Bavelier, 2003; Mondéjar, Hervás, Johnson, Gutierrez, & Latorre, 2016; Trisolini, Petilli, & Daini, 2017). However, some studies have been unable to replicate these findings or obtain positive effects of playing video games (Irons, Remington, & McLean, 2011; Kable et al. 2017; Murphy & Spencer, 2009); many interventions have been developed under controlled conditions, using non-action video games like adaptive brain games, but the results are not conclusive either (Chiappe, Conger, Liao, Caldwell, & Vu, 2013; Hutchinson, Barrett, Nitka, & Raynes, 2016; Nelson & Strachan, 2009; van Muijden, Band & Hommel, 2012). There are many factors that could explain these contradictory results, including the training regime, the kind of video game used, the kind of control group, and the experimental task used to measure transfer of learning to cognitive functions. Therefore, some studies have highlighted the importance of finding the appropriate methodological approach to this field of study and have suggested some guidelines that we will discuss in the next section.

1.2. Methodological Approaches

Due to a lack of consensus in the literature about the neurocognitive benefits of video-game training (Lamb, Annetta, Firestone, & Etopio, 2018; Sala, Tatlidil, & Gobet, 2017; Stanmore, Stubbs, Vancampfort, de Bruin, & Firth, 2017), many studies have pointed out the importance of using an appropriate methodological approach (Shawn Green, Strobach, & Schubert, 2013; Dale & Shawn Green, 2017; García-Betances, Cabrera-Umpiérrez, & Arredondo, 2017; Schubert, Strobach, & Karbach, 2014; Seitz, 2018). Below, we describe briefly the most commonly used experimental designs, the relationship between the type of video game and training effects, the difficulty of assessing the transfer of learning, and further proposals put forward by the scientific community to prevent the misleading information that can be found in this field of study.

1.2.1. Types of studies

Many video-game studies report data arising from cross-sectional designs, where video-game players (users who play 5 hours per week or more) are compared with non-players (who play 1 hour or less per week) (i.e., Shawn Green & Bavelier, 2006; Kowal, Toth, Exton, & Campbell, 2018; McDermott et al., 2014; Murphy & Spencer, 2009; Trisolini et al., 2017). Results from these studies are mixed. One reason could be the difficulty of comparing groups without randomization, where differences between players and non-players on non-target variables could drive other results on the variables under research (Boot, Blakely, & Simons, 2011; Simons et al., 2016; Suresh, 2011). Thus, during the last decade, many researchers have conducted randomized controlled studies with participants with similar video-game experience. However, results remain inconclusive (e.g., Ballesteros et al., 2014; Nouchi et al., 2013; Kable et al., 2017); some studies have found moderate benefits of video-game training, while others have been unable to replicate those findings or find any positive effects. Thus, other elements should be considered to explain the reasons for these mixed results.

1.2.2. Types of video games used for cognitive stimulation

Many investigations use action video games because action and shooting games represent more than half of the genres that players generally prefer, although other genres are also growing in popularity: role playing (12.9%), sports (11.7%), adventure (7.8%), fighting (5.8%), strategy (4.3%), racing (3.3%), and others (4.1%) (The Entertainment Software Association, 2017). Each type of video game trains different cognitive processes (Dale & Shawn Green, 2017). Action video games (e.g., Call of Duty, Medal of Honor, or Gears of War) have specific features that make them different from other genres: they are usually fast, and they require higher perceptual and motor skills, which could produce different transfer effects; these factors should therefore be considered when designing intervention programs.

Bediou et al. (2018) conducted a meta-analysis to investigate the impact of action video games on eight cognitive domains (perception, bottom-up attention, top-down attention, spatial cognition, multi-tasking, inhibition, problem-solving and verbal cognition); they collected information from cross-sectional and interventional studies that included active control groups whose participants trained under the same conditions as the experimental group but with non-action video games. Six moderating variables were identified: cognitive domain (with 8 previously mentioned levels), age (with 2 levels: children and young adults), type of dependent variable (2 levels: reaction times and accuracy), type of effect (2 levels: main, difference), laboratory (2 levels: Bavelier, others) and recruitment (public or covert). The analysis showed a significant effect of video game training in both types of study, with a mean effect size in the habitual players and a moderate to medium effect in interventional studies. Specifically, a greater effect was perceived in perception (g = 0.62), spatial cognition (g = 0.75) and top-down attention (g = 0.62) in the cross-sectional studies; similar results were observed with greater gains in terms of spatial cognition and top-down attention in the intervention studies. These results are in line with those obtained from the meta-analyses conducted by Powers and Brooks (2014), Powers, Brooks, Aldrich, Palladino, and Alfieri (2013), and Wang et al. (2016), who found that different types of video games have differential effects on performance in tasks that evaluate cognitive functions, and that the effect size is usually greater when using action video games. However, Wang et al. (2017) observed that the cognitive benefits of action video games are lower for older than younger adults.

Young adults like non-action video games but prefer shooting and strategy games, while older adults prefer casual games that are non-violent, intellectually stimulating and easy to play (Blocker, Wright, & Boot, 2014; Nap, Kort, & IJsselsteijn, 2009; Salmon et al., 2017). Nowadays, more people play cognitive video games or brain games (e.g., CogniFit, Lumosity or IBM CityOne Game), which are non-action video games, also called serious or casual games, designed not only for entertainment but also for health and education. These games are specifically developed to improve learning, wellness and healthy living. There is a steady increase in the number of studies on this topic (McCallum & Boletsis, 2013). Non-action video games could share some features, so it is necessary to analyze how these relate to the cognitive benefits. To control for training effects, Laamarti, Eid, and El Saddik (2014) drew up a taxonomy in order to identify key elements of serious video games: the kind of activity, the sensorial modalities in which the information is presented (visual, auditory, haptic), the kind of interface (keyboard, mouse, joystick, or touchscreen), the environment (bidimensional, tridimensional or both), motion allowed, the social factor, and the field of application (education, health, culture, welfare, communication, etc.). All these elements should be examined, because they could explain why some studies find positive cognitive effects while others do not.

1.2.3. Transfer of learning

A long time ago, Thorndike introduced the concept of transfer effect (1906) and studied the generalization of learning between similar and different tasks, concluding that transfer is only possible when the tasks share many features. Subsequently, many studies have been conducted in this field, and two types of transfer of learning have been identified: near and far transfer (Barnett & Ceci, 2002; Boot & Kramer, 2014; Thorndike, 1906). Near transfer corresponds to Thorndike's observation, namely, the transfer of learning between identical or very similar tasks. Far transfer is the generalization of a trained skill to a function that does not share many elements with the first task. Cognitive stimulation programs such as video games are based on the assumption that they have far transfer effects, but this is currently a controversial issue as the results are not conclusive.

Olfers and Band (2018) conducted an interesting experiment to investigate near and far transfer effects on flexibility after brain training. They randomized 72 young adults into 3 brain-training groups: (1) a cognitive flexibility and task switching group, (2) an attention and working-memory group, and (3) an active control group that trained with math games. All the participants trained with brain games from Lumosity. Results revealed that not just the flexibility group (near transfer) but also de attention group (far transfer) performed an alternating-runs task- switch paradigm better than the active control group. Furthermore, the electrophysiological responses of participants in the experimental groups revealed larger N2 amplitude (related to response selection), and reduced Nc/CRN showing more efficient conflict monitoring (related to error detection). This experiment provides a clear example of near and far transfer effects arising from cognitive training. However, several publications have reported either only near transfer effects, or no transfer of learning at all (Li et al., 2008; Souders et al., 2017). For instance, Guye and von Bastian (2017) conducted a Bayesian linear mixed-effects analysis with the results of a computerized training program with older adults (aged 65 to 80 years). Participants were randomly assigned to an adaptive working-memory training intervention or to an adaptive visual search control group. Both groups improved significantly in the trained program from pre- to post-assessment, but there were no significant gains on working memory-related tasks (near transfer), inhibition, shifting, or fluid intelligence (far transfer tasks).

These two studies were conducted with different age groups, and it is possible that young players benefit more than older adults from training with computer games. For example, Karbach and Kray (2009) investigated task-switching transfer to similar and dissimilar executive tasks and fluid intelligence in three age groups (8-10; 18-26; 62-76 years). They found near and far transfer effects in all age groups but transfer of learning was modulated according to the age.

Some authors point out that training intervention studies should be designed in such a way that generality and specificity facilitate transfer effects (Schubert et al., 2014; Shipstead, Redick, & Engle, 2012). This has been widely achieved in the field of perceptual learning, where some authors have studied various factors, such as the variety of stimuli, optimization of stimulus presentation, multisensory facilitation, or consistent reinforcement, which could modulate the generalization of learning (Seitz, 2018).

Moreover, it is not always easy to assess far transfer effects. Some studies on aging have measured far transfer effects quantitatively with laboratory tasks simulating everyday activities; for example, Timed Instrumental activities of daily living, the Everyday Problem test, Cooking Breakfast, Virtual Week or Memory for Health Information (Tetlow & Edwards, 2017; McDaniel et al., 2014). However, as Boot and Kramer (2014) pointed out, “this is still a very active area of research”.

1.2.4. Placebo effects

Controlling for the placebo effect has long been a matter of debate in psychotherapy interventions and is particularly important in game training. As mentioned above, when designing a study to investigate video-game effects, it is essential to compare an experimental group with an active control group training under matching conditions to show whether the benefits of video games are a direct result of training. It is also very important to assess the participants’ expectations to analyze any possible placebo effect and avoid the possibility that positive or negative effects observed after training could be explained by factors other than the intervention. The only way to ensure identical expectations in the two groups is to measure expectations at baseline and, if possible, during the training intervention. Moreover, motivation, engagement and other factors should also be assessed in order to determine any placebo effects in these game studies (Boot & Simons, 2012; Boot, Simons, Stothart, & Stutts, 2013; C. Shawn Green et al., 2013; Simons et al., 2016).

1.2.5. The gold standard design

Ideally, studies on game training should be conducted using a model called "The gold standard design"; this is a double blinded study with randomization of participants and an appropriate active control group that matches the experimental group, where placebo effects depending on motivation, engagement and expectations are controlled, and which measures the transfer of learning from the intervention to the neurocognitive functions under study (Boot et al., 2011; Boot & Simons, 2012; Boot et al., 2013; Simons et al., 2016).

1.3. Neuroplasticity and Learning

Neurocognitive stimulation programs are based on the capacity of cognitive and behavioral systems to learn; that is, to improve performance as a consequence of a training program (Green & Bavelier, 2008). At a neural level, these changes are related to the ability of neural networks to reorganize as a result of stimulation. These modifications could occur at molecular, biochemical, synaptic, dendritic, axonal, morphological, or connectome levels (Keller & Just, 2016), and lead to the acquisition of new information, the development of new abilities, and adaptation to new environments. When we talk about brain games, cognitive stimulation programs, learning or neuroplasticity, we refer to ways that promote myriad changes, implying that the neurocognitive systems involved in these processes are not rigid, fixed, static or hermetic; on the contrary, they are flexible, open, and dynamic.

During most of the twentieth century it was believed that the mature mammalian central nervous system could not change, improve or develop, but around the seventies, research showed that the brain could be modified because of environmental changes or training (Taub, 2014). Consequently, the concept of neuroplasticity was introduced, and many studies have found evidence that brain cells can reorganize over the lifespan, not only in old age but also after brain injury (Nudo, 2013; Phillips, 2017). The scientific community recognizes some principles that characterize and describe the concept of neuroplasticity (Kolb & Muhammad, 2014; Merzenich, Van Vleet, & Nahum, 2014). We will briefly describe some of them:

1. Neural plasticity is found in all nervous systems, including the simplest species such as the roundworm (C. Elegans).

2. The primary plastic change concerns the strength of the connections in brain circuits (Hebb, 1949), and the development of a skill is associated with synaptogenesis and formation of connections; in the same way, these changes are reversible without practice of the skill.

3. Neural plasticity involves physical changes related to molecular and cellular variations in terms of dendrite ramifications, terminals, axons, metabolic alterations or myelin changes; it also involves chemical changes related to trophic factors, and release of excitatory, inhibitory or neuromodulatory neurotransmitters.

4. Motivation plays a key role in the development of neuroplastic changes.

5. Brain neuroplasticity continues throughout the lifespan, but how the changes are regulated depends on age. Moreover, regulation is the result of the release of neurotransmitters, which depends on the stimulation context.

6. Neuroplastic changes occur at every brain level but are controlled from the top cortical levels.

7. Neurocognitive or neurobehavioral training could modify inputs or actions by controlling neuronal responses, duration of stimulus, spatio-temporal complexity, etc.

These findings and technological advances have led to the development of a large number of neurocognitive stimulation programs. Brain game training has become a major industry (George & Whitehouse, 2011), and the relationship between brain plasticity and cognitive training with video games is thus an important field of study. Studies focusing on neuroplasticity and video-game training are conducted at two levels of neuroplasticity - structural and functional (Demarin & Béné, 2014).

At the structural level, some studies have reported changes associated with playing video games in cortical and subcortical regions. For example, Sagi et al. (2012) analyzed the timescale of structured remodeling in neuroplasticity in a short-term learning from video games. To do so, 46 young adults were divided into three groups: a learning group and two control groups (one active and one passive). The learning group performed a spatial learning and memory task based on a computer car race game (Electronic Arts). The total training period was about 90 minutes and each participant underwent a DTI (Diffusion Tensor Imaging, a marker of tissue microstructure) scan, before and immediately after the task. Participants in the experimental group showed a significant improvement in task performance and their lap times decreased significantly. Moreover, DTI analysis showed significant negative correlations between improvement rates in the car racing task and a decrease in mean diffusivity (a measure of tissue density) in the left hippocampus and right hippocampus, illustrating the structural aspects of neuroplasticity.

At a structural connectivity level, many studies have found gray matter changes after video-game training. For example, Kühn, Gleich, Lorenz, Lindenberger, and Gallinat (2014) found that participants in a video-game training group who played Super Mario 64 for two months showed significant gray matter improvement in the right hippocampal formation, the right dorsolateral prefrontal cortex and the bilateral cerebellum, in comparison with a passive control group. However, other researchers have found large-scale white matter changes related to playing action video games. For example, Gong et al. (2017) compared a group of young adults who were expert action video gamers and a group of amateurs. Working memory networks were assessed in terms of overall efficiency, mean clustering coefficient, local efficiency and local characteristics such as connections, nodal efficiency, nodal strength and nodal clustering coefficient. The results showed that, overall, the expert gamers had significantly enhanced working memory networks in the prefrontal area, the limbic system and the sensorimotor network, and significantly strengthened connections in these networks, which could be interpreted as more efficient coordination and communication between brain cortexes, and the influence of video-game experience on plasticity.

Only a few studies have assessed structural brain changes after video-game training in older adults, but some of them have found positive effects. For example, West et al. (2017) reported gray-matter improvement in the hippocampus and the cerebellum of adults aged between 55 and 75 years, following 3D-platform video-game training (Super Mario 64). The study compared three groups: an experimental group (game training), an active control group (computerized piano lessons) and a passive group. Gray matter changes in the hippocampus were only observed in the experimental group, although the active control group also showed neuroplasticity in the cerebellum and the dorsolateral prefrontal cortex.

In the same way, few studies have analyzed the effect of cognitive training in pathological aging, but some research has found game-related neuroplastic changes. Rosen, Sugiura, Kramer, Whitfield-Gabrieli, and Gabrieli (2011) conducted a randomized pilot study with participants aged over 70 years suffering from mild cognitive impairment. The experimental group trained with adaptive computer exercises or casual games developed by Posit Science Corporation that have been shown to improve processing speed and auditory processing, and the active control group carried out computer-based tasks (listening to audio books, reading online newspapers, and playing a visuospatial oriented game called “Myst”). The results showed significantly higher scores on verbal memory in the experimental group than in the active control group, and greater left anterior hippocampal activation in the experimental group, which correlated with behavioral data.

There are also functional changes associated with neuroplasticity that result from video-game training. For example, Wu et al. (2012) reported electrophysiological changes associated with playing first-person shooter (FPS) video games. Participants were divided into an experimental group that played the FPS game “Medal of Honor: Pacific Assault”, and an active control group that trained with a three-dimensional puzzle game (“Ballance"). The program was carried out over a 3-week period, with ten 1-hour training sessions. Spatial selective attention was measured with an attentional visual field task, and ERPs were also measured. The results revealed that the participants in the experimental group showed significant improvement in spatial attentional skills, and these changes were associated with modulation of the P2 and P3 waves, showing an enhancement of the top-down allocation of attentional resources and a suppression of distractors.

Nonetheless, further studies are needed to better understand brain plasticity and its relationships with video-game stimulation programs in young and older adults at different levels of analysis.

CHAPTER 2

VIDEO GAMES TO PREVENT COGNITIVE DECLINE IN OLDER ADULTS

According to the World Health Organization, global average life expectancy has increased by about 3 years per decade since 1950, but with a dramatic increase of 5 years between 2000 and 2015 in most regions (World Health Organization, 2015). However, normal aging is associated with sensorial and cognitive declines that limit personal autonomy (Çevirme, Ugurlu, & Misirli, 2016; Harada, Natelson Love, & Triebel, 2013; Monge & Madden, 2016; Murman, 2015). Thus, it is crucial to develop methods to understand this process and work to ensure a healthy and independent life with ageing.

2.1. Normal Neurocognitive Aging

Cognition could be defined as a multidimensional construct that covers mental functions such as language, attention, memory, executive functions, reasoning, spatial skills, etc. All these interconnected processes depend on the Central Nervous System to work correctly, and they change through the lifespan depending on the acquisition of new information, interaction with the environment, and learning. Some of these functions could be improved during the lifetime, others could be preserved, and other capabilities could be damaged or lost during aging. These changes do not occur uniformly in the population, but show considerable heterogeneity, with significant intra- and inter-individual variability. This explains why age-related neurocognitive changes show many differences depending on individual factors including life experiences and genetics. Nonetheless, anatomically and physiologically, the brain changes with age in the same way as other organs, affecting cognitive functions. Much of the research conducted on age-related neurocognitive changes focus on the negative aspects, the decline and loss of functionality that compromises daily life activities and independent living. However, it is important to mention that this decline is not only associated with pathological aging but also with normal aging.

The cognitive functions that usually decline with aging are memory, attentional and executive control functions, with speed of processing being significantly impaired in all these domains.

2.1.1. Memory

Atkinson and Shiffrin (1968) were the first researchers to establish a framework to understand memory function. Their model is still well accepted by the scientific community (Baddeley, 2012). Initially, memory was defined in relation to the length of time that information was stored in short-term and long-term memory. Later, Baddeley and Hitch (1974) carried out an in-depth study of short-term memory and established the concept of working memory, a system with three main components: the central executive, the phonological loop and the visuospatial sketchpad. The central executive controls the flow of information between the other two components, regulating the dynamic of the whole system. The phonological loop is defined as a store where verbal information is processed, while the visuospatial sketchpad processes visuospatial information. It is important to note that information usually remains in these two stores for a short period of time. This multi-store model of short-term memory or working memory is still valid, but some researchers have introduced a number of modifications, generating alternative models (e.g. Cowan's model, Jonides' model and computation models). We will describe these contributions briefly in the following paragraphs.

The first model introduced by Cowan postulates that working memory capacity depends on attentional focus, which has a limit of 3-5 items and works by activating Long Term Memory (Cowan, 2013). By contrast, theories focused on individual differences, mainly based on experimental and correlational studies, emphasize the factors underlying individual differences in processing time, such as strategy use, resistance to fatigue, flexibility and mental control (Engle and Kane, 2003). Thirdly, Jonides' model is a brain-mind paradigm based on neuroimaging data, which postulates that there is no neuronal architecture that can distinguish between short- and long-term memory (Jonides et al., 2008). Lastly, computational models, such as Barnard's (1985), Subsystems model or the model based on information processing developed by Oberauer (2009), try to generate computational predictive models and simulations to explain memory capabilities.

Squire (1987) referred to two kinds of long-term memory: declarative and procedural. The former refers to an active and voluntary process of information, whereas procedural memory refers to the abilities required to carry out certain actions. Declarative memory is further divided into episodic and semantic memory; episodic memory refers to the recall of facts and past experiences, and semantic memory is related to general knowledge about the world, facts, concepts and language. By contrast, procedural memory is an automatic process related to motor and cognitive skills, and includes implicit memory, and memory based on priming and classical conditioning, which involve no voluntary, intentional or conscious process of information retrieval.

Normal cognitive aging is generally characterized by a decline of working memory, episodic memory, information consolidation, formation of new memories and the use of strategies to improve memory and learning.

As mentioned above, working memory is defined as a multi-store system where verbal and visuospatial information is processed and stored for a short period of time. There are different ways to measure this function in experimental psychology and related scientific fields. The most commonly used tasks include memory span tasks with letters and digits, the N-*back* task and the Corsi Block Test. These tasks all involve presentation of a list of items in different modalities, for example, letters, numbers or pictures, and the participant must focus on them and recall as many as possible. Sometimes they have to pay attention to just one feature of the stimulus, such as the color (selective attention), or to several features, such as color and position (divided attention).

Using these approaches, many studies have shown a decline of working memory during aging. For example, Jenkins, Myerson, Joerding, and Hale (2000) conducted three experiments with one experimental group comprising 16 young adults aged between 18 and 24 years, and a second group composed of 16 older adults aged between 62 and 77 years. The tasks measured verbal and visuospatial processing, verbal and visuospatial working memory, and learning verbal and visuospatial paired associates. The results showed that older adults had greater difficulty acquiring new information and spent more time memorizing it. Moreover, the older adults recalled fewer items than the younger adults, and they had greater difficulty recalling visuospatial than verbal information.

Many other studies confirm these results, though there are some controversial issues related to the modality of the task. For example, some researchers (Klencklen, Banta Lavenex, Brandner, & Lavenex, 2017) compared the performance of two age groups (24 young adults and 24 older adults) on a working memory task with spatial and chromatic allocentric information, and they found that performance declined with age, with no difference according to the modality in which the information was presented. The authors suggested that the divergent results in other studies could be due to the experimental conditions; the task is frequently presented on a computer (spatial egocentric representations), while in their experiment, the information was presented in a real-world context (allocentric spatial representations).

It is also well known that episodic memory is negatively affected by aging, and that people often complain about memory lapses; for example, they cannot remember where they left their keys, names, or all the items in their shopping list. It is difficult to find a theory that explains the neurodegenerative mechanisms that account for these lapses or mistakes, but many studies have found evidence that frontotemporal damage is responsible for these memory deficits. The medial temporal lobe, which includes the hippocampus, the parahippocampal cortex, and the entorhinal and perirhinal cortexes, is known to be essential for long-term memory. An increasing number of studies have reported correlations between age-related atrophies, hippocampal volume changes and declining performance on cognitive mnesic tasks. For example, Nordin, Herlitz, Larsson, and Söderlund (2017) compared a group of younger adults (40 to 50 years) and a group of older adults (60 to 70 years). They used memory tasks and neuroimaging techniques (fMRI) and observed that the older participants obtained lower scores on the psychological tests. They also found hippocampal activation and volume decrease that could have various causes: neuronal loss, dendritic ramification alterations, atrophy, synaptic density changes, glial cell loss, myelin alterations, etc. Furthermore, hippocampal and frontal areas are interconnected, and several studies have reported frontal lobe alterations (hypo- or hyper-activation), which could be related to changes in the control of top-down information, responsible for the acquisition of new information, attention and recall.

2.1.2. Attention

Traditionally, attention, in other words, the capacity to focus on a stimulus and ignore irrelevant information, has been considered an independent component of memory. However, many studies have shown that there is a strong relationship between working memory and selective attention, and sometimes it is hard to separate the two processes because they overlap. Historically, working memory models center on the system's limited information capacity, its temporary nature and the continuous updating of information. By contrast, selective attention models emphasize the importance of stimulus codification to conduct a specific action in a complex multi-sensorial context. However, both functions are constantly interacting in different ways to process the information correctly from sensorial to post-perceptive phases. Moreover, these processes interact depending on the kind of information, activating various working memory subsystems and different attentional structures that allow not just the flow of information to the working memory system but also the maintenance of information in spatial working memory (Awh, Vogel, & Oh, 2006). A top-down model regulates all these functions, where inferior neural activation is controlled by superior neural activation in sensorial and motor cortexes. This regulation depends on the task to be performed, which implies that activation of the representation must either increase or be suppressed, depending on the relevance of the task. Moreover, fMRI studies investigating the cortical regions that modulate the top-down processing of information in working memory show prefrontal activation. This prefrontal activation seems to be related to information processing and filtering out distractors, indicating that the prefrontal cortex plays an important role not only in the selective attention process but also in codifying information in working memory. Any alteration in this area could therefore lead to disorders of memory and attention. According to some authors, age-related alterations in top-down modulation result in a deficit in the suppression of distractors in the early stages of visual information processing. Paneri and Gregoriou (2017) studied the fundamental role of the prefrontal cortex (PFC) in stimulus selection (voluntary attention), through visual areas. The PFC is interconnected with visual areas and could specialize and be subdivided depending on the nature of the stimulus attended to; for example, when we search for something, the attention to that specific object, modulate neural activity at visual areas.

It is also well known that PFC controls top-down processes such as attention and voluntary orienting, but the role of other cortical areas in the control of involuntary attention, and the interaction between voluntary and involuntary attention, are not thoroughly understood. The voluntary control of attention refers to the intentional change of attentional focus to achieve a goal, while the involuntary control of attention is not intentional, or goal directed but occurs spontaneously because of exogenous or endogenous factors, for example, in response to a loud sound or bright light. According to some researchers (e.g., Chica, Bartolomeo, & Lupiáñez, 2013; Meyer, Du, Parks, & Hopfinger, 2018; Monge, Greenwood, Parasuraman, & Strenziok, 2016), the voluntary control of attention depends on the dorsal prefrontal cortex, while involuntary control involves ventral, frontal and parietal networks. Some of these authors also suggest that voluntary control of attention is affected by ageing, unlike involuntary control.

Olk and Kingstone (2015) raised doubts about the methodological approach of these investigations, asserting that the assessment tasks used cannot measure voluntary and involuntary attention in isolated conditions but only in interaction. They conducted an experiment with older adults divided into three groups. Voluntary orienting of attention was assessed in the first group, involuntary orienting in the second, and a combination of voluntary and involuntary orienting of attention in the third. The authors observed that many previous studies investigating the effect of age on voluntary attention confounded voluntary and involuntary orienting. Their analysis demonstrated that the performance of older adults in a cueing task that isolated voluntary orienting was similar to that of young adults, indicating that older adults can use cues to direct their spatial attention strategically.

Moreover, there is a lack of consensus in the literature about the selective attention performance of young and older adults. Williams et al. (2016) investigated the factors underlying these discrepancies. To do so, they collected behavioral and electrophysiological data from 24 young adults (18 to 29 years old) and 24 older adults (60 to 76 years old). They used the Attention Network Test to assess alerting, orienting and executive control of attention and observed that older adults showed reduced alerting compared to younger adults, but there were no significant differences between groups on orienting or attentional control; however, the electrophysiological components related to alerting and orienting (P1, N1, CNV) were similar, but the attentional control components (N2, P3) differed significantly between young and older adults.

These behavioral and electrophysiological data are interesting, but further investigations are needed to gain a better understanding of how attentional systems and mensic systems interact and are affected by aging.

2.1.3. Executive functions

Executive functions refer to several abilities, including problem solving, planning, information organization and adaptation. They involve four main processes: inhibition or inhibitory control; interference control, which is also related to selective attention and cognitive inhibition; working memory; and cognitive or mental flexibility. Inhibitory control is defined as the control of attention, behavior, thoughts and emotions, and enables us to choose between different options and to proceed in the best way in a given situation, inhibiting some responses and activating others. Traditionally, inhibitory control is assessed using experimental tasks such as the Stroop Task, the Simon Task, the Flanker Task, and the Go-no-Go Task. We will now briefly explain some of them.

The Stroop Task consists of a color word that is written in either the same or a different color; for example, the word “green” appears on the screen in red, and the participants must ignore the meaning of the word (i.e. inhibit the meaning response) and pay attention to the color of the word, which can be difficult and increase errors and reaction times.

The Simon Task is based on two simple rules: two stimuli are presented, A and B. Participants are instructed to press the left key for A, and the right key for B. The stimulus is sometimes presented on the opposite side, which usually leads to a decrease in precision and longer reaction times. This is generally explained by a tendency to respond to the same side as the stimulus.

The Flanker Task requires selective attention to concentrate on a central stimulus while ignoring surrounding information; normally, participants take longer to respond when the direction of the surrounding stimuli differs from that of the central target, because it is harder for our attentional system to ignore and suppress a response to the most prominent stimulus.

Cognitive flexibility refers to the capacity to adapt to new situations, changing behavior, and reorganizing priorities according to the context; it is related to inhibitory control and interference control. Traditionally, this function is measured using verbal fluency, semantic and categorical verbal fluency tests, such as the Wisconsin Card Sorting Test and Switch Tasks.

To assess verbal, categorical and semantic fluency, participants may be asked to list all the uses of a table, write a list of words that start with a given letter, name a few countries, or give names of animals and foods alternately. Generally, answers change during the task; initially, participants give ordinary examples, such as a table is used for eating or writing, and more creative people, with greater cognitive flexibility, may then say that it can be used as a musical instrument or to dance on, etc.

The Wisconsin Card Sorting Test is used to assess executive functions, mainly mental flexibility and prefrontal cortex functions. The test cards can be classified according to color, shape and number. The objective is to deduce the right classification criterion using feedback from the experimenter. The rules usually change as a function of classification criteria deduction.

Most switching paradigms consist of two tasks; for example, participants must say whether a letter is a vowel or a consonant, an even or odd number, or say the color or shape of a stimulus or indicate its position (right or left, top or bottom). Frequently, these tasks consist of pressing a right or left key according to the goal (left could be used to indicate a consonant or an even number, and the right key for a vowel or an odd number). Usually, stimuli are bivalent; in other words, they have a feature that is relevant for both tasks and the answer that is right for one task is wrong for the other; for example, if we take the stimulus “A2”, the right answer for the letter task is to press the right key since A is a vowel, but for the number task, the right answer is to press the left key because 2 is an even number.

According to some authors (Williams, Ponesse, Schachar, Logan, & Tannock, 1999), inhibition or mental control processes could be described as an inverted U across the lifespan, showing a decline during aging.

Some studies show that inhibitory control could be subdivided into two inhibition types: reactive and proactive (Braver, 2012; Kleerekooper et al., 2016). Reactive inhibition refers to the inhibition of an impulsive motor response when a stop signal appears; by contrast, proactive inhibition occurs when the probability of a stop signal increases, and anticipation is thus required, which depends on the frontal-striatal system. Many of the studies conducted with older adults in this field of study have focused mainly on reactive inhibition, with mixed results. Kleerekooper et al. (2016) conducted a study with 73 participants aged 30 to 70 years, using a stop-signal task in order to differentiate between reactive and proactive inhibition. The results showed that reactive inhibition precision was not affected by age, but reaction times were longer, indicating an effect of age in the reactive inhibition aspect of cognitive processing. However, proactive inhibition precision and processing of information were not affected by age. These studies also included functional neuroimaging, and they showed that although processing speed decreased on reactive inhibition tasks, motor activation increased; moreover, structural and functional data revealed higher activation at the right inferior frontal gyrus of older adults carrying out proactive inhibition tasks, although no behavioral changes were observed. This could be explained as a general hyperactivation and a lack of flexible regulation of brain activation according to task demands.

These data support the neural compensation hypothesis, which postulates that mental processing declines with age but is compensated by general brain activation. The results of the previous study separate reactive and proactive inhibition for the first time and demonstrate that the brain activation increase, normally observed in these kinds of study, is likely to be the result of neural compensation associated with reduced cognitive flexibility related to proactive inhibition lack of strategies. Furthermore, some studies have found that hyperactivation involves some structural changes related to gray matter atrophy (Di, Rypma, & Biswal, 2014; Van Petten et al., 2004).

2.2. Video Games and Normal Neurocognitive Aging

Neurocognitive decline associated with normal aging mainly affects memory (working memory, episodic memory, information retrieval and consolidation), executive functions (decision making, problem solving and mental control), attentional networks (selective and divided attention and visuospatial abilities) and reaction times. Thus, it is a priority to investigate the effects of cognitive stimulation programs and optimize them. Among these programs, video games offer many advantages because they are enjoyable, adaptive and engaging for aging people. Considerable research is being conducted to elucidate the features of video games that help to slow down cognitive decline and the best methodological approach to successfully obtain those data. Some studies show benefits derived from video game training in different domains.

Toril, Reales and Ballesteros (2014) conducted a meta-analysis of 20 experimental studies and found that older adults experience positive effects after video-game training in many cognitive functions (memory, attention, global cognition and reaction times), with a mean effect size of 0.37, 95% IC [0.26, 0.48]; moderators included the type of video game, the training duration, the number of games used for the training, the kind of training, the kind of control group, and participants’ age. The authors hypothesized that training duration directly affected the results, with longer training regimes producing greater benefits; however, the results also showed that training was more efficient when conducted in short-term periods (1 to 6 weeks), maybe because this increased adherence to the program. Likewise, they hypothesized that training effects would be higher in younger old adults (60 to 70 years); however, older old adults (71 to 80 years) derived the greatest benefits from video games. The authors also believed that complex games would have better cognitive effects because they require the use of many cognitive and perceptive resources; however, they found no significant differences on execution related to the degree of game complexity. The meta-analysis revealed benefits on memory, attention, global cognition and reaction times, but no gains on executive functions (d = 0.16, 95 % [-0.10, 0.42]).

Similarly, a systematic review by Kueider, Parisi, Gross, and Rebok (2012) showed mixed effects of video-game training on executive functions. They reported significant improvements in executive function on several assessment tasks (Symbol Digit Modalities Test and Trail Making Test). However, they did not find positive results when using the classic Stroop Test. The review included 6 studies of executive function training using video games, but the effect size was between 0.11 and 0.42, with a mean of 0.25. Thus, there were some gains in executive functions, but less than the positive effects observed on reaction times and processing speed. The authors suggested that the inconsistent results of the executive functions training could be explained by the experimental tasks traditionally used to assess this psychological construct, or by the fact that video games are not appropriate for improving those skills in older adults.

Other interventions have shown positive effects of game training on executive functions. For example, Basak, Boot, Voss, and Kramer (2008) conducted an experiment with 40 participants, with a mean age of 69 years, divided into an experimental group playing strategy games (The Rise of Nations) and a passive control group. The training program lasted 7 to 8 weeks, and the assessment battery included 10 tasks: 6 executive function tests (Operation Span, Task Switching, N-Back Test, VSTM and Raven's Advanced Progressive Matrices and Stopping Tasks), and 4 visuo-spatial tasks (Functional Field of View, Attentional Blink, Enumeration and Mental Rotation). The results showed that the executive control of the experimental group improved significantly after training.

Nouchi et al. (2012) randomized 32 old adults with a mean age of 68 years into an experimental group playing brain games (Brain Age, de Nintendo DSi) and an active control group playing puzzle games (Tetris, developed by Nintendo). Training was conducted in the participants' home for 4 weeks, 5 days per week, around 15 min per day, and evaluation included tasks to assess 4 categories of cognitive functions: global cognition, executive function, attention and speed of processing. Here again, an increase in executive functions was observed using the Frontal Assessment Battery (FAB) and the Trail Making Test (TMT-B). FAB is frequently used to assess executive functions and consists of 6 subtests: similarities (conceptualization), phonological fluency (mental flexibility), motor series, conflicting instructions (sensitivity to interference), Go-No-Go (inhibitory control), and Prehension behavior (environmental autonomy). In the TMT-B, participants are asked to link visually presented digits, following an order criterion, and to alternate digits and letters (e.g. 1-A-2-B, etc). The mean outcome is time (in seconds) taken to complete the task. MANCOVAs showed a significantly higher transfer of learning in the brain game group for every executive function. Nonetheless, more experimental studies and meta-analyses are needed to gain further information about the specific features of video games underlying the beneficial executive effects in older adults.

Attentional, memory and speed processing gains derived from video-game training in aging have not been extensively studied at different levels of analysis, but some authors have found gains with very short training regimes. For example, Stroud and Whitbourne (2015) compared younger and older adults after playing a casual game (Bejeweletz Blitz) for 30 minutes and found attentional benefits in simple visual search (spatial distribution of attention) and speed of processing. Belchior et al. (2012) also investigated attention (useful field of view performance), randomizing older adults into three groups: one playing an action game, one playing an arcade game, and a passive control group; they found that both intervention groups improved significantly more than the passive control group in the three domains (selective attention, divided attention and processing speed). Moreover, they did not find any differences in the cognitive benefits derived from these two types of games. These results were also confirmed recently in another study conducted by Belchior et al. (2018) comparing older adults playing a cognitive game and a group playing non-mental games; they also reported positive effects on visual attention and processing speed that were maintained at the end of a three-month follow-up period in the cognitive group and emerged after the follow-up period in the non-mental game training at a higher degree. Meanwhile, we recently published the results of a video-game intervention study (Ballesteros et al., 2017b) conducted to assess selective attention and distraction using a Crossmodal Oddball Task and comparing an experimental group that played brain games and an active control group that played simulation games (participants aged over 55 years). The results showed small benefits derived from both types of video games and a moderate positive effect on distraction, which was significantly higher in the simulation-game group. Further interventional studies should be conducted to understand better which specific attentional networks benefit most as a result of video-game training in aging.

Similarly, studies about memory benefits in older adults are not conclusive. Several meta-analyses and reviews have shown moderate positive effects on non-verbal memory, verbal memory and working memory (Lampit, Hallock, & Valenzuela, 2014; Toril et al., 2014). Ballesteros et al. (2014) found significant improvements on visual recognition memory (immediate and delayed recall of family pictures measured with the Memory Wechsler Scale WMS-III (1999)) when comparing older adults trained with brain games and an active control group that attended several meetings with the research team, but the gains had vanished at the 3-month follow-up.

By contrast, Miller et al. (2013) compared aging participants trained with a computerized cognitive program and a passive group; they found delayed memory improvements (Delayed Buschke-Fuld, Delayed Rey-Psterrieth and Delayed Recall VPA II) but no immediate memory benefits (Total Buschke-Fuld, Copy Rey-Osterrieth, and Total Learning VPA I) after a two-month intervention (5 days a week, 20-25 min per day), but a second analysis examining dose-dependent relationships showed that participants who played more than 40 sessions over a period of 6 months improved both memory types (immediate and delayed recall). However, these results are not congruent with the previously mentioned meta-analysis by Toril et al. (2014), where older adults seemed to benefit more from short training regimes (1 to 6 weeks) than longer ones.

Simpson, Camfield, Pipingas, Macpherson, and Stough (2012) compared a group of participants aged 53 to 75 years playing computer-based brain games and an active control group playing Solitaire (an online card game) for 21 days (20 min per day, 5 days a week). They observed no improvement in the short-term memory for words, visual spatial acuity or N-back working memory of the experimental group at post-test or 3-month follow-up, but they did find significant improvements in simple reaction time and choice reaction time. By contrast, Mahncke et al. (2006) found global auditory working memory improvements after training that were maintained at 3-month follow-up. They used six tests of the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) in an experimental group that trained with an adaptive cognitive computer-based program. Nonetheless, their performance was compared with that of an active control group who listened to educational lectures on DVDs and a passive control group.

Toril, Reales, Mayas, and Ballesteros (2016) found that older adults trained with brain games made significant improvements in visuospatial working memory (assessed with the Corsi Block Task and the Jigsaw Puzzle Task), immediate and delayed episodic memory (measured with Faces and Family Pictures) and short-term memory (assessed with the Digit Span Test). In that study, the cognitive benefits were maintained at three-month follow-up. But, the experimental group was compared with a no-contact group. New research has recently been published (Ballesteros et al., 2017b) comparing an experimental group trained with brain games and an active control group playing simulation games. The results showed that both groups improved significantly in spatial working memory (assessed with the Corsi Block Test) at post-test, and the experimental group also showed marginal training effects in verbal working memory (measured with the N-Back Task).

Further investigations are needed to replicate previous positive effects and to understand better the mnesic elements that could be enhanced by video-game training and the neural bases underlying these changes.

2.3. Pathological Neurocognitive Aging

Neurocognitive deficits associated with normal aging usually occur in pathological aging, with differences in degree, intensity, frequency and temporal distribution (de Flores, La Joie, & Chételat, 2015; Hullinger & Puglielli, 2017; Tarantini, Tran, Gordon, Ungvari, & Csiszar, 2017; Tromp, Dufour, Lithfous, Pebayle, & Després, 2015; Wilmott, Neuner, Burger, & Kaczorowski, 2017). Around 47 million people worldwide suffered from dementia in 2015, and it is estimated that 8 million people develop dementia every year. The cost for governments and citizens by 2030 is likely to be around US$1.2 trillion (WHO, 2015). It is therefore essential to study normal and pathological aging, the mechanisms that these processes share, and the stimulation programs that could help to avoid or attenuate them.

While neurocognitive changes associated with normal aging can affect some complex functional abilities, they do not impair daily life activities. However, cognitive deficits that affect memory, language or thought and compromise autonomy can be considered as mild cognitive impairment, which is an early stage of dementia. In this stage, patients frequently ask their doctors for information, but as neurocognitive and behavioral symptoms intensify, the effects on their lives can be dramatic.

Dementias can be classified according to the brain areas affected and the symptoms observed (Alzheimer’s Disease, Frontal Dementia, Dementia with Lewy Bodies, etc); Alzheimer´s Disease (AD) is the one that affects the greatest number of people. Its characteristic features are amyloid plaques, neurofibrillary tangles, a diffuse loss of neurons and synapses in the hippocampus. These changes mainly affect the cortex and areas responsible for memory and learning. Amyloid, neuronal and neurogenesis defects can be seen during normal aging, but the degree of amyloid formation is lower, and it normally happens at the brain parenchyma. Beta-amyloid proteins form aggregates that surround dendrites, dystrophic axons, microglia and reactive astrocytes that constitute the amyloid plaques; and neurofibrillary tangles grow in the neurons' cytoplasm and consist of polymers of TAU protein. These proteins are linked to intracellular microtubules, and after hyperphosphorylation they separate from microtubules, polymerize and configure insoluble conglomerates.

Important cognitive functions that are compromised during normal aging are also affected by pathological aging: memory, attention, executive functions and speed of processing. The main cognitive function that is affected is memory, leading to significant difficulties for people with dementia. But not all mnesic systems are affected in the same way; working memory and episodic memory are normally compromised, while non-declarative memory, especially procedural memory, does not change with age or because of neurodegenerative disease. However, there is a fundamental difference between normal and pathological memory decline. In normal aging, deficits are mainly the result of prefrontal cortex changes, followed by damage to the temporal and parietal lobes, hippocampal and parahippocampal regions, the cingulate gyrus and the cerebellum. By contrast, in dementias, particularly AD, cognitive decline is mainly the result of damage to the temporal and entorhinal cortexes, extending to the frontal areas, affecting attentional and executive networks and leading to severe cognitive function impairments.

2.4. Video Games and Pathological Neurocognitive Aging

To date, there have been few studies and little evidence of the benefits of brain-game training to people with AD or other dementias, but there is growing interest in this field of study. Robert et al. (2014) developed a systematic analysis focusing on four factors related to the development of this type of training with a preventive or therapeutic purpose: weak aspects, strong aspects, opportunities and challenges. They found that serious games specifically designed for people with dementia increase motivation, positive emotions and mood, improve the autonomous practice of the gamers, and enhance social relationships. Other advantages of these environments include the fact that they are not dangerous or risky, they are easy to use under experimental conditions because ecological validity is easier to control than with other programs, it is possible to control feedback to enhance learning, and they are cheap and easy to play without previous experience.

Dementia, as described above, is mainly characterized by memory loss, but other functions can also be impaired, such as communication, attention, orientation, and daily life activities; in advanced stages, some personality changes can also appear, as well as anxiety, compulsive behaviors or depression.

Several reviews and meta-analyses (Ge, Zhu, Wu, & McConnell, 2018; Klimova & Maresova, 2017; McCallum & Boletsis, 2013; Mewborn, Lindbergh, & Stephen Miller, 2017; Reijnders, van Heugten, & van Boxtel, 2013; Teixeira et al., 2012) have found cognitive benefits resulting from cognitive video games and computer-based training in people with mild cognitive impairment (MCI) and dementia. The cognitive functions that gain most from these programs are working memory, attention, speed of processing, executive functions and fluid intelligence. Moreover, some studies found behavioral and affective benefits derived from these kinds of intervention; however, they highlight the need to improve the quality of research. Most studies use randomized controlled trials, but there are many methodological inconsistences related to the factors presented in Chapter One. Furthermore, a systematic review by Bahar-Fuchs, Clare, and Woods (2013) found no positive effects of computerized cognitive training or cognitive games in patients with mild Alzheimer's disease or vascular dementia. Most of the positive effects on memory have been observed in randomized controlled clinical trials conducted with patients with MCI, mild dementia or early Alzheimer's Disease (AD) (Barnes et al., 2009; Gooding et al., 2016; Rosen et al., 2011; Talassi et al., 2007).

Only a few studies have focused on the memory gains derived from cognitive computerized and brain-game training interventions in people suffering amnestic mild cognitive impairment (Savulich et al., 2017), observing not only pre-post training benefits but also maintenance of memory gains at 3-month follow-up (Vermeij, Claassen, Dautzenberg, & Kessels, 2016).

Furthermore, few studies have investigated the neural basis of cognitive games training in pathological populations. Rosen et al. (2011) found improvements in verbal memory and a significant increase in activation in the left hippocampus of people with MCI participating in a cognitive game program (Posit Science) compared to an active control group. However, few studies have assessed the effects of brain games on people with dementia. Cipriani, Bianchetti, and Trabucchi (2006) compared people with MCI, AD and multiple system atrophy (MSA) using Computer-based Neuropsychological Training (NPT); they found that the AD group showed improvement not only in MMSE scores but also in verbal production and executive functions, while the MCI showed enhanced behavioral memory, assessed with the Rivermead Behavioral Memory Test (RBMT, Wilson et al., 1985).

Fernández-Calvo, Rodríguez-Pérez, Contador, Rubio-Santorum, and Ramos (2011) observed that a brain training program, the Big Brain Academy (BBA; Nintendo), had greater positive cognitive and emotional effects on patients with AD than a traditional computer-based program (Integrated Psychostimulation Program, PPI). They recruited 45 participants with AD and divided them into 3 groups: BBA, PPI and passive control. Results showed that brain games were more efficient than traditional stimulation programs in reducing not only cognitive decline but also depressive symptoms in AD patients. The authors identified two factors underlying these results: first, the recreative elements of video games, and second, the systematic reinforcements that enhanced motivation, improved performance and benefited emotions and mood.

Far-transfer effects of video-game training needs to be assessed to gain a better understanding of the learning associated with functional activities derived from cognitive training and that can improve the daily life of people with dementia. Hagovská, Dzvoník, and Olekszyová (2017) compared an experimental group that trained with CogniPlus and an active control group following a traditional group-based cognitive training program. They evaluated functional activity (using the Functional Activity Questionnaire, FAQ), cognitive abilities (Addenbrooke's Cognitive Examination, which includes measures of attention, memory, verbal fluency, language and visuospatial abilities, and the Stroop Test), and quality of life (using the Quality of Life Questionnaire, QOL). Results showed better attention and improved quality of life in the group trained with cognitive games, but no transfer of learning to daily functioning. However, Stavros, Fotini, and Magda (2010) investigated several cognitive domains and daily functioning in people with MCI and found that the experimental group benefited more from brain training in terms of attention, verbal fluency, verbal memory, visual memory and learning, than a waiting-list control group. And they also observed within-group improvements in daily functions.

In conclusion, further research is needed to understand better the mechanisms underlying the success of video-game training in pathological aging.

CHAPTER 3

VIDEO GAMES TO OPTIMIZE COGNITIVE PERFORMANCE IN YOUNG ADULTS

Traditionally, research focusing on neurocognitive gains derived from video game training has compared young adults who regularly play video games, mainly action games, and those who do not play regularly. Reports by the video-game industry indicate that the majority of habitual players (more than 150 million Americans are regular players) are in the age range corresponding to university studies, although this is currently diversifying (among women who play video games, 11% are under 18, 10% are aged between 18 and 35, 8% between 36 and 49, and 13% are over 50 years of age; for male players, the figures are: 18% under 18, 17% between 18 and 35, 10% between 36 and 49, and 13% over 50) (The Entertainment Software Association, 2017)).

The neurocognitive functions that benefit most from action video games in young adults are executive functions (decision making, problem solving, risk taking, and switching), attentional functions (multi-tasking, attentional control, visuospatial skills, selective and sustained attention), memory (short-term memory and working memory), and processing speed (Blacker & Curby, 2013; Dye, Green, & Bavelier, 2009; Mishra, Zinni, Bavelier, & Hillyard, 2011).

Many studies have shown positive effects on executive functions derived from video-game play in young adults (Buelow, Okdie, & Cooper, 2015; Cain et al., 2012; Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010; Hutchinson et al., 2016; Mondéjar, et al., 2016; Hazarika, Kant, Dasgupta, & Laskar, 2018; Parong et al., 2017). Some of these are cross-sectional studies that compare gamers and non-gamers, and they usually choose people who play action video games. For example, Colzato et al. (2010) compared first person shooter gamers with non-gamers on a switching task and observed smaller switch costs and greater flexibility in gamers than in non-gamers. Similarly, Cain et al. (2012) also compared the performance of first-person shooters or action video gamers (AVGPs) and non-gamers (nAVGPs) on a Flanker Task, to analyze switch tasking and distractor filtering; they also found lower switch costs in the group of gamers, but no significant differences in filtering out irrelevant flanking information.

Switching abilities depend on selective attention and executive control, among other factors. Executive control is responsible for supervising the choice, beginning, execution and ending of single or multiple tasks, and comprises multiple separable subcomponents that enable task switching (Rubinstein, Meyer, & Evans, 2001). However, some authors consider that the switching abilities observed in gamers are not the result of more efficient cognitive control but of higher attentional skills.

Karle, Watter, and Shedden (2010) conducted two experiments comparing young action video game players (AVGPs) and non-action video game players (nAVGPa) to assess the aspects of task switching and cognitive control that may help to differentiate between players and non-players. The first experiment consisted of a task-switching situation with no stimulus or response overlap and a direct univalent 1-to-1 mapping of each individual stimulus to a separate response. The second experiment was a switching task with more overlap, and two alternative responses were mapped in each of three different tasks, requiring greater cognitive control to deal with trial-to-trial proactive interference. Results showed that AVGPs were faster using informative cues and long cue-to-target intervals, which the authors interpreted as showing that game-playing benefits the ability of controlling selective attention; however, AVGPs did not perform better that nAVPGs in the second experiment. This suggests that gamers do not perform better than non-gamers under proactive interference conditions, and that gaming benefits selective attention allocation but not cognitive control. This result is in line with the findings of Cain et al. (2012) discussed above, who did not find any benefit for AVGPs on distractor filtering using a Flanker task with long intertrial intervals (ITIs), strong stimuli and response overlap and with no pre-stimulus cues.

According to Parmentier and Hebrero (2013), distraction by deviant sounds is reduced by cognitive control and not by sharing of attentional resources. They used an auditory oddball task with two conditions: an unpredictable condition (the deviant sound was non-cued), and a predictable condition (a color cue predicted the upcoming sound: standard or deviant) with different ITIs to analyze whether distraction could be reduced or suppressed through voluntary cognitive control (cued condition). The results showed that distraction was eliminated by presentation of a cue, irrespective of the interval between the appearance of the cue and the auditory target (250 ms or 2500 ms), ruling out the possibility of competition for attentional resources with longer intervals. The authors concluded that distraction can be eliminated by cognitive control.

Strobach et al. (2012) conducted a study using two types of experimental paradigm, dual task and task-switching, to measure executive control in young video game players; they found that gamers performed better than non-gamers under conditions with two tasks processed simultaneously or sequentially. In a second experiment (an interventional study), they compared a group playing action video games and a group playing puzzle games for 15 hours, and a passive control group. The results showed gains derived from playing video games on executive control.

Physiological studies show that video game experience has no positive effects on cognitive control but has a negative effect on proactive cognitive control and no influence on reactive cognitive control (Bailey, West, & Anderson, 2010). The Dual Mechanism of Cognitive Control Theory posits that individuals use proactive or reactive cognitive control depending on the environmental requirements. Proactive control refers to the ability to prepare the processing information system to respond before the onset of a critical stimulus, while reactive control occurs when the stimulus is already present (Braver, 2012). According to previous studies, proactive and reactive cognitive control are related to the anterior cingulate, lateral prefrontal cortex and anterior prefrontal cortex (West, 2003). Bailey et al. (2010) developed an experiment comparing high-frequency gamers (M = 43.4 hours per week) and low-frequency gamers (M = 1.76 hours per week) on a Stroop Task and event-related brain potential recordings (ERPs). They measured the Conflict Adaptation Effect, a behavioral index of proactive control that represents the differences in reaction times for an incongruent trial preceded by either a congruent or an incongruent trial. Frequently, the response time for incongruent-incongruent trials is faster than for congruent-incongruent trials. This effect seems to be regulated by top-down control. The authors also measured the Stroop Interference Effect to assess reactive cognitive control. From an electrophysiological point of view, they recorded medial frontal negativity (MFN) as an index of proactive control, and the conflict slow potential (SP) was used as an index of reactive cognitive control. Results suggested that video game experience was not related to reactive control, but it was negatively related to proactive cognitive control. The Conflict Adaptation Effect, MFN, and frontal slow wave were attenuated in high gamers, which the authors interpreted as a decrease in the ability of high gamers to maintain goal-directed action when the environment is not intrinsically engaging.

Howard, Johnson, and Pascual-Leone (2014) performed a confirmatory factor analysis of four types of inhibition model and highlighted the importance of differentiating between effortful and automatic inhibition. The former is traditionally studied with tasks such as the Stroop Task, and the latter with tasks based on resistance to interference by distractors (e.g. Flanker Task). The authors demonstrated that attentional systems are fundamental to explain inhibition, but they are insufficient to account for the complex inhibitory system.

In a recent investigation, Hazariza et al. (2018) studied inhibitory control abilities in AVGPs with the Bivalent Shape Task (BST), an attentional inhibition task, and they found that video gamers could voluntary enhance the neural control mechanism of interference suppression as a form of cognitive control. Moreover, the study reported that gamers could effectively modulate alpha, beta and gamma frequency ranges on EEG, showing superior attentional and inhibitory abilities than non-gamers.

Many studies have reported physiological and behavioral attentional gains derived from video-game training in terms of sustained attention (Trisolini et al., 2017), attentional allocation (Chisholm & Kingstone, 2015; Dye, Green, & Bavelier, 2009), temporal attention (Murphy & Spencer, 2009), visual attention (Green & Bavelier, 2003; Mishra et al., 2011), and selective attention (Bavelier, Achtman, Mani, & Föcker, 2012). However, the attentional demands required by each cognitive control mechanism (proactive or reactive control) are not clear, and further research is also needed to clarify other executive subcomponents such as inhibition, shifting and working memory.

Nouchi et al. (2013) conducted an interventional study in which young adults played mental games or puzzle games. The assessment included a broad range of cognitive functions, and the results showed significant near transfer of learning on executive functions, processing speed and working memory in the brain-training group.

Memory gains from video games have also been observed in cross-sectional studies with action video gamers (Blacker & Curby, 2013; Clemenson & Stark, 2015; McDermott et al., 2014; Moisala et al., 2017), and there is evidence of short-term visual memory benefits among regular players, but little evidence of long-term memory benefits. McDermott et al. (2014) compared AVGPs and nAVGPs, using four different tasks to better understand the aspects of memory that benefit from action video games:

the Posner Letter Identity Task to measure the time required to access long-term memory, the Proactive Interference Task (PI), the N-Back Task to assess working memory, and a short-term memory task to estimate memory capacity. Analysis showed the AVGPs had the fastest access to memory. The differences between groups in the Proactive Interference Task seems to be related to speed of processing rather than accuracy or real resolution of conflict, and in the *N*-back Task, gamers were faster than non-gamers, but accuracy was similar, while in the short-term visual tasks, focused mainly on accuracy, players scored significantly higher than non-players. Thus, the main gains derived from action video games seem to be related only to an enhancement of visuospatial memory and not to long-term memory improvements. However, behavioral and neuroimaging analysis in another study (Moisala et al., 2017) showed benefits from games on speed and accuracy using the *N*-back Task in gamers with different levels of experience. The improved working memory performance involved frontoparietal cortical network recruitment, mainly in the dorsolateral prefrontal cortex. These results conflict with the *Neural Efficiency Hypothesis*, which posits that greater cognitive ability and repeated training is related to lower cortical activity. However, there is still no consensus, some researchers reporting increased activity, others finding no activity changes or observing a decrease in frontal and parietal activity (Clark, Lawlor-Savage, & Goghari, 2017; Heinzel et al., 2016; Olesen, Westerberg, & Klingberg, 2004).

Future research should study the real benefits of video-game training on memory, especially long-term and working memory, and analyze in depth the neural bases of those findings.

CHAPTER 4

OBJECTIVES AND HYPOTHESES

In the present study, we aimed to overcome the methodological limitations of previous video-game studies. We conducted two randomized interventions to analyze the effects of brain-game training on memory and attentional functions in young and older adults.

4.1. Objectives

Our main objectives were:

1. To conduct two video-game randomized intervention studies of about 15 training sessions; the first with participants aged over 50 years, and the second with participants aged 18 to 35 years.

2. To measure the effects of non-action adaptive mental games on the cognition of older and young participants, specifically working memory, selective attention, distraction and response inhibition.

3. To overcome some previous methodological limitations in terms of randomization, clinical trial registration, control group and placebo effect control.

4. To choose an appropriate active control group playing non-action, non-adaptive, and non-cognitive games under similar conditions to the experimental group (small groups with the same trainer and playing on tablets).

5. To control for the placebo effect, which could be responsible for differences in cognitive performance. To do so, we measured motivation and engagement during the training and assessment sessions and we also checked that expectations of game training benefits were similar in the two groups and did not influence cognitive results.

4.2. Hypotheses

We made the following hypotheses:

1. The experimental group of older adults trained with non-action, adaptive mental games would show significant cognitive improvement after training, and they would show significantly greater benefit than the active control group in working memory, attention, distraction and response inhibition.

2. The active control group of older adults trained with non-adaptive simulation games would not show significant cognitive improvement after training, and they would not show significant benefits in comparison with the experimental group.

3. We expected that the experimental group of young adults would improve cognitive performance after the intervention and that the active control group would not.

4. We expected that the performance of both training groups would improve throughout the training period, as in previous studies.

5. We expected that motivation, engagement and expectations would not differ between groups in either study and would not be able to explain cognitive differences.

CHAPTER 5

EFFECTS OF VIDEO GAME TRAINING IN HEALTHY OLDER ADULTS

Ballesteros, S., Mayas, J., Prieto, A., Ruiz-Marquez, E., Toril, P., & Reales, J. M. (2017). Effects of Video Game Training on Measures of Selective Attention and Working Memory in Older Adults: Results from a Randomized Controlled Trial. *Frontiers in Aging Neuroscience, 9,* 354

5.1. Abstract

Video game training with older adults potentially enhances aspects of cognition that decline with aging and could therefore offer a promising training approach. Although previous published studies suggest that training can produce transfer, many of them have certain shortcomings. This randomized controlled trial (RCT; Clinicaltrials.gov ID: NCT02796508) tried to overcome some of these limitations by incorporating an active control group and the assessment of motivation and expectations. Seventy-five older healthy volunteers were randomly assigned to the experimental group trained for 16 sessions with non-action video games from Lumosity, a commercial platform (http://www.lumosity.com/) or to an active control group trained for the same number of sessions with simulation games. The final sample included 55 older adults (30 in the experimental group and 25 in the active control group). Participants were tested individually before and after training to assess working memory (WM) and selective attention and reported their perceived improvement, motivation and engagement. The results showed improved performance across the training sessions. The main results were: (1) the experimental group did not show greater improvements in measures of selective attention and working memory than the active control group (the opposite occurred in the oddball task); (2) a marginal training effect was observed for the N-back task, but not for the Stroop task while both groups improved in the Corsi Blocks task. Based on these results, one can conclude that training with non-action games provide modest benefits for untrained tasks. The effect is not specific for that kind of training as a similar effect was observed for simulation video games. Groups did not differ in motivation, engagement or expectations.

Keywords: selective attention, cognitive training, healthy aging, video games, working memory

Trial Registration: Clinicaltrials. gov ID: NCT02796508;
https://clinicaltrials.gov/ct2/show/NCT02796508

5.2. Introduction

Aging produces declines in several cognitive processes, especially in executive function and attentional control, mediated by the dorsolateral prefrontal cortex. These brain areas as well as the hippocampus suffer the highest degree of age-related atrophy (Raz et al., 2005). Moreover, the prefrontal cortex facilitates the organization and contextualization of incoming information and interacts with the hippocampus when carrying out working memory (WM) tasks (A. Baddeley, 2003; Dennis, Kim, & Cabeza, 2008; Spaniol et al., 2009). The failure of these basic cognitive abilities is a significant predictor of older adults' difficulties with the instrumental activities of daily living, leading to loss of independence (Owsley, Sloane, McGwin Jr., & Ball, 2002). Therefore, it is vital to investigate whether cognitive decline can be reversed or delayed through cognitive training interventions (Ball, Edwards, & Ross, 2007).

The efficacy of computer-based cognitive training to improve executive functions, including selective attention and working memory in older adults has been extensively investigated (Lussier et al., 2015; see Ballesteros, Kraft, Santana, & Tziraki, 2015, for a review). Executive functions are central to most cognitive processes (Barkley, 2001). Selective attention refers to the ability to focus on the task at hand while simultaneously suppressing (inhibiting) irrelevant or distracting information. This ability is closely related to the quantity of the information stored in working memory. Selective attention filters out irrelevant information, enhancing encoding, and maintenance of information in working memory (Blacker et al., 2014). This is important, as WM is a capacity-limited cognitive system responsible for temporarily storing and actively processing information needed for ongoing cognition. This cognitive system is vital to keep information in mind while performing complex tasks such as, comprehension and reasoning (Baddeley & Hitch, 1974). This key component of cognition declines in healthy aging (Park et al., 2002; Bopp & Verhaeghen, 2005) and more profoundly in patients with Alzheimer's disease (e.g., A. D. Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991; Belleville, Chertkow, & Gauthier, 2007; Huntley & Howard, 2010) and type 2 diabetes mellitus (e.g., Redondo, Beltrán-Brotóns, Reales, & Ballesteros, 2016; see Monette, Baird, & Jackson, 2014; Mayeda, Whitmer, & Yaffe, 2015 for meta-analyses), amongst others. A question of great practical relevance is whether WM training methods are effective in older adults, their effect size, their cost effectiveness, and how they affect untrained tasks, in near (between very similar but not identical contexts) and far transfer (between contexts that appear on the surface to be remote and unrelated to each other).

Results of training studies are mixed. Some studies have shown positive transfer effects in young adults (e.g., Brehmer, Westerberg, & Bäckman, 2012; Blacker et al., 2014; Maraver, Bajo, & Gomez-Ariza, 2016) and in older adults (e.g., Buschkuehl et al., 2008; Borella, Carretti, Zanoni, Zavagnin, & De Beni, 2010, Borella et al., 2014; Heinzel et al., 2014; Toril et al., 2016) while others have reported negative results (e.g., Dahlin, Nyberg, Bäckman, & Neely, 2008; Zinke, Zeintl, Eschen, Herzog, & Kliegel, 2012; von Bastian, Langer, Jäncke, & Oberauer, 2013; Ballesteros et al., 2014; Bürki, Ludwig, Chicherio, & de Ribaupierre, 2014; Kable et al., 2017). A meta-analysis of training studies conducted with older adults reported improvements in tasks like the trained tasks (near transfer) as well as small far-transfer effects (Karbach & Verhaeghen, 2014). However, despite the positive results of some training studies, far transfer effects have been questioned. A recent meta-analysis of working-memory training studies with pre-post design and control groups (87 publications) reported reliable improvements immediately after training on measures of verbal and visuospatial WM, but these specific training effects did not generalize to other cognitive skills (Melby-Lervåg, Redick, & Hulme, 2016).

5.2.1. Methodological issues

Researchers are increasingly using new technology, including cognitive training platforms and video games, to investigate its impact on cognition, brain plasticity and aging (e.g., Basak et al., 2008; Mozolic, Long, Morgan, Rawley-Payne, & Laurienti, 2011; Buitenweg, Murre, & Ridderinkhof, 2012; Boot et al., 2013; Ballesteros et al., 2014; Anguera & Gazzaley, 2015; Boot, 2015; Binder et al., 2016; Toril et al., 2016). The idea that video games could enhance aspects of older adults' cognition has attracted the interest of researchers and led to a great explosion of software devoted to brain training (Anguera et al., 2013; Baniquet et al., 2013; Ballesteros et al., 2015a). However, several methodological concerns have been raised related to the efficacy and validity of video-game training studies (Boot et al., 2011; Green, Strobach, & Schubert, 2014). A recent extensive review (Simons et al., 2016) concluded: "practicing a cognitive task consistently improves performance on that task and closely related tasks, but the available evidence that such training generalizes to other tasks, or to real-world performance, is not compelling" (p. 173). Non-specific factors like expectancy, motivation, and engagement, as well as the quality of the active control group, are important aspects of the intervention design that should be certain that computerized cognitive training is a good method for enhancing cognition (Motter, Devanand, Doraiswamy, & Sneed, 2016).

An effective cognitive intervention in older adults should show a transfer of training gains to untrained tasks. It is also of paramount importance that the intervention encourages compliance. Older adults prefer mentally challenging games (Nap et al., 2009), while studies with young adults have shown that fast-paced action games result in broader transfer effects (Green & Bavelier, 2003; Baniqued et al., 2014; for a review see Bavelier et al., 2012).

A systematic review (Kueider et al., 2012) and several meta- analyses suggest that playing video games improves information processing, with interesting larger effects in old-older adults than in young-older adults (Powers et al., 2013; Lampit et al., 2014; Toril et al., 2014). A recent meta-analysis of action video game training studies found that healthy young and older adults benefited from training in overall and specific cognitive domains, but that young adults benefited more than older adults (Wang et al., 2017). These findings suggest the potential of video-game training as an intervention tool for cognitive improvement.

In a previous RCT study (Ballesteros et al., 2014), two groups of older adults participated in 20 1-h training sessions with non-action games or were assigned to a passive control group. Groups were similar at baseline on demographics, vocabulary, global cognition, and depression status. The results showed improvements in the video-game group and no change in the control group in processing speed, attention, immediate, and delayed visual recognition memory, and a trend to improve in Affection and Assertivity, two dimensions of the Wellbeing Scale (Nieboer, Lindenberg, Boomsma, & Bruggen, 2005). However, visuospatial WM and executive control (shifting strategy) functions did not improve. These enhancements in processing speed, selective attention, and spatial memory disappeared after a 3-month non-contact period (Ballesteros et al., 2015b), suggesting that cognitive plasticity can be induced in healthy older adults by training, but that periodic boosting sessions are needed to maintain the benefits.

In a more recent intervention study, we investigated specifically the effects of video game training on visuospatial WM and episodic memory in healthy older adults after 15 1-h sessions playing six non-action video games. Training produced significant improvements compared to a passive control group in two visuospatial WM tasks (Corsi blocks and Jigsaw puzzle task) and other episodic and short-term memory tasks. Gains in the Jigsaw puzzle task, short-term memory, and episodic memory were maintained over a 3-month follow-up period (Toril et al., 2016). In both studies, we compared the performance of experimental groups trained with non-action video games with that of passive control groups who participated in discussion groups on themes related to aging (Ballesteros et al., 2014, 2015b) or who attended courses in the community center for older adults (Toril et al., 2016). It could be argued that participants in the control group who simply met the trainer several times would not expect to improve as much on the transfer tasks as those who received video-game training (Boot & Kramer, 2014; Melby-Lervåg et al., 2016; Simons et al., 2016). Expectancy can influence training results through the placebo effect. In the present RCT, we address several of these significant issues in cognitive training research (Boot et al., 2011, 2013; see Baniqued et al., 2014; Blacker et al., 2014).

5.2.2. The current randomized controlled trial

To attribute possible training-related improvements to the intervention and avoid placebo effects (Boot et al., 2011; Foroughi, Monfort, Paczynski, McKnight, & Greenwood, 2016), the current RCT (Ballesteros et al., 2017b) compared performance on a series of transfer tasks of an experimental group playing selected adaptive non-action video games from Lumosity (http://www.lumosity.com) with that of an active control group. The active control group had the same number of sessions playing The Sims (Electronic Arts Inc.), a simulation game in which the player takes control of the life of a character in everyday activities, and SimCity, a life simulation game in which the player is the Mayor of a city that he or she must expand. Unlike the non-action games, control games were non-adaptative (the difficulty was not adjusted over the training to the actual level of performance of the trainee). Some results suggest that adaptive computerized training regimes may improve executive functioning (e.g., Ball et al., 2002; Dahlin et al., 2008; Morrison & Chain, 2011). Both groups used a mobile tablet device to play. At the end of the assessment session, participants in the current study reported their expectations (increase or decrease) regarding their performance on the assessment tasks, using a 5-point Likert scale. Moreover, at the 1st, 8th, and 16th training sessions, participants responded to questions about motivation and engagement for each of the video games.

In sum, we investigated possible cognitive and neural changes in attention and working memory functions in healthy older adults trained in small groups with adaptive non-action video games selected from Lumosity for 16 sessions in the presence of the trainer. Their performance on two attentional and two working-memory tasks was compared pre- and post-training with that of an active control group who played a simulation games for the same number of sessions. The electrophysiological data recorded to assess possible neural changes will not be presented in this paper. The objectives of this study were as follows. First, to examine possible effects of playing adaptive non-action video games on older adults' performance on a series of cognitive tasks designed to assess selective attentional functions, mainly distraction and alertness (Oddball Task), effortfuf (Stroop) and automatic inhibition (Negative Priming), and working memory, mainly maintenance and updating (N-back task and Corsi blocks) in verbal and visuospatial working memory. Second, to explore whether motivation, engagement, and expectations account for possible training-related improvements. We hypothesized that the non-action, adaptive video game group would show greater improvements in selective attention (exhibiting less distraction, more alertness, and better effortful inhibition after training), and enhanced working memory (maintenance and updating) than the active control group.

5.3. Materials and Methods

5.3.1. Participants

Participants were volunteers recruited from several older adult groups attending lectures and courses for senior citizens in UNED Associated Centers in Madrid. Eligible participants were randomized into the cognitive non-action video-game training group and the active control group in which participants played a simulation game. Exclusion criteria were self-reported neurological, psychiatric, or addictive disorders. All the participants lived independently, with normal or corrected-to normal hearing and vision and were free of neurological and psychiatric disorders, or traumatic brain injury. To determine their eligibility, each participant completed a screening battery consisting of the Mini-Mental State Examination (M*MSE*; Folstein et al., 1975) to rule out possible cognitive impairment (cut-off score of 27 out of a maximum of 30 points), the Yesavage

Depression Scale (Yesavage et al., 1982) to screen for depression (more than six points), and the Information subtest of the WAIS-III scale (Wechsler, 1999). Exclusion criteria were a diagnosis of dementia, cognitive impairment (score of <27 on the Mini-Mental State Examination, M*MSE*), <20/60 vision with or without correction, inability to complete the study activities, or communication problems. Demographic data and screening test scores corresponding to each group are summarized in Table 1. T-tests showed that groups did not differ on these measures (all ps > 0.05) at pre-test.

Twenty participants (26.6%) were lost at post-test. The study was completed by 30 of the 38 participants in the non-action video game training group and by 25 of the 37 in the active control group. Analyses of background characteristics showed no differences between dropouts and participants remaining in the respective group. Figure 1 shows the CONSORT Flow diagram of the present study.

Transfer of training was measured as performance improvement at post-test relative to pre-test (baseline) on untrained tasks, measuring selective attention, and working memory. To explore successful transfer of training gains to attentional mechanisms and working memory, data were recorded and analyzed at pre-training (T1) and posttraining (T2). Participants in both groups (experimental and active control) completed pre-test and post-test assessments individually in the laboratory. The assessment lasted ∼31/2 h (including rest periods). It included a Cross-modal oddball task and a Stroop-Negative Priming task to assess the effects of video-game training on attention and top-down control mechanisms, and a n-back task and the Corsi Blocks task to assess working memory.

All the methodological designs of the outcome measures were constructed using the rules of counterbalancing and stimulus rotation. Response keys were counterbalanced across conditions. All computerized cognitive tasks were programmed with E-Prime 2.0 (Psychology Software Tools Inc., Pittsburg, PA, USA). The statistical analyses of the behavioral results were conducted with SPSS (version 22). Results were considered significant at $p < 0.05$, with Bonferroni-corrected post-hoc tests performed as appropriate. The present study was conducted in accordance with the recommendations of the Research Ethics Committee of the UNED (Universidad Nacional de Educación a Distancia, Madrid). The UNED Institutional Review Board approved the study protocol. All participants provided written informed consent and were informed of their right to cease participation in the study at any time. The study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013).

Table 1. Demographic information for participants in each group

CHARACTERISTICS	Experimental G. (n = 30)	Control G. (n = 25)	*t-test*	*p*
Age (Years)	66.40 (5.64)	64.52 (4.51)	1.34	0.31
GDS	2.03 (2.35)	1.16 (1.49)	1.60	0.11
MMSE	28.70 (1.29)	29.00 (0.91)	0.97	0.33
Information (WAIS)	20.80 (3.53)	22.12 (2.90)	-1.39	0.17
Educational level	15.9 (4.55)	17.3 (0.27)	-0.25	0.80

Mean and Standard deviations (in parentheses). Experimental group age range: 55-84 years; 1 participant 60 years or younger and 2 participants 75 years or order. Active control group range: 55-76; 3 participants 60 years or younger; 2 participants 75 years or older.

5.3.2. Cognitive evaluation: assessment tasks and procedures

The experimental tasks performed before and after training are described below. At the end of the last assessment session, participants answered questions regarding their study expectations and perceived improvement in the different tasks.

Attentional tasks

Distraction and alertness, two important functions of selective attention were assessed with a cross-modal oddball task. Effortful inhibitory control and automatic passive inhibition was measured with the Stroop task and the Negative Priming task, respectively, both included in a computerized task.

Cross-modal oddball attention task

As in our previous RCT (Ballesteros et al., 2014; Mayas, Parmentier, Andrés, & Ballesteros, 2014), we assessed selective attention with a cross-modal oddball task. This would allow us to compare performance after nonaction video game training when the control group was a passive control group (as in our previous study) with that of an active group (the present study). The task comprised three blocks of 384 trials each (24 practice trials and 360 test trials, as described below). In each trial, participants categorized a visual digit from 1 to 8 as odd or even by pressing one of two response keys (counterbalanced across participants). Each trial began with the presentation of a white fixation cross in the center of a black screen together with a 200 ms sound. The digit appeared in white in the center of the screen 100 ms after the sound's offset and remained on the screen for 200 ms. A response window was displayed for 1,200 ms from the digit's onset. There were three sound conditions: A silent block and two blocks of trials containing two different sounds, the standard sound presented in 80% of the trials that was a 600 Hz sine wave tone of 200 ms, and a novel sound used in 20% of the trials taken from a list of 72 environmental sounds (e.g., hammer, drill, door, rain, etc.) used in Andrés, Parmentier, & Escera, (2006). All sounds were normalized and presented binaurally through headphones at a constant volume. Participants were instructed to focus on the digit categorization task and ignore any sound, and to respond as fast and accurately as possible.

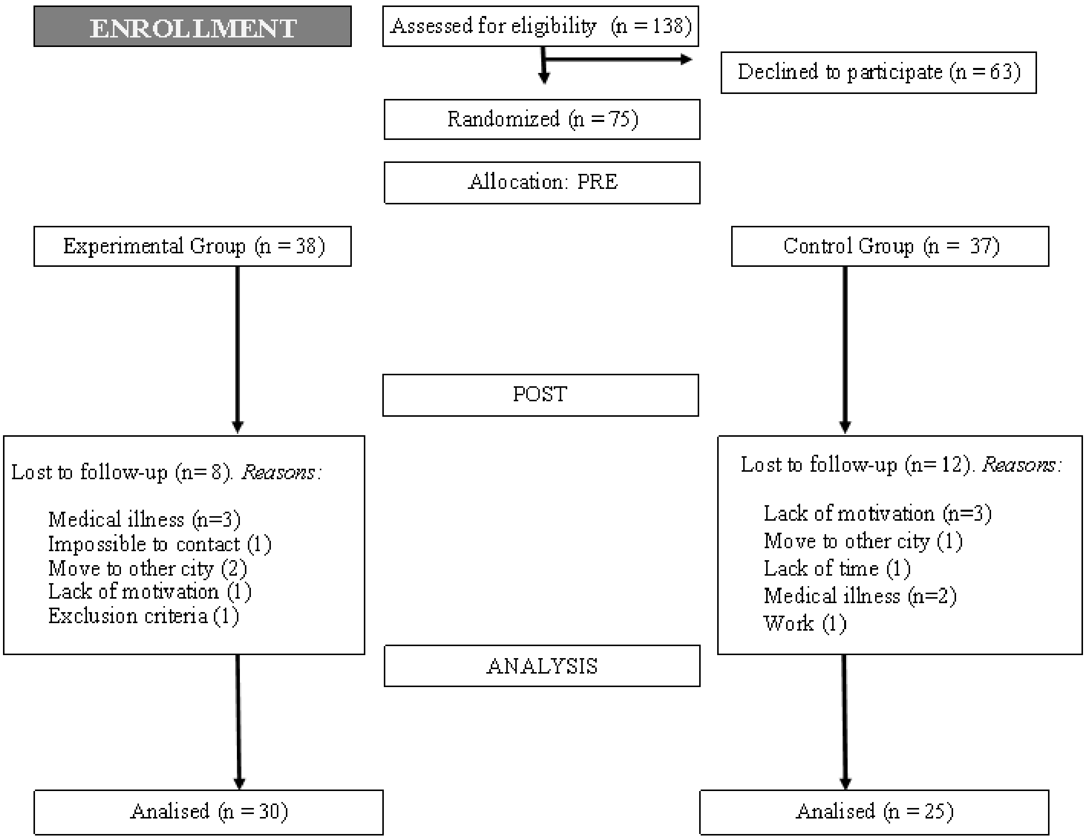
Stroop-negative priming (NP) task

Cognitive processes that involve top-down control mechanisms decline with aging, but more automatic processes do not (Ballesteros & Reales, 2004). The Stroop interference effect reflects the extra time needed to resolve the conflict generated by an automatically processed irrelevant dimension. NP and the standard Stroop effect were evaluated within the same task. In the standard NP procedure, participants are presented with pairs of prime and probe displays containing two stimuli, the to-be responded target and the to-be-ignored distractor. In the critical trials, participants must respond to a target that served as a distractor in the previous prime display (the ignored repetition condition). Reaction times (RTs) to targets in the ignored repetition condition are slower than in the control condition, in which the distractor in the prime display is not repeated

as the target in the probe display (Tipper & Cranston, 1985; Tipper, 2001; Andrés, Guerrini, Phillips, & Perfect, 2008). The aim was to investigate whether training older adults improved controlled, effortful inhibition (measured by Stroop interference) to a greater extent than automatic passive inhibition (NP).

The stimuli were three basic color words (“red,” “green,” and “blue”) written in red, green, or blue, presented in the center of the computer screen. Participants responded by pressing the appropriate key of the computer keyboard. Each trial started with a black fixation cross, presented in the center of the screen on a white background. Stimuli were presented randomly and remained on the screen for 200 ms. Participants responded as quickly and accurately as possible by pressing a key according to the color of the stimulus word while ignoring its semantic meaning. Participants performed a block of 18 practice trials (with feedback) and four experimental blocks of 144 trials each. Responses for the Stroop analysis were coded as a function of the congruency between the color and the meaning of the stimulus.

Figure 1. Consort Flowchart



Working memory

Visuospatial WM was assessed with a computerized version of the Corsi Blocks task. Maintaining and updating in verbal working memory was evaluated with the n-back task.

Corsi blocks task

Visuospatial working memory (Baddeley & Hitch, 1974) was assessed with a computerized version of the Corsi task (Milner, 1971), similar to the task used in our previous intervention studies (Ballesteros et al., 2014; Toril et al., 2016), with six levels of increasing difficulty (2, 3, 4, 5, 6, and 7 cube positions) and 12 trials per level. The first two trials in each difficulty level were used as practice trials and were not analyzed. The stimuli consisted of black squares that appeared one by one in the center of the computer screen inside a 3 × 3matrix for 1,000 ms each, with a 500 ms inter-stimulus interval (ISI). The positions in each sequence were randomly selected for each participant, the only restriction being that two cubes did not appear in the same position within the same trial. In each trial, participants were asked to reproduce the sequence of cubes in the same order as in the presentation. Participants responded by marking the presentation order of the cubes on a separate response sheet. They started the next trial by pressing the space bar. The final score was the proportion of correct sequences reproduced at each difficulty level.

N-back memory task

As a measure of maintenance and updating of information in WM, participants performed a verbal n-back task (Kirchner, 1958). This task has been widely used to assess WM in young (Baniqued et al., 2015; Kable et al., 2017) and older adult training studies (Basak et al., 2008; Dahlin et al., 2008; Redondo et al., 2016). We used an adapted version of the Robinson and Fuller (2004) computerized task. Participants viewed a sequence of centrally presented stimuli (letters) and indicated whether the last stimulus was identical to the one presented “n” trials back by pressing one key for “yes” and another for “no.” In this task we used three difficulty levels (1, 2, and 3 back). In the one-back level, participants had to remember the item presented just before the current item; in the two-back level, they had to remember the item presented two positions before; and in three-back level, three positions before. The stimuli in all blocks were 20 consonants (B, C, D, F, G, H, J, K, L, M, N, P, Q, R, S, T, V, W, Y, and Z). The letters appeared one by one in the center of the computer screen (font: Palatino Linotype, size: 30) for 500 ms, with an ISI of 3,000 ms for participants’ responses. The task started with a practice session of 17 trials at each level, followed by the experimental session and feedback. Each level contained three blocks of 27 trials, giving a total of 81 trials per level. Each block of 27 trials consisted of 17 “non-targets” (“no” response) and 10 “targets” (“yes” response).

5.3.3. Motivation and engagement self-reports

Motivation and engagement across the training period were assessed at pretest, at training sessions 1, 8, and 16, and at post-test. Participants responded on a 10-point Likert scale to questions about their motivation (“How motivated were you to achieve the highest score on the game? 1 = not motivated at all; 10 = extremely motivated”) and engagement (“How engaging was each game? 1 = not engaging at all; 10 = extremely engaging”).

5.3.4. Post-experiment survey

At the very end of the post-assessment session, participants answered questions related to whether they felt that participation in the study changed how they performed daily life activities, memory, processing speed, emotions, attention, and visual acuity, using a 5-point Likert scale (1 very much; 5 not at all). They also provided information about their expectations of improvement after training on the four transfer tasks.

5.3.5. Overview of the training program

Training was conducted in small groups of 10–12 participants at the UNED Associated Center in Madrid. At the beginning of each training session, the experimenter handed out an iPad (Brigmton BTPC 1018OC) to each participant. Participants in the experimental and the active control groups completed 16 training sessions of ∼40–50 min each over 10–12 weeks. According to the results of our meta-analytic study (Toril et al., 2014), short training regimes are better than long ones. We therefore used a training regime that was not too long to avoid loss of motivation.

Cognitive training intervention with non-action games

In each session, the trainees in the experimental group played 10 non-action video games selected from the commercial Lumosity (http://www.lumosity.com/) computerized training program. Some video games from this platform are based on traditional psychological tasks. The video games are quiet-pace, short (3–6 min), and were designed to be engaging. All participants played the same video games. The selected video games claim to train the following specific cognitive domains: working memory (20% of the games), attention (30%), response inhibition (10%), task switching (20%) and speed of processing (20%). Table 2 provides a short description of the games and their trained domains. These video games were: Playing Koi, Highway Hazards, Speed Match, Tidal Treasures, Star Search, Color Mach, Lost in Migration, Pinball Recall, Ebb and Flow, and Disillusion. A main feature of these video games is that they are adaptive meaning that as performance improved, difficulty increased progressively.

Active control condition

Participants in the active control condition practiced video games not designed to train specific cognitive domains but allows to trigger expectancy, contact with the trainer, motivation, and novelty. Participants played the same number of sessions for the same time than the cognitive trained group. Game difficulty was not adapted each session to the user ability. Participants in this group started each training session from the beginning of the video game. It is important to mention that both groups had the same contact with the trainer as all the training sessions were conducted on the present of the trainer and in small groups. Moreover, participants in both conditions received the same completion incentives. The active control group played The Sims and SimCity Build (Electronic Arts Inc.), simulation games. The Sims was used as control in previous intervention studies conducted with young adults (e.g., Oei & Patterson, 2013; Blacker et al., 2014). These simulation games did not appear to have the same cognitive demands as the behavioral tasks. They have some memory demands as the player must keep track of the goals to achieve but it is not necessary to do so as the goals are available in the menu (see Oei & Patterson, 2013). For example, The Sims player created and controlled characters that accomplished and performed several tasks like real-life activities (making friends, sleeping, have a bath, find a job, and soon). Sims City BuildIt is also a simulation game in which the player performed the tasks corresponding to the Mayor of the city. The task is to create and expand the city. Players are not required to accomplish objectives in a predetermined order. Table 3 presents a short summary of these games.

Table 2. Short description of the 10 non-action video games played by the experimental group (selected from *Lumosity*).

GAME NAME	GAME DESCRIPTION
Tidal Treasures	The player must choose objects and memorize their choice.
Pinball Recall	The player has to predict a ball’s path.
Playing Koi	The task consists of feeding fish and remembering those that have already been fed.
Star Search	The player has to choose the odd-one-out in a group of objects.
Lost in Migration	A flock of birds appears at the center of the screen. The player has to identify the orientation of the bird in the middle by pressing one arrow key.
Color Match	The player has to compare one word's meaning to another word's color.
Disillusion	The task consists of matching tiles with different shapes, colors or symbols.
Ebb and Flow	Leaves appear on the screen and the player has to swipe in the direction they are moving or pointing.
Highway Hazards	The player races a car across the desert avoiding colliding with obstacles.
Speed Match	A card appears on the screen and the player must determine whether the card is the same as the previous one.

Table 3. Short description of the life simulation games played by the active control group (*Electronic Arts, Inc.*)

GAME NAME	GAME DESCRIPTION
SimCity Build It	Life simulation game in which the player is the Mayor of a city that he or she must expand.
The Sims	Life simulation game in which the player creates characters (The Sims) that live in a virtual world that is similar to the real one. The Sims have to work, build their own homes, develop relationships, ecc.

5.4. Results

We first examined whether there were practice-related improvements on the trained games across the 16 training sessions. Next, we analyzed whether video-game training gains transferred to untrained tasks by comparing baseline (pre-test) to post-test performance in each group. We also considered whether perceived improvements in attention and working memory differed between groups. Levels of motivation and engagement throughout the training were assessed from the participants' answers to the selfreport questions at pretest, at the 1st, 8th, and 16th training sessions, and at post-test. Groups did not differ in motivation [$t\ (53) = 0.35$, $p = 0.72$], engagement [$t(53) = 0.24$, $p = 0.81$], or expectation [$t(53) = -1.26$, $p = 0.72$] at pretest.

5.4.1. Video game performance and game experience across sessions

The difficulty of the non-action video games was modified using an adaptive algorithm within and across the training sessions. The results showed that video game performance improved across sessions (see Figure 2). Comparisons between the first and last sessions were conducted on the performance Z-scores (Table 4). As expected, the results showed that training improved accuracy in all the video games.

Video game performance across training sessions

Responses to questions on motivation (How motivated were you to achieve the highest score on the game?) and engagement (How engaging was each game?) were analyzed separately using mixed ANOVAs with group (experimental vs. active control) as abetween-subjects factor, and training session (1,8, and 16) as the within-subjects factor. Rating scores to these questions were averaged across all the games. The ANOVA conducted on motivation scores showed that neither the main effect of group [$F\ (1,52) = 0.513$, $MSE = 8.350$, $p > 0.05$] nor session [$F\ (2, 104) = 0.863$, $MSE = 1$, 204, p > 0.05] were statistically significant. More importantly, the group by session interaction was marginally significant [*F (*2, 104) = 2.955, *MSE* = 1.204, p = 0.056, η_p^2= 0.054]. However, the simple effects analysis of this marginally significant interaction showed no effect whatsoever in the group variable across sessions, suggesting that the two groups were similarly motivated across sessions.

The ANOVA conducted on engagement showed that the two groups were similarly engaged [*F (*1, 52) = 0.411, *MSE* = 7.07, *p* > 0.05], but engagement differed across sessions [*F (*2, 104) = 3.212, *MSE* = 1.354, *p* > 0.05, η_p^2 = 0.058]. Pairwise comparisons showed that the scores at session 16 (post-test) were significantly lower (x = 7.588, SE = 0.241) than at session 8 (x = 7.971, SE = 0.213). The group by session interaction was also statistically significant [*F (*2, 104) = 3.376, *MSE* = 1.354, *p* > 0.05, η_p^2 = 0.061].

Simple effects analysis of this interaction did not show any effect of group on session, except the 16th, which showed a marginal pvalue (*p* = 0.065), suggesting that the two groups were similarly engaged, although the experimental group showed a slight drop in engagement in the final part of the experiment.

Perceived improvement: post-assessment survey

Transfer expectations of video-game training on a series of different activities were assessed with a 5-point Likert scale (1 expectation of no change, and 5 expectation that training will have strong positive effects). A series of one-factor ANOVAs (group: experimental, active control) were performed to assess the perceived improvement of video-game training on daily life activities, memory, processing speed, current studies, emotions, attention and visual acuity. The results showed that groups did not differ in their expectations of improvement in daily life activities [F(1, 52) = 0.91, *MSE* = 0.89, p

> 0.05, η_p^2= 0.02], memory [F(1, 52) = 1.12, *MSE* = 1.27, p > 0.05, η_p^2= 0.02], processing speed [F(1, 52) = 2.48, *MSE* = 3.22, p > 0.05, η_p^2= 0.05] or emotions [F(1, 52) = 2.22, *MSE* = 2.50, p > 0.05, η_p^2= 0.0]. The experimental group had higher expectations of improved attention [*F (*1, 52) = 5.12, *MSE* = 6.23, $p < 0.05$, η_p^2 = 0.09] and visual acuity [*F (*1, 52) = 5.69, *MSE* = 7.50, $p < 0.05$] after training than the control group. To assess possible differences in expectation of improvement after training on the experimental tasks (Oddball task, Stroop-NP task, Corsi task, N-back task), participants indicated their expected improvement after video-game training on a scale of 1 to 5. ANOVAs revealed that groups did not differ in their expectations of improving their performance on the Oddball 2 [*F (*1, 53) = 0.91, *MSE* = 0.62, p > 0.05, η_p^2 = 0.02] and N-back tasks [*F* (1, 53) = 0.52, *MSE* = 0.27, $p > 0.05$, η_p^2= 0.01]. The ANOVAs revealed a significant group effect for the Stroop task [*F*(1, 53) = 6.06, *MSE* = 3.69, $p < 0.05$, η_p^2 = 0.10] and the Corsi task [*F*(1, 53) = 9.52, *MSE* = 4.80, $p < 0.05$, η_p^2 = 0.15], with higher ratings in the experimental than the active control group.

Figure 2. Average performance scores obtained in each video game across the training sessions in Z scores (mean 0; standard deviation 1).

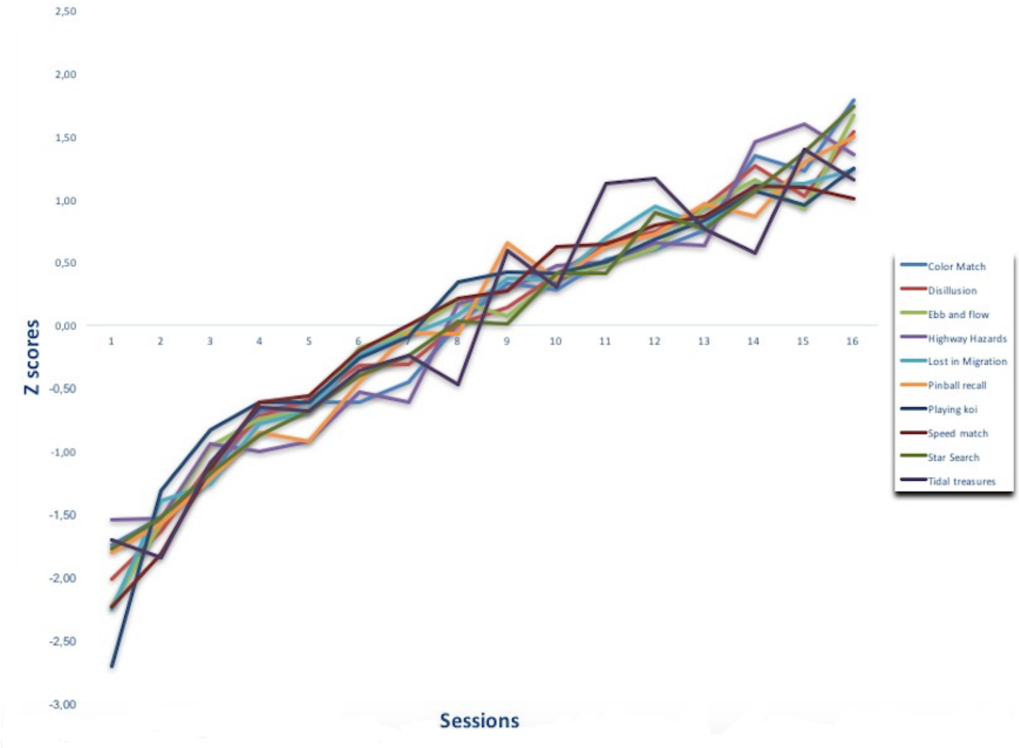


Table 4. Performance (Z-Scores) of the 30 participants in the experimental group in the first and last training session on each of the 10 practiced non-action video games.

GAME	*t (19)*	*p – value*
Color Match	1.99	.02
Disillusion	16.2	.00
Ebb and Flow	15.28	.00
Highway Hazards	4.96	.00
Lost in Migration	19.64	.00
Pinball Recall	9.53	.00
Playing Kol	15.62	.00
Speed Match	15.50	.00
Star Search	21.77	.00
Tidal Treasures	3.77	.00

5.4.2. Transfer of video-game training gains

The main results obtained in the transfer tasks at pre-training and post-training by the experimental and the active control groups are displayed in Table 5 and Figure 3.

Attentional functions

Cross-modal oddball task

The main dependent variables for this task were distraction and alertness. We did not apply an ANCOVA with the pre-test scores as covariates because the assumption of independence with the inter-subject's factor was not met. The 2 group (experimental vs. control) × 2 session (pre-vs. post-test) × 3 sound condition (silence, standard, novel) mixed ANOVA conducted on the mean of the RTs of the correct responses showed a main effect of sound condition [*F (*2, 104) = 33.79, *MSe* = 1075.94, $p < 0.001$, η_p^2 = 0.394]. Post-hoc pairwise comparisons were all significant: standard sound condition was faster (622 ms) than the silence (645 ms) and novel (658 ms) conditions (ps < 0.001), while mean RT of the silence condition was faster than that of the novel condition (p = 0.03). The analysis also yielded a main effect of group [*F (*1, 52) = 5.70, p = 0.021, *MSe* = 26573.78, η_p^2 = 0.10]. This result indicates that the active control group was faster (620 ms) than the experimental group (664 ms) overall. The main effect of session was also significant [*F (*1, 52) = 11.01, p = 0.002, *MSe* = 1087.59, η_p^2 = 0.175]. RTs were faster at post-test (636 ms) than pre-test (647 ms). Finally, the session × sound interaction was statistically significant [*F (*2, 104) = 4.69, *MSe* = 717.65, p = 0.017, η_p^2 = 0.08]. Post-hoc comparisons indicated that RTs were faster at post-test only in the standard (617 and 627 ms for pre-and post-test, respectively) and novel (646 and 670 ms for pre-and post-test, respectively) conditions (p = 0.05 and $p < 0.001$, respectively). Additional analyses were conducted on distraction and alertness. We computed the distraction effect as the difference between the RT of the novel trials and the RT of the standard trials. A 2 group × 2 session ANOVA was performed on the distraction effect. Only the two-way group × session interaction was significant [*F (*1, 52) = 5.7, *MSe* = 222.53, p = 0.020, η_p^2 = 0.10], indicating that the active control group improved at posttest (27.33 and 19.49 for pre-and post-test, respectively) but the experimental group did not (26.32 and 32.37 for pre-and post-test, respectively). We computed the alertness effect as the difference between the RT of the silence trials and the RT of the standard trials. The ANOVA conducted on alertness did not show any significant effect (all ps > 0.05). Figure 3A represents the difference in RTs between conditions for distraction and alertness.

Stroop—NP task

Stroop results Responses for the Stroop analysis were coded as a function of the congruency between the color and the meaning of the color word. Congruent trials were those in which the color of the word coincided with the color in which it was presented. Incongruent trials were those in which the color word did not coincide with the color in which it was displayed. Trials were also coded according to the congruency of the word in the previous trial (N-1) with the color in the current trial in order to compute the NP effect. Thirty participants in the experimental group and 25 participants in the control group were included in this analysis.

To analyze the results of the Stroop task, a 2 group × 2 session × 2congruency (congruent andincongruent) mixed ANOVA was conducted on the mean RTs for correct trials as the dependent variable. The analysis showed a highly significant main effect of congruency (classic Stroop effect) [*F (*1, 53) = 345.62; *MSe* = 109.86, $p < 0.001$, η_p^2 = 0.867]. Responses to the incongruent stimuli were slower (884 ms) than to the congruent ones (801 ms; $p < 0.001$). The main effect of group was significant [*F* (1, 53) = 4.70, *MSe* = 40729.29, $p < 0.05$, η_p^2 = 0.081], showing that the control group was faster (813 ms) than the experimental group (872 ms). The significant group × congruency interaction qualifies the main effect of group [*F* (1, 53) = 4.53, *MSe* = 1098.86, $p < 0.05$, $\eta_p^2 = 0.08$]. Post-hoc comparisons revealed that the active control group was faster than the experimental group (850 and 919 ms for the control and the experimental group, respectively), but only for incongruent stimuli ($p < 0.02$). Finally, we computed the Stroop effect as the difference between Incongruent RT—Congruent RT for each participant. A 2 group × 2session mixed ANOVA showed that only the main effect of group was significant

[*F (*1, 53) = 4.53, *MSe* = 2197.72, $p < 0.05$, $\eta_p^2 = 0.08$]. No other main effect or interaction was statistically significant. See Figure 3B.

NP results Responses for NP analyses were coded as a function of the relationship between the color of the current target word and the color denoted by the word in the previous trial (distractor). Different types of trials were coded: (a) ignored repetition trials were those in which the word in the preceding trial denoted the color of the word color of the current stimulus; and (b) control trials were those in which both the target (color) and the distractor (word) in the current trial were different from the target and distractor in the previous trial. The ignored repetition condition and the control condition were always an incongruent trial preceded by an incongruent trial.

A 2 group × 2 session × 2 repetition (ignored repetition, control condition) mixed ANOVA was performed on the mean RTs for correct trials. The NP effect was computed as the difference between ignored repetition and control conditions. The analysis showed a significant main effect of group [*F* (1, 53) = 4.45, *MSe* = 58822.53, $p < 0.05$, $\eta_p^2 = 0.07$], indicating that the experimental group was significantly slower (941 ms) than the control group (871 ms) in all conditions. The main effect of repetition was also significant [F(1, 53) = 133.36, *MSe* = 987.94, $p < 0.001$; $\eta_p^2 = 0.71$], showing that ignored repetition trials were slower than control trials for both groups (for the experimental group: 968 and 913 ms for ignored repetition and control trials, respectively; for the control group: 893 and 849ms for ignored repetition and control trials, respectively). The size of the NP effect was 55 ms for the experimental group and 44 ms for the control group. Finally, neither the main effect of session nor any interactions were significant (all ps > 0.05).

Effects of training on spatial working memory

Corsi blocks

We conducted a 2 group × 6 level ANCOVA with the pre-test scores as covariates conducted on the proportion of correct sequences obtained at each difficulty level. The assumption of no relationship between the inter-subjects factor (group) and the covariates was met (all ps > 0.05) as well as the equality of slopes (all p> 0.05). The results showed a main effect of level [*F* (5, 235) = 13.706, *MSe* = 0.022, $p < 0.001$, 2

η$\eta_p^2 = 0.382$]. The mean correct proportions were 0.97, 0.78, 0.69, 0.41, 0.24, and 0.13 for levels 2, 3, 4, 5, and 6, respectively. Post-hoc pairwise comparisons showed that all levels differed significantly from each other (all ps < 0.05). Neither other main effects nor any interaction reached statistical significance. However, as the ANCOVA did not include session as a factor, we also performed an ANOVA to assess specifically the effect of session. This analysis showed that session was highly significant [*F* (1, 53) = 22.57, *MSe* = 0.027, $p < 0.001$, $\eta_p^2 = 0.299$]. The mean correct proportion at pre-test was 0.48 while at posttest the mean was 0.54. The interaction session × group was not significant, suggesting that both groups benefited equally after training (see Figure 3C).

N-back task

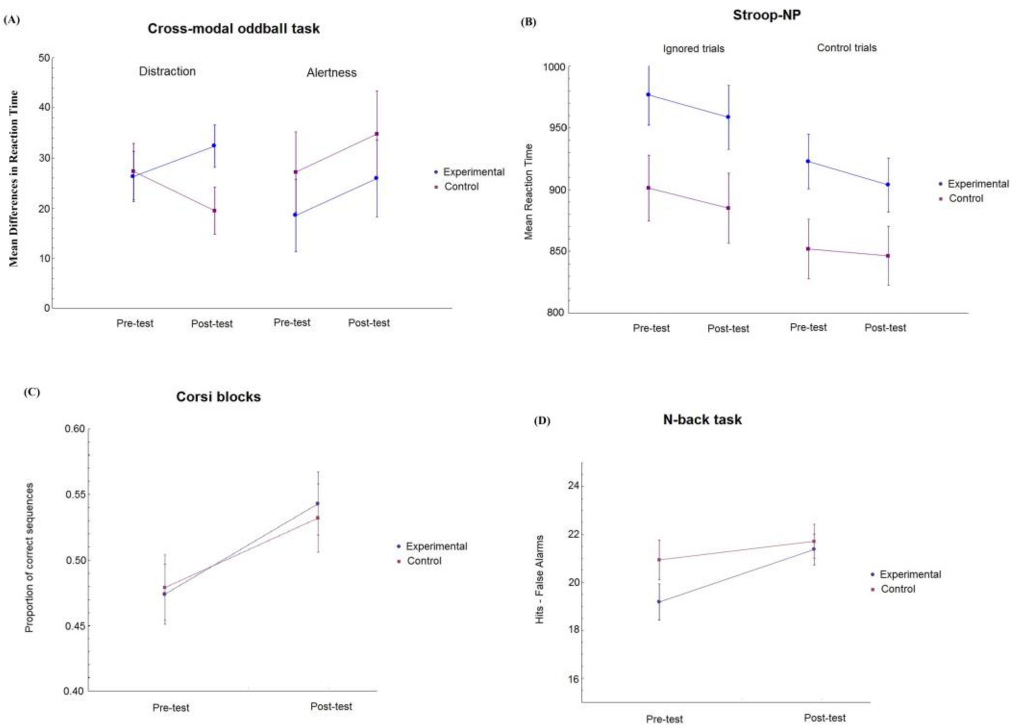
One participant in the experimental group and one in the control group were excluded from the analysis due to the large number of no responses (more than 50%). Thus, data from 29 participants in the experimental group and 24 participants in the control group were included in this analysis. We did not perform an ANCOVA with the pre-test scores as covariate because the assumption of no relationship between the inter-subjects group factor andthe covariates was not met. The 2 group × 2session × 3level mixed ANOVA conducted on the means of Hits minus False Alarms yielded a significant main effect of Level [*F (*2, 102) = 188, 68, *MSe* = 13, 21, $p < 0.001$, $\eta_p^2 = 0.79$] with means of 25.39, 21.33, and 15.69 for 1-back, 2-back, and 3-back levels, respectively. A main effect of session also reached significance [*F (*1, 51) = 13.91, *MSe* = 12.51, $p < 0.001$, $\eta_p^2 = 0.21$]. The Hits-FA mean was 20.06 at pre-test and 21.55 at posttest. The session × level interaction was marginally significant [*F* (2, 102) = 3.06, *MSe* = 9.48, $p = 0.051$, $\eta_p^2 = 0.067$], showing that only 1-back and 3-back levels improved between pre-and post-test. Finally, the group × session interaction was also marginally significant [*F (*1, 51) = 3, 162, *MSe* = 12.518, $p = 0.08$, $\eta_p^2 = 0.06$], suggesting that the experimental group improved marginally at post-test compared to the control group (19.18 and 20.94 at pre-and post-test for the experimental group; 21.37 and 21.72 at pre-and post-test for the control group). Figure 3D shows this marginal interaction.

Table 5. Pre- and post-training performance on psychological measures for the experimental and active control groups.

		PRE EXP	POST EXP	PRE CTL	POST CTL	PRE-POST EF EFECTS (*d*)
CROSSMODAL ODDBALL TASK	Distraction (ms) +	26.32 (28.62)	32.37 (25.33)	27.33 (25.69)	19.49 (20.11)	0.67
	Alertness (ms)	18.55 (23.87)	25.93 (31.38)	27.19 (52.8)	34.80 (52.56)	0
STROOP-NP TASK	Stroop effect (ms)	93.93 (42.38)	92.05 (39.41)	79.29 (32.31)	72.94 (29.29)	-8.43
	NP effect (ms)	53.91 (43.00)	54.74 (46.86)	49.26 (28.59)	38.66 (33.05)	-0.24
CORSI BLOCKS TASK	2 Serial Position	.92 (.11)	.97 (.04)	.90 (.21)	.95 (.05)	0
	3 Serial Position	.71 (.16)	.76 (.14)	.76 (.16)	.79 (.14)	.12
	4 Serial Position	.60 (.23)	.67(.22)	.66 (.23)	.71 (.23)	.07
	5 Serial Position	.29 (.23)	.40 (.27)	.32 (.26)	.41 (.24)	.04
	6 Serial Position	.16 (.18)	.27 (.23)	.15 (.14)	.20 (.15)	.37
N-BACK TASK	1-back (Hits-FA)	23.93 (4.42)	26.68 (2.03)	24.58 (3.47)	26.37 (2.53)	2.27
	2-back (Hits-FA)	19.82 (5.73)	21.20 (5.18)	22.54 (3.18)	21.75 (5.84)	0.42
	3-back (Hits-FA)	13.79 (5.43)	16.24 (4.82)	15.70 (6.26)	17.04 (4.85)	0.23

Mean scores of the outcome measures with standard deviations in parentheses. Single asterisk (*) indicates tasks on which there was a trend for large improvements in the experimental group; the cross (+) indicates tasks on which the active control group showed significantly greater improvement than the experimental group and the double cross (++) indicates that both groups improved after training. Effect size (d) is the standardized mean difference for designs with two groups (experimental and control) in a pre-post test design. CI is the confidence interval of d.

Figure 3. Mean performance of the experimental and active control groups at pre-test and post-test



(A) Mean differences between conditions for distraction (novel – standard) and alertness (silence – standard) in ms. (B) Mean RTs for ignored and control trials in the Stroop task. (C) Mean proportion of correct sequences in the Corsi blocks task. (D) Mean hits-false alarms rates obtained in the n-back task. Error bars represent plus minus 1 standard error.

5.5. Discussion

The present study yielded three main results: (1) Unsurprisingly, participants improved significantly in the video games across the training sessions; (2) the experimental group did not show greater improvements in measures of selective attention and working memory compared to the control group; and (3) a marginal training effect was observed for the N-back task, but not for the Stroop task in the experimental group while both groups improved similarly in the Corsi Blocks task. On the basis of these results, one can conclude that training with nonaction video games provide modest benefits for untrained tasks (near transfer) that were not directly trained but were under the umbrella of the executive function. Moreover, the effect was not specific for that kind of training, since a similar effect was observed in the group trained with simulation video games.

Older adult participants in the non-action adaptive video games improved on all the practiced games across the training sessions. This is in line with previous findings reported in a large number of intervention studies (e.g., Ackerman, Kanfer, & Calderwood, 2010; Redick et al., 2013; Ballesteros et al., 2014; Baniqued et al., 2014; Toril et al., 2016).

5.5.1. Transfer effects

Motivated by results suggesting that training older adults with non-action video games improve aspects of cognition when compare performance with that of a passive control group (Ballesteros et al., 2014; Toril et al., 2016), and by others showing that executive control functions could improve with adaptive computerized training (Morrison & Chain, 2011; Nouchi et al., 2013; Hardy et al., 2015), we hypothesized that older adults trained with adaptive cognitive video games would show greater improvements in measures of executive function than an active control group trained with video games not designed specifically for cognitive training. The experimental group trained with the commercial adaptive games showed a trend to improve in the N-back task after training and a similar degree of improvement on the Corsi task than the active control group. The opposite occurred in the Oddball task in which only the active control group showed less distraction after training. Based on these results, one might conclude that training with non-action games provide modest benefits for untrained tasks compared with an active control group trained with non-adaptive simulation video games.

Arecent randomized controlledtrial conductedwith 64 healthy young adults, trained with the same commercial webbased cognitive training video games and 64 trained with webbased video games that do not target executive functions or adapt the difficulty during training (active control group) found that performance over time in the cognitive training group improved across sessions in the trained video games. However, both training conditions improved similarly in the cognitive assessment battery that included tests of attention, working memory (visual/spatial n-back), response inhibition, interference control (Stroop test), and cognitive flexibility, not directly trained but in the domain of executive function targeted by the training regimen (Kable et al., 2017).

It is central to consider the importance of the control group, as most previous intervention studies did not include an active control condition as similar as possible to the experimental condition (Lampit et al., 2014; Toril et al., 2014) and with similar levels of motivation, social contact, and engagement (Blacker et al., 2014; Motter et al., 2016). In the current RCT, we tried to equate task factors that might contribute to differential improvements. First, the number of older participants was almost double that of our previous intervention studies. They were randomly assigned to a group trained with video games from Lumosity or to an active control group playing The Sims and SimCity (two simulation games) for the same number of sessions. The inclusion of an active control group is considered critical for inferences about the specific potential effects of the intervention (Dougherty, Hamovitz, & Tidwell, 2016; Motter et al., 2016; Simons et al., 2016). We selected an active control condition as similar as possible to the training condition in that the control group also played non-action games. In several recent intervention studies conducted with young adults to investigate whether training with action video games enhances aspects of cognition, including visual WM (Blacker et al., 2014), cognitive flexibility (Glass, Maddox, & Love, 2013), plasticity in the visual system (Li, Ngo, Nguyen, & Levi, 2011) or several aspects of perception and cognition (Oei & Patterson, 2013), the active control participants also played non-action strategy video games.

Boot et al. (2011), Dougherty et al. (2016) and Simons et al. (2016) warned that the use of a control group per se does not preclude the possibility of differential placebo effects contaminating the results of the trained group. The argument is that the experimental group might have higher expectations of their performance on the transfer tasks compared to the active control group. Recently, Blacker et al. (2014) collected measures of expectations in a group trained on action games and in an active control group trained with The Sims. Baniqued et al. (2014) used casual video games to train young adults. The intervention included an active control group that played several games not related to WM and reasoning, and responded to feedback questions about engagement, motivation, enjoyment, and perceived effort.

In order to match the expectations of our experimental group (trained with non-action games) with those of the active control group, we evaluated both groups' expectations for improvement on each outcome measure. Results showed that groups did not differ in their expectations of improvement in the attentional Oddball task and the verbal WM N-back task. The experimental group had higher expectations of improvement than the active control group in the response inhibition Stroop task and the visuospatial WM Corsi blocks task. The expectations and outcomes of the two groups were not aligned, so it is unlikely that the results were driven by a placebo effect.

There are discrepancies between the findings of the present training study and those of Toril et al. (2016) intervention study, which reported significant improvement by the experimental group after training with non-action video games in two computerized spatial WM tasks, the Corsi blocks and the Jigsaw puzzle task, and no change in a passive control group. In the present study, both groups improved their performance on the Corsi blocks after training. This suggests that playing simulation games also enhances visuospatial WM. This specific difference could be due to the fact that the games played by the active control group involve not only managing the characters' lives or a city but also traveling visually around the city to identify resources and opportunities. This visual navigation may be partly responsible for the results obtained in the visuospatial WM task. The discrepancy between the results of the two studies might thus be due to the type of control group, either passive (Toril et al., 2016) or active (the present study).

As indicated above, participants were randomly assigned to either the experimental group or the active control group before performing the cognitive tasks in the laboratory (pretesting). However, the active control group was faster than the group trained with non-action cognitive video games in those cognitive tasks in which the dependent variable was response time (Oddball and Stroop-NP tasks). In the working memory tasks (Corsi Blocks and N-back tasks) in which the dependent variable was accuracy, experimental and control groups did not differ.

5.6. Limitations

A number of limitations of the present study need to be acknowledged. First, although the number of participants in the present study was larger than many previously published training studies, it is always desirable to include a large number of participants per condition to increase power. Null effects may reflect the lack of power and variability within the groups. For example, Melby-Lervåg et al. (2016) advised that studies with small sample sizes (<20 participants per condition) and passive (untreated) control groups produce a bias toward significant (although low-powered) results (see also Maraver et al., 2016). In the current study, there were more than 20 participants per group and the active control group was also trained with video games. Secondly, it is possible that the 16 training sessions were insufficient to show transfer, and that a longer or denser (more hours per week) training regime could have yielded greater enhancements. However, as mentioned in the Introduction, recent meta-analyses (Lampit et al., 2014; Toril et al., 2014) showed that shorter training regimes were better than longer ones that can lead to loss of motivation. For that reason, we decided to have only 16 training sessions in the current study. Thirdly, as mentioned above, in two previous studies, we included a passive control group. In the present study we did not include a passive control group to control for unspecific repetition effects. Instead, in this RCT, we included an active control group and almost double the number of participants compared to our previous studies (Ballesteros et al., 2014; Toril et al., 2016). The inclusion of a passive control group would not have determined whether the improvements observed were due to the specific video games used in the training regimes to the use of iPads, or simply to social interaction with the trainer and the other participants during the training sessions (see Ballesteros et al., 2015a; Schmicker, Schwefel, Vellage, & Müller, 2016). Even if a significant group by session interaction would be found, the result could be due to different factors as mention in the section Introduction. Finally, the participants in the present study were older adults without cognitive impairment. It could be the case that these elders were performing at a high level and training with the video games would not produce greater benefits (Toril et al., 2014). In fact, Kable et al. (2017) in their RCT with young adults included both, an active control group and a passive control group assessed at pretest and post-test without any training. The results showed that the improvement observed in the passive group was comparable to that of the group trained with adaptive commercial cognitive games and the active control group (Kable et al., 2017).

5.7. Conclusion

In sum, further research is needed to ascertain whether computerized cognitive training improves executive functions, specifically selective attention and working memory, as well as everyday functioning in healthy older adults. While high levels of mental activity have been associated with both better cognitive performance and reduced risk of dementia (Valenzuela & Sachdev, 2006), in view of the modest benefits for untrained working memory and attentional functions of non-action video game training is vital to explore more deeply whether video games or other types of computerized cognitive training can improve executive functions in older adults (Foroughi et al., 2016; Motter et al., 2016; Simons et al., 2016) and whether there are stable relations between training with video games and cognitive abilities in general (McCabe, Redick, & Engle, 2016). Special attention deserves multi-domain interventions that combine cognitive training with physical activity embedded in a social environment for supporting cognition and independent living of an increasing older adults' population (Ballesteros et al., 2015b).

CHAPTER 6

EFFECTS OF VIDEO GAME TRAINING IN YOUNG ADULTS

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6.1. Abstract

Objective: In this intervention study, we investigated the benefits of non-action video games on measures of selective attention and visuospatial working memory (WM) in young adults.

Materials and Methods: Forty-eight young adults were randomly assigned to the experimental group or to the active control group. The experimental group played 10 non-action adaptive video games selected from Lumosity, while the active control group played two non-adaptive simulation-strategy games (SimCity and The Sims). Participants in both groups completed 15 training sessions of 30 minutes each. The training was conducted in small groups. All the participants were tested individually before and after training to assess possible transfer effects to selective attention, using a Cross-modal Oddball task, inhibition with the Stroop task, and visuospatial WM enhancements with the Corsi blocks task.

Results: Participants improved video game performance across the training sessions. The results of the transfer tasks show that the two groups benefited similarly from game training. They were less distracted and improved visuospatial WM.

Conclusion: Overall, there was no significant interaction between group (group trained with adaptive non-action video games and the active control group that played simulation games) and session (pre-, post-assessment). As we did not have a passive non-intervention control group, we cannot conclude that adaptive non-action video

games had a positive effect, because some external factor might account for the pre- and post-test improvements observed in both groups.

6.2. Introduction

Over the last few decades, the number of publications focused on neurocognitive training with video games has increased substantially (Palaus, Marron, Viejo-Sobera, & Redolar-Ripoll, 2017). These studies cover from educational (Qian & Clark, 2016) to clinical rehabilitation (Stanmore, Stubbs, Vancampfort, de Bruin, & Firth, 2017) and include participants from different age stages (Ballesteros et al., 2017b; Baniqued et al., 2014; Belchior et al., 2013; Franceschini et al., 2013; Kable et al., 2017; Mackey, Hill, Stone, & Bunge, 2011; Toril et al., 2016).Video games are virtual environments that motivate, engage and generate positive emotions that help people to keep training (Bediou et al., 2018; Belchior, et al., 2012; Burgers et al., 2015; Eseryel, Law, Ifenthaler, Ge, & Miller, 2013; Johnson et al., 2016)

Despite the great interest that it has generated, there is no consensus on the cognitive benefits of brain-training games (Chiappe et al., 2013; Hutchinson et al., 2016; Irons et al., 2011; Karle, Watter, & Shedden, 2010; Mack, Wiesmann, & Ilg, 2016; Murphy & Spencer, 2009; Trisolini et al., 2017; Wang et al., 2016).The results of several meta-analyses suggest that brain training with video games and other computerized programs improves aspects of cognition, in young and in older adults, (Kim et al., 2015; Toril et al., 2014) while a meta-analysis reported small or null overall effect sizes (Sala et al., 2017.) As a consequence of these mixed results, some authors have proposed that the appropriate design for these interventions is a double blind, placebo controlled and randomized study with an adequate active control (Boot et al., 2011; Boot & Simons, 2012; Boot et al., 2013; Zelinski, 2009).

In this intervention study participants were randomly assigned to an experimental group or an active control group, with the same number of training sessions and identical conditions. Participants in the experimental group played adaptive non-action video games from *Lumosity,* while those in the active control group played simulation games, previously used as active control condition (Green & Seitz, 2015; Li, Chen, & Chen, 2016; Powers & Brooks, 2014.) We also controlled for placebo effects by assessing motivation, engagement and expectations. We hypothesized that young adults in the experimental group would transfer the abilities developed as a result of the video game training to visuospatial working memory (WM) and to aspects of attention including distraction, alertness and controlled inhibition of interference.

6.3. Materials and Methods

6.3.1. Participants

Forty-eight volunteers between 18 and 35 years of age were recruited from flyers and project presentations at university lectures; they received 85€ for travel costs. We included participants from 18 to 35 years of age because this age range is normally identified with early adulthood (Medley., 1980), and has previously been used in other young adult intervention studies (Andrés, Parmentier, & Escera, 2006). All participants had normal hearing and vision and were free of neurological or psychiatric disorders. Exclusion criteria were depression (more than 15 points on BDI), < 20/60 vision with or without correction, inability to complete training, and communication problems. They completed a screening test battery consisting of the Information subtest of the WAIS-III scale (Wechsler, 1999), the short version of the Beck Depression Inventory (BDI) (Beck & Beck, 1972), and the Quality of Life Questionnaire from the World Health Organization (WHOQOL-BREF) (The WHOQOL Group, 1996.) The WAIS-III was validated using Common Factor Analysis, showing that the four factors accounted for

61 % of the total variance (Watkins, 1998). The WHOQOL-BREF had good internal consistency (Amir et al., 2003) in terms of Cronbach's alpha (physical domain = 0.73, psychological domain = 0.80, social domain = 0.62, environment domain = 0.71). The Beck Depression Inventory has shown acceptable reliability (Cronbach´s alpha = 0.83) (Sanz, J., Vazquez, 1998).

For assessment of the placebo effect, we used questionnaires based on two studies that did not report validity coefficients (Blacker, Curby, Klobusicky, & Chein, 2014; Boot et al., 2013). However, other researchers have adapted the questionnaires (Boot et al., 2013) producing the Expectation Assessment Scale (EAS) and analyzed their psychometric properties (Rabipour, Davidson, & Kristjansson, 2018). They reported an internal consistency of 0.87.

The cognitive assessment tasks are not usually analyzed psychometrically in terms of their validity and other psychometrical properties, but the Stroop Test showed a convergent validity of -0.35 y -0.41 for the 3 subscales (P-Word, C-Color, PC-Word-Color). Moreover, its construct validity was assessed by a factorial analysis and the three components explained 47 %, 23 % and 16 % of the total variance, respectively (Rodríguez Barreto, Pineda Roa, & Pulido, 2016).

Participants were randomly assigned to the experimental or to the active control group using the random generator of integer numbers from Matlab. There were no differences between groups at pre-test in outcome variables (Table 1). The gender ratio and educational level of our sample differed slightly from the Spanish population of the same age; females represented 66.7 % of our sample and males 33.3 %, compared to 50.78 % and 49.22 % respectively in the general population. For educational level, 79.8 % of our participants had completed secondary education, compared to only 10.3 % of the Spanish population; 15.5 % of our participants had completed higher education, compared to 6.4 % of the Spanish population.

Table 1. Demographic information. Mean, standard deviation (in parentheses), range [in brakets], *F* values of anovas, *P* or significance level and effect size (η_p^2).

CHARACTERISTICS	EXPERIMENTAL GROUP (n = 18)	ACTIVE CONTROL GROUP (n = 21)	*F*	*P*	μ_ρ^2
AGE (years)	22.78 (4.83) [18-33]	22.48 (4.07) [18-32]	0.04	0.83	0.001
GENDER N (%)					
Female	12 (66.7)	14 (66.7)			
Male	6 (33.3)	7 (33.3)			
EDUCATION N (%)					
High school/some college	14 (77.8)	17 (81)			
College degree	3 (16.7)	3 (14.3)			
Postgraduate degree	1 (5.6)	1 (4.8)			
BDI pretest	3.17 (2.33) [0-9]	3.95 (4.22) [0-15]	0.51	0.482	0.013
BDI postest	1.89 (2.32) [0-8]	3.14 (3.58) [0-14]	1.62	0.210	0.042
INFORMATION (WAIS)	19.28 (3.86) [14-26]	20.19 (4.10) [10-25]	0.51	0.482	0.013
WHOQOL pretest					
D1 (physical health)	27.5 (3.74) [22-34]	27.28 (3.99) [21-35]	0.03	0.86	0.001
D2 (psychological health)	22.24 (1.98) [19-27]	22.14 (3.44) [15-27]	0.11	0.74	0.003
D3 (social relationships)	11.61 (2.09) [7-14]	12.28 (1.95) [8-15}	1.08	0.30	0.028
D4 (environment)	30.05 (3.98) [24-37]	29.71 (4.78) [17-37]	0.06	0.81	0.002
WHOQOL postest					
D1 (physical health)	26.89 (3.94) [17-33]	28.05 (3.93) [20-34]	0.84	0.36	0.022
D2 (psychological health)	23 (2.7) [16-28]	21.95 (3.84) [13-27]	0.94	0.34	0.025
D3 (social relationships)	11 (1.97) [7-14]	11.71 (2.19) [7-15]	1.13	0.29	0.030
D4 (environment)	31.83 (4.42) [24-40]	29.81 (4.98) [19-37]	1.77	1.19	0.046

Participants gave their informed consent. The study was conducted in accordance with the Declaration of Helsinki ("World Medical Association Declaration of Helsinki," 2013.) No participants were excluded after screening. Nine of the 48 participants (18.75 %) were lost at post-test. The study was thus completed by 18 out of 24 participants in the experimental group and by 21 out of 24 in the control group.

We conducted an a priori power analysis (G-Power 3.1.9.2) to calculate the value of a sufficient sample size. Using an alpha of 0.05, a power of 0.80, and a medium effect size (d = 0.29) (Faul, Erdfelder, Buchner, & Lang, 2009), a sample of 38 participants would be sufficient to detect significant interaction effects. Accordingly, the adequate number of participants in each group is about 19 participants. Scores of dropouts participants after pre-test did not differ from those who continued in the study: Corsi task (t_{45} = -0.25, P = 0.81), Stroop (t_{45} = 1.37, P = 0.21) and Oddball task [silence condition: t_{45}= -4.42, P = 0.68, standard condition: t_{45} = -0.9, P = 0.92, novel condition: t_{45} = 0.52, P = 0.96; distraction effect: t_{45} = 0.53, P = 0.59: alertness effect: t_{45} = 0.68, P = 0.50].

Our power calculations did not take into account loss of data, so we performed a test to evaluate the missingness pattern of our actual data. The results of this analysis showed that the data were missing completely at random (MCAR) in the Corsi Blocks Test, the Oddball Task and the Stroop Test (Little MCART Test: Chi-square = 2.781, DF = 6, *P* = 0.836; Little MCART Test: Chi-Square = 0.926, DF = 5, *P* = 0.968; Little MCART Test: Chi-square = 0.000 DF = 3, *P* = 1.000, respectively).

We also performed an intention-to-treat analysis (ITT) by the multiple imputation of missing values through the maximum likelihood estimation procedure with five replications. The result of this ITT analysis is reported adding a mean-*p*-value ($\overline{P}$) on significant effects of the main non-imputed analysis.

6.3.2. Cognitive evaluation: tasks and procedures

Attentional tasks

We assessed distraction and alertness with the Cross-modal Oddball task, and effortful inhibitory control with the Stroop task.

The Cross-modal Oddball task

The task comprised three blocks of 384 trials each (24 practice trials and 360 test trials). In each trial, participants categorized a visual digit from 1 to 7 as odd or even by pressing one of two response keys, which were counterbalanced across participants.

Each trial began with the presentation of a white fixation cross in the center of a grey screen together with a 200 ms sound. The digit appeared in white in the center of the screen 100 ms after the sound's offset and remained on the screen for 200 ms. A response window was displayed for 1,200 ms from the digit's onset. There were three conditions: silent in one block of trials, and two different sounds (standard and novel) in two blocks. The standard sound (80% of the trials), consisted of a 600 Hz sine-wave tone of 200 ms, and the novel sound, used in 20% of the trials, was taken from a list of 72 environmental sounds (e.g., hammer, drill, door, rain, etc.). See Ballesteros et al., (2017b), for a detailed description.

Stroop task

The Stroop task assesses controlled, effortful inhibition. The stimuli were three color words ("red", "green" and "blue") presented in three colors (red, green, or blue) in the center of the screen. Participants responded by pressing the appropriate key of the computer, which were counterbalanced across participants. Each trial started with a black fixation cross, which appeared in the center of the screen on a white background. Stimuli were presented randomly for 200 ms. Participants responded as quickly and accurately as possible by pressing the key corresponding to the color of the stimulus word while ignoring its semantic meaning. See Ballesteros et al., (2017b) for a detailed description.

Visuospatial WM

Corsi Blocks Task

We used a computerized version of the Corsi Blocks task with six levels of increasing difficulty (2, 3, 4, 5, 6, and 7 cube positions) and 12 trials per level. The stimuli consisted of black squares that appeared one by one in the center of the computer screen inside a 3×3 matrix for 1,000 ms each, with a 500 ms inter- stimulus interval (ISI). The final score was the proportion of correct sequences reproduced at each difficulty level.

6.3.3. Assessment of motivation, engagement and expectations

Motivation was assessed at pre- and post-test using a 10-point Likert-type scale (1= not motivated, to 10 = extremely motivated). Participants were asked how engaged they felt during the pre-test and post-test (1 = not engaged at all, 10 = extremely engaged on the task).

Expectations were assessed at pre-test and post-test by asking participants to indicate on a 5-point Likert-type scale how much they thought their overall performance on the experimental tasks would improve after video game training (1 = the results will be much worse, 3 = there won't be any change, 5 = the results will be much better). We also evaluated differences in expectations of improvement after training on each specific experimental task. Participants were asked to indicate what they thought the effects of training would be on each assessment task (1 = the results will be much worse, 3 = there won't be any change, 5 = the results will be much better). Finally, participants reported (1 = no improvement, to 5 = great improvement) how much they thought they had improved in various skills (daily life activities, attention, visual acuity, memory, speed of processing, current studies and emotions) as a consequence of their participation in the project.

6.3.4. The training programs

Participants in the experimental group played 10 video games from *Lumosity* in a randomized order while the active control group played 2 simulation games (*SimCity*, *The Sims*; Electronic Arts Inc.). See Table 2. The selected *Lumosity* games were those that train the following cognitive domain: executive functions, speed of processing, attention and memory, all of them fundamentals for global cognition. The SimCity and Sims games were not specifically designed to train cognitive skills and the difficulty level was not adaptive. Previous young adult studies used *The Sims* as the active control condition (Blacker et al., 2014; Oei & Patterson, 2013.) Both groups completed 15 training sessions (30-35 min per session) in subgroups of 8-15 participants in the presence of the trainer over a period of 3-4 weeks. Each participant was given a tablet (Brigmton BTPC 1018OC) and a headphone. Approximately, each participant played for a total of 7.5 hours.

Table 2. Description of video games.

GAME NAME LUMOSITY ***(Experimental Group)***	**TRAINING FUNCTION**	**DESCRIPTION**
TIDAL TREASURES	Working memory	You have to choose objects and memorize your choice.
PINBALL RECALL	Working memory	You have to predict a balls’ path.
PLAYING KOI	Divided Attention	You have to feed some fish, remembering those that you have already fed.
STAR SEARCH	Selective Attention	There is a bunch of objects and you have to choose the one that is different.
LOST IN MIGRATION	Selective Attention	A flock of birds will appear on the screen and you have to swipe in the direction the middle bird is facing.
COLOR MATCH	Response Inhibition	You have to compare one word’s meaning to another word’s color.
DISILLUSION	Task Switching	You have to solve a puzzle, matching titles with different shapes, colors or symbols.
EBB AND FLOW	Task Switching	Leaves appear on the screen; you must swipe in the direction they are moving or pointing towards.
HIGHWAY HAZARDS	Information Processing	You have to race a car across the desert avoiding colliding with the obstacles that you will encounter.
SPEED MATCH	Information Processing	A card appears on the screen and you must determine whether it is the same as the previous one.
GAME NAME ***(Control Group)***	**TRAINING FUNCTION**	**DESCRIPTION**
SimCity BuildIt	None	Life simulation game in which the player is the mayor of a city that he or she must expand.
The Sims (Free to Play)	None	Life simulation game in which the player creates characters (Sims) who live in a virtual world that is similar to the real one. Sims have to work, build their homes, plan activities, etc.

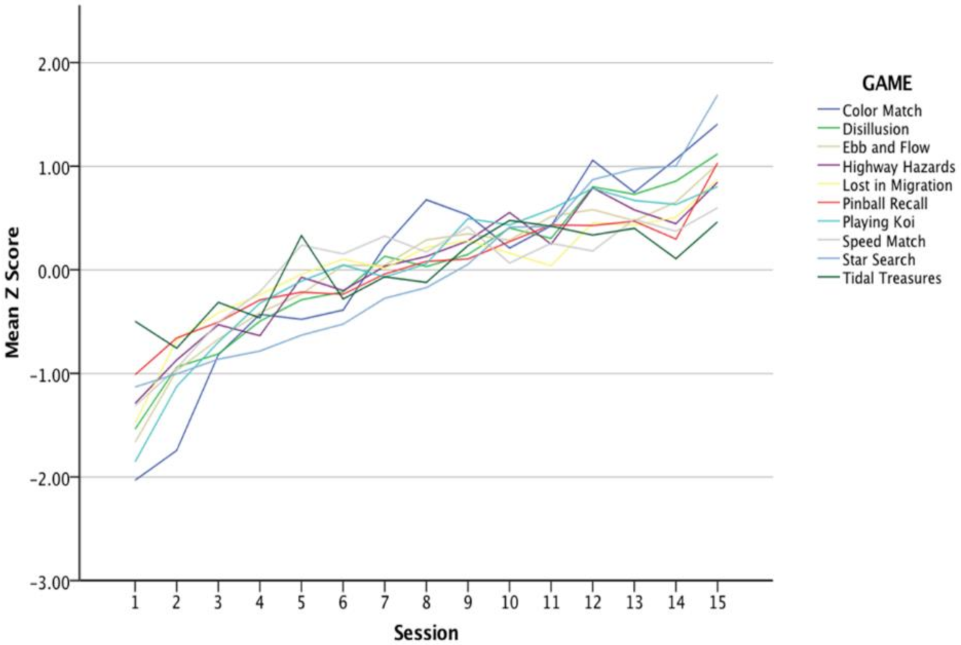
6.4. Results

In all the analyses, we used an alpha of 0.05. All the statistical tests were Bonferroni corrected for multiple comparisons.

6.4.1. Video game performance across training sessions

To assess performance in the experimental group, we analyzed the mean accuracy performance on Z-scores for each of the 10 games that participants played during the training period. Video games performance significantly improved across sessions ($P < 0.01$ in all cases). See Figure 1.

Figure 1. Average performance scores obtained in each video game across the training sessions in Z scores (mean 0; standard deviation 1).



To measure the game performance of the control group, we analyzed two main measures provided by both simulation games: average experience level (mean = 14.84; standard deviation = 4.32) and city population (mean = 32942; standard deviation = 22597). T-test revealed a significant difference between the first and the last training session for both measures [experience level: $t36 = -11.09$; $P < 0.01$ and city population: $t36 = -6.19$; $P < 0.05$].

6.4.2. Motivation, engagement and expectations

Mixed measures ANOVAs with 2 groups (experimental, active control group) x 2 sessions (pre, post) were conducted separately for motivation, engagement and expectations.

***Motivation**:* The ANOVA showed a significant effect of group [$F_{1, 36} = 6.4$; $MSE = 1.34$; $P = 0.001$; $\eta^2 = 0.15$; $1 - \beta = 0.69$]. The experimental group was more motivated (8.03) than the active control group (7.07). Session was also significant [$F_{1, 36} = 12.15$; $MSE = 0.94$; $P = 0.001$; $\eta^2 = 0.25$; $1 - \beta = 0.92$]. Motivation was lower at post-test (7.16) than at pre-test (7.94). There was not significant interaction between group and session.

Engagement**:** The ANOVA showed that group was significant [$F_{1, 37} = 6.80$; $MSE = 1.49$; $P = 0.001$; $\eta^2 = 0.15$; $1 - \beta = 0.72$]. The experimental group was more engaged (7.33) than the active control group (6.31). The effect of session was also significant [$F_{1,37} = 12{,}46$; $MSE = 0.92$; $P = 0.001$; $\eta^2 = 0.25$; $1 - \beta = 0.93$]. Participants were more engaged at pre-test (7.21) than at post-test (6.44). There was not significant interaction between group and session.

Expectations: To assess the reliability of this scale, we combined the items in a global index and computed Cronbach’s alpha. Our results show a reliability of 0.64 for expectations and 0.86 for perceived improvement.

An ANOVA with group and session showed that there was a significant effect of group [$F_{1, 37} = 7.80$; $MSE = 0.18$; $P = 0.008$; $\eta^2 = 0.99$; $1 - \beta = 0.78$]. The

Experimental group holds higher expectations (4.03) than the control group (3.64) and a significant effect of session [$F_{1, 37}$ = 11.09, *MSE* = 0.33; *P* = 0.002; η^2 = 0.23; $1 - \beta$ = 0.9]. Expectations were higher at pre-test (4.05) than at post-test (3.62). There was no interaction between group and session.

Moreover, expectations of improvement after training on the experimental tasks were assessed using a 3 tasks x 2 groups mixed ANOVA. The analysis showed that there was a significant effect of experimental task expectations [$F_{2, 74}$ = 4.69; *MSE* = 0.46; *P* = 0.012; $\eta^2 = 0.11$; $1 - \beta$ = 0.77]. Expectations were higher for the Corsi (3.86) than the Oddball (3.43). Group was also significant [$F_{1, 37}$ = 9.03; *MSE* = 0.65; *P* = 0.005; $\eta^2 = 0.196$; $1 - \beta$ = 0.83]. The experimental group had higher expectations (3.81) than the control group (3.36).

We also assessed differences in expectations regarding daily life activities, memory, processing speed, attention, visual acuity, and emotions as a consequence of their participation in the project, using a 5-point Likert-type scale. *T*-tests showed that there were no main differences between groups for daily life activities [t_{37} = 0.77; *P* = 0.44], attention [t_{37} = 0.78; *P* = 0.44], visual acuity [t_{37} = 1.44; *P* = 0.16], current studies [t_{37} = 0.31; *P* = 0.76] and emotions [t_{37} = 1.02; *P* = 0.31]. However, there were significant differences between groups in their expectations regarding improvements in memory [t_{37} = 3.14; *P* = 0.003]. Expectations regarding memory transfer were higher in the experimental group (3.06) than in the control group (1.71).

6.4.3. Transfer effects of video game training to the experimental tasks

The main results obtained in the transfer tasks by both groups are shown in Table 3.

Table 3. Pre and post training performance on psychological measures for the experimental and control groups.

	MEASURES	PRE EXP G.	POST EXP G.	PRE CTL G.	POST CTL G.	Hedges'g with CI
CORSI BLOCKS TASK	2 Serial Position [a]	0.99 (0.04)	0.98 (0.06)	1 (0)	0.99 (0.02)	0 [-0.63, 0.63]
	3 Serial Position	0.87 (0.05)	0.82 (0.14)	0.87 (0.08)	0.88 (0.07)	0.8 [0.2, 1.5]
	4 Serial Position [a]	0.8 (0.22)	0.87 (0.21)	0.85 (0.12)	0.92 (0.08)	0 [-0.63, 0.63]
	5 Serial Position [a]	0.56 (0.28)	0.73 (0.19)	0.69 (0.19)	0.75 (0.16)	- 0.46 [-1.1, 0.18]
	6 Serial Position [a]	0.42 (0.28)	0.48 (0.26)	0.54 (0.23)	0.63 (0.25)	0.11 [0.52, 0.75]
	7 Serial Position [a,b]	0.15 (0.16)	0.27 (0.22)	0.28 (0.21)	0.39 (0.26)	- 0.05 [-0.69, 0.58]
STROOP TASK	Stroop Congruent Condition (ms)	653.5 (90.16)	652.1 (97.48)	636 (110.71)	646.89 (99.4)	0.12 [0.52, 0.75]
	Stroop Incongruente Condition (ms)	704.4 (94.62)	701.9 (105.69)	686.2 (119.9)	692.27 (103.27)	0.08 [-0.56, 0.71]
	Stroop effect (ms) [a]	50.92 (19.16)	49.8 (38.38)	50.17 (31.10)	45.39 (26.37)	- 0.14 [-0.77, 0.5]
ODDBALL TASK	Oddball Silence Condition	588.1 (81.8)	563.35 (99.54)	568.82 (72.26)	573.37 (71.72)	0.37 [-0.27, 1.01]
	Oddball Standard Condition	557.93 (75.80)	534.09 (86.06)	539.95(66.99)	544.54(57.97)	0.4 [-0.25, 1.03]
	Oddball Novel Condition [a]	585.18 (82.70)	549.99 (91.14)	560.72 (71.92)	548.11(66.87)	0.29 [-0.35, 0.92]
	Distraction (ms) [a,b]	27.25 (24.62)	15.89 (18.13)	20.77 (14.99)	3.57(20.03)	- 0.29 [0.92, 0.35]
	Alertness (ms) [a]	30.17 (37.08)	29.26 (30.15)	28.87 (32.88)	28.83 (28.12)	0.02 [-0.61, 0.66]
PLACEBO EFFECT	Motivation	8.28 (1.23)	7.78 (1.06)	7.60 (1.57)	6.55 (1.43)	- 0.38 [0.26, -1,02]
	Engagement	7.56 (0.98)	7.11 (1.68)	6.86 (1.24)	5.76 (1.58)	- 0,56 [0,08, -1.21]
	General Expectations	4.06 (0.54)	4 (0.68)	4.05(0.38)	3.24 (0.7)	- 1,59 [-0.86, -2.33]
	Task Expectations Corsi		3.72 (0.57)		3.15 (0.79)	0.80 [0.15, 1.45]
	Task Expectations Stroop		3.67 (0.68)		3.28 (0.78)	0.65 [0.01, 1.30]
	Task Expectations Oddball		4.05 (0.72)		3.67 (0.73)	0.51 [-0.13, 1.15]
	Perceived improvement dailylife		1.67 (1.28)		1.38 (1.02)	0.25 [-0.38, 0.88]
	Perceived improvement attention		3.11 (1.37)		2.81 (1.03)	0.24 [-0.39, 0.88]
	Perceived improvement visual acq.		2.89 (1.57)		2.24 (1.26)	0.45 [-0.19, 1.09]
	Perceived improvement studies		1.83 (1.09)		1.71 (1.27)	0.10[-0.53, 0.73]
	Perceived improvement emotions		1.72 (1.45)		1.28 (1.23)	0.32 [-0.31, 0.96]
	Perceived improvement memory[b]		3.05 (1.05)		1.71 (1.52)	0.99 [0.32, 1.66]
	Perceived improvement speed[b]		3 (1.14)		2.14 (1.49)	0.63 [-0.02, 1.27]

Mean scores of the outcome measures with standard deviations in parentheses. (a) Indicates that both groups improved after training. (b) Indicates tasks on wich there was a trend to larg improvements in the experimental group. Effect size (Hedge's g) is the standardized mean difference for pre-/post test designs with two groups (experimental and control). CI is the confidence interval of Hedge's g.

Cross-modal Oddball task

We conducted a 2 group (experimental, active control group) x 2 session (pre-test, post-test) x 3 sound conditions (silence, standard sound, novel sound) mixed ANOVA on the RTs of the correct responses after deleting outliers (reaction times less than 200 ms and more than 1500 ms). The multivariate analysis showed the following results: Wilks´s Λ (session) = 0.09, F (1, 271) = 23.6; P = 0.001; Wilks´Λ (session*group) = 0.93, F (2, 271) = 9.92; P = 0.001; Wilks´Λ (sound condition) = 0.35, F (2, 270) = 251.75; P = 0.001. As these statistics were significant, we examined the univariate results. The results showed a main effect of session [$F_{1, 37}$ = 4.70; *MSE* = 2614.3; *P* = 0.04; $\bar{P}$ = 0.05; $\eta^2 = 0.11$; $1 - \beta$ = 0.56]; RTs were significantly faster at post-test (552 ms) than at pre-test (567 ms). The session by group interaction was significant [$F_{1, 37}$ = 3.98; *MSE* = 2614.3; *P* = 0.05; $\bar{P}$ = 0,23; η^2 = 0.09; $1 - \beta$ = 0.94]; *Post-hoc* pairwise comparisons showed that only the experimental group significantly improved from pre-test (577 ms) to post-test (549.1) ($P < 0.05$). The main effect of sound was also significant [$F_{1.7, 61.9}$ = 32.68; *MSE* = 612.6; $P < 0.001$; $\bar{P}$ = 0,001; η^2= 0.47; $1 - \beta$ = 1]; RTs were faster under the standard sound condition (544 ms) than under the silence (573 ms) and novel sound (561 ms) conditions ($P < 0.01$) but not between silence and novel sound conditions. No other interaction was significant.

We conducted additional analyses on *distraction* and *alertness*. The distraction effect was calculated as the difference between the RTs in novel sound trials and the RTs in the standard sound trials. A 2-group x 2 session mixed ANOVA performed on distraction showed that session was significant [$F_{1, 37}$ = 26.56; *MSE* = 148.7; $P < 0.05$; $\bar{P} < 0,01$; η^2 = 0.42; $1 - \beta$ = 0.99]. Distraction at post-test significantly decreased compared to pre-test for both the experimental group (pre-test = 27 ms; post-test = 16 ms) and the control group (pre-test = 21 ms; post-test = 4 ms). No other effect or interaction was significant.

Alertness was calculated as the difference between RTs under the silence condition and RTs under the standard sound condition. The 2-group x 2 session mixed ANOVA showed neither a significant main effect nor an interaction (all *Ps* > 0.05).

Stroop task

Responses were coded according to the congruency between the color and the meaning of the word. Outliers (1% of the trials) were defined as reaction time responses less than 200 ms and more than 1500 ms.

We conducted a 2-group x 2 session x 2 congruency condition (congruent, incongruent) mixed ANOVA on the mean reaction times (RTs) for correct trials as the dependent variable. The multivariate analysis showed the following results: Wilks´Λ (congruency) = 0.21, *F* (1, 37) = 140.85; *P* = 0.001. As these statistics were significant, we examined the univariate results. Congruency was significant [$F_{1, 37}$ = 140.85; *MSE* = 662.83; *P* < 0.01; $\bar{P}$ = 0.005; η^2 = 0.79; $1 - \beta$ = 1]. Congruent trials were faster than incongruent trials. There were no further significant main effects or interactions (all *P´s* > 0.05). We also computed the Stroop effect as the difference between incongruent RTs and congruent RTs. A 2-group x 2 session mixed ANOVA showed that neither the main effects nor the interaction was significant (all *P´s* > 0.05).

Corsi blocks

We performed a mixed 2 group x 2 session x 6 Corsi level (2, 3, 4, 5, 6 and 7) ANOVA with the last two factors within-subjects. The multivariate analysis showed the following results: Wilks' Λ (session) = 0.73, F (1, 37) = 13.34; P = 0.01, Wilks´ Λ (level) = 0.045, F (5, 33) = 139.08; P = 0.001 and Wilks´ Λ (session*level) = 0.66, F (5, 33) = 3.45; P = 0.013. As these statistics were significant, we examine the univariate results, which showed a significant main effect of level [$F_{5, 185 =}$ 203.89; MSE = 0.03; P = 0.001; $\boldsymbol{\bar{P}}$ = 0.001; η^2 = 0.85; 1 – β = 1] with lower scores as increasing level. Session was also significant [$F_{1, 37}$ = 13.34; MSE = 0.029; P < 0.01; $\bar{P}$ = 0.047; η^2 = 0.25; 1 – β = 0.94]. Participants performed better at post-test (0.73) than at pre-test (0.67). The interaction between level and session [$F_{3.5, 130}$ = 4.73; MSE = 0.02; P = 0.001; $\bar{P}$ = 0.001; η^2 = 0.113; 1 – β = 0.97] was also significant. Post-hoc pairwise comparisons showed that both groups improved after training at levels 3 (0.82 and 0.89), 4 (0.62 and

0.74), and 6 (0.22 and 0.33), and marginally significant (P = 0.059) at level 5 (0.48 and 0.56 at pre and post-test, respectively). No other effects or interactions were significant.

6.5. Discussion

The present study yielded the following main results. First, participants' video game performance improved across the training sessions (Ballesteros et al., 2014; Wu et al., 2012). Second, both groups were less distracted after training. Third, effortful inhibition did not show any improvement at post-test in either group. Fourth, visuospatial WM improved after training in both groups.

Our results did not show the expected effect of training. The interaction between group (the experimental group trained with non-action video games and the active control group trained with the non-adaptive simulation-strategy games) and session was not significant, except in the overall scores of the oddball task. The results revealed a similar effect of training both groups, showing no differential effect of the type of video games used (Lumosity and SimCity/The Sims). Since the present study did not include a passive control group, we cannot conclude that the adaptive non-action games had an effect, as some external factor might account for increases in both groups.

A recent study conducted with older adults trained with video games from *Lumosity* and a control group that did not receive training showed that the trained group improved significantly on the Corsi Blocks after video game training, but a passive control group showed no change (Toril et al., 2016). Most spatial cognition tasks depend on attention and WM capacities, which are closely interconnected (Awh & Jonides, 2001; Olivers, 2008; Spence & Feng, 2010), but few studies have focused on visuospatial WM changes resulting from video game practice in young adults. Nonetheless, the present study also showed that experimental group performed better than the control group at post-test on the Cross-modal Oddball task, but only for the global scores. This interaction did not show up in the distraction scores, suggesting that if there is any effect, it is very small. Some authors have suggested that players benefit in the control and allocation of selective attention. The shifting of mental set is a different executive function than updating of WM, inhibition of responses, and separable components of selective attention, Fournier-Vicente, Larigauderie, & Gaonac'h, 2008), but most of the classic switching tasks assess all of these elements as a whole. However, Karle et al. (2010) indicated that gamers have reduced task-switching costs due to their ability to control selective attention, rather than a more general benefit in cognitive control abilities. Thus, there are mixed results about selective attention, distraction and attention capture. Further research is needed to clarify them. Stroop interference did not show any improvement after training in response inhibition in either group. These results are in agreement with findings from older adults (Ballesteros et al., 2017b).

We hypothesized that playing adaptive brain games would improve visuospatial WM and attention. We tried to overcome some methodological limitations in other studies by including an active control group. The present results showed that non-action video games could mildly benefit young adults from pre- to post-intervention, but the benefits were not exclusive to brain training games as we also found some cognitive improvement in the active control group. We assessed motivation, engagement and expectations and they do not seem to explain the benefits derived from the video game training. Based on these results, it seems that general expectations could not affect primary outcomes measures because expectations were higher at pre-test, but significant effects were found at the Oddball Task and Corsi Block Test after training. Participants showed higher expectations at Corsi Test than at the Oddball Task but both results were significantly higher at post-test.

6.6. Conclusions and limitations

To conclude, we did not find a significant difference between adaptive non-action video games and the active control games used. As we did not have a non-intervention control group, we cannot conclude that adaptive non-active video games had an effect, because some external factor might account for observed increases in both groups. Thus, future studies should include both an active control group and a no-contact group. Moreover, our power calculations did not anticipate the loss of data due to outliers. Consequently, we performed a test for missingness of data at random, and the results showed that the data were missing completely at random in all the experimental tasks. A limitation of the present study is that males were underrepresented in our sample and highly educated young people were overrepresented. This limitation could have produced some bias in our results and should be addressed in future studies. Further research should include not only an active control group but also a passive control group to explore possible test-retest effects.

CHAPTER 7

DISCUSSION AND CONCLUSION

7.1. Study 1

Title: Effects of Video Game Training on Measures of Selective Attention and Working Memory in Older Adults: Results from a Randomized Controlled Trial.

7.1.1. Abstract

Normal aging is mainly characterized by a decline in memory, attention and executive functions. The results of non-action video-game studies are not yet conclusive due to methodological limitations related to the randomization of participants, the use of adequate control groups, the type of design and control of the placebo effect. To overcome these limitations, we designed this research with adults aged over 50 years. The intervention was registered as a Clinical Trial and 55 participants were randomized into an experimental group that played cognitive or brain games from Lumosity and an active control group that played simulation games (The Sims, and SimCity BuildIt, from Electronic Arts). The participants played under the experimenter's supervision in small groups (6-10 participants per group) for two months, two sessions per week, 30 min per session for a total of 15-16 sessions. Primary outcomes were: selective attention, distraction and alertness (measured with the Crossmodal Oddball Task), effortful inhibition (measured with the classic Stroop Test), visuospatial working memory (measured with the Corsi Block Test) and verbal working memory (measured with the NBack Task). Secondary outcomes referred to control of the placebo effect. We measured motivation, engagement and expectations at pre-test, training and post-test. Analysis showed moderate effects in working memory in both groups, and the active control group moderately improve in distraction, but there were no pre-post differences in inhibitory control in either group. These results could not be explained by placebo effects related to motivation, engagement or expectations.

7.1.2. Conclusion

Brain games and other kinds of video games such as simulation games could positively benefit the attention and working memory of older adults, but the effects are moderate in terms of near and far transfer of learning. However, older adults showed no gains in inhibitory control after training with non-action video games.

7.2. Study 2

Title: Effects of Cognitive Training with Non-Action Video Games on Measures of Selective Attention and Working Memory in Young Adults.

7.2.1. Abstract

The aim of this study was to analyze cognitive gains after brain-game training in young adults. To do so, 48 participants were randomized into an experimental group that trained with brain games (from Lumosity), and an active control group that trained with simulation games (SimCity BuildIt, from Electronic Arts), under identical conditions. Participants were divided into small groups (6 – 10 participants per group), for a period of 3 weeks, 5 times per week, 30 min per session for a total of 15 sessions. To measure selective attention, inhibitory control and visuospatial working memory, and to assess possible benefits derived from video-game training, we used the Crossmodal Oddball Task, the classic Stroop Task and the Corsi Blocks Test. To control for the placebo effect, we collected data about motivation, engagement and expectations to avoid any possible influence of these variables. The results showed moderate positive effects in terms of selective attention, distraction, and visuospatial working memory, but no gains were observed in effortful inhibition. However, these effects were not exclusive to the brain-training group, and the participants in the active control group also showed moderate benefits in the same domains as those in the

experimental group after video-game training. As we did not have a passive non-intervention control group, we cannot conclude that adaptive non-action video games had a positive effect, because some external factor might account for the pre- and post-test improvements observed in both groups.

7.2.2. Conclusion

Young adults are able to transfer learning from non-action adaptive brain games to attention and visuo-spatial working memory with moderate effect sizes, and the positive results could also be obtained with other non-action video games such as simulation games. Nonetheless, playing non-action video games did not improve inhibition responses in young adults. However, as we did not have a non-intervention control group, we cannot conclude that adaptive non-active video games had an effect. Thus, future studies should include both an active control group and a no-contact group.

7.3. General conclusions

7.3.1. Contributions of this thesis

In the present work, we analyze changes in memory and attentional functions that result from brain training in young adults aged 18 to 35 years and older adults aged over 50. Results are positive but moderate and are not exclusive to adaptive brain games. In fact, the active control group playing simulation games also showed cognitive improvements. In this project, we wished to overcome previous methodological limitations that some authors consider underlying conflicting results, some studies describing benefits from video games, while others found no positive effects. We randomized participants into two groups: an experimental group and an active control group. Both groups trained with the same devices under identical conditions, and we controlled for the placebo effect by measuring motivation, expectations and engagement. Our main purpose was to assess behavioral benefits resulting from brain-game training in terms of working memory, selective attention, and response inhibition; these cognitive functions are very important for life-long learning and are usually affected during normal and pathological aging, compromising independent living. To do so, we developed an intervention program with a total of 15-16 training sessions. To evaluate the impact of video-game training, participants completed the Corsi Blocks Task, the *N*-Back Task, the Cross-modal Oddball Task, and the Stroop Test before and after the intervention. Younger and older adults in both experimental and active control groups showed benefits in visuospatial working memory, selective attention and distraction (measured by subtracting the reaction times in the baseline condition from those in the novel condition). However, there were no changes related to response inhibition. We hypothesized that memory, attention and executive functions would improve more by playing cognitive or brain games than non-mental non-adaptative games. However, our results show that brain games have positive effects on cognition, but other video games such as simulation games that share some elements with brain games can also improve learning and transfer in young and older adults.

It is also important to mention that the lack of improvement on the Stroop Test after video-game training is in line with previous studies; only a few studies have reported positive effects on response inhibition. It would therefore be important in the future to identify the factors that affect performance on this task, and the transfer of learning. Further studies of the distraction effect are also needed. In younger adults, brain games and simulation games produce transfer of learning, decreasing the distraction effect, while in older adults, the active control group showed significant improvement while the experimental group did not benefit from training. According to the literature, older adults are more distracted than younger adults, which affects the acquisition and recall of new information. It is important to understand this process and to explain our results, and to understand the way that task modality can influence the results. However, it is beyond the scope of this work to explain this phenomenon in depth.

In conclusion, our research shows that adaptive video games and other games could help optimize cognitive performance in visuospatial working memory, selective attention and distraction in young adults and in adults aged over 50, which could help attenuate the decline associated with normal aging.

7.3.2. Future research

Future research should analyze the features of video games that promote learning, near and far transfer, and the components of the assessment tasks that are related to the cognitive functions associated with video games. Moreover, it should seek to develop methods to measure near and far transfer because of video-game training. Future research should also include a passive control group and seek to replicate these moderate positive effects, taking into consideration the placebo effects related to motivation, engagement and expectations.

CHAPTER 8

RESUMEN

EFECTOS DEL ENTRENAMIENTO CON VIDEOJUEGOS EN ATENCIÓN Y MEMORIA EN ADULTOS JÓVENES Y MAYORES.

MEDIDAS CONDUCTUALES

DOCTORADO EN PSICOLOGÍA DE LA SALUD

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8.1. Introducción

Durante la última década se ha producido un auge en la investigación sobre los efectos de los videojuegos cognitivos y educativos y sus diferentes aplicaciones (Palaus et al., 2017). La industria del entretenimiento ha aumentado su inversión en el desarrollo de estos productos dado que cada vez existe mayor cantidad y diversidad de usuarios. El interés de estos videojuegos radica en su aplicabilidad y accesibilidad. Pueden utilizarse con fines pedagógicos, pero también preventivos y rehabilitadores en diferentes contextos clínicos y educativos (Barnes & Prescott, 2018; Best, 2013; Neri et al., 2017). Cualquier persona, independientemente de su edad y experiencia previa, puede aprender a jugar con ellos. Además, son económicos y de fácil acceso al ser jugados a través de dispositivos portátiles y táctiles como móviles y tablets (Joddrell & Astell, 2016).

Sin embargo, en el contexto de la investigación psicológica aún no existe consenso respecto a los beneficios reales en términos de optimización de funciones cognitivas o prevención de déficits cognitivos asociados a diferentes patologías o procesos del desarrollo (Simons et al., 2016).

Las investigaciones realizadas durante los últimos años por el grupo de investigación de la UNED "Estudios en Envejecimiento y Enfermedades Neurodegenerativas" se han centrado en el estudio de programas de intervención que ayuden a prevenir el deterioro cognitivo asociado a la edad. La literatura sobre el tema ha mostrado resultados mixtos en función de los estudios, las tareas utilizadas y los constructos psicológicos estudiados (Ballesteros et al., 2014; Ballesteros et al., 2017b; Toril et al., 2016).

Investigaciones de otros grupos han mostrado también diversidad de resultados (Cain et al., 2012; Mondéjar et al., 2016; Kable et al., 2017; Murphy & Spencer, 2009). Ante la necesidad de encontrar los factores que puedan explicar estas divergencias, algunos autores han señalado pautas metodológicas necesarias para mejorar la calidad de estas intervenciones. Entre otras, cabe mencionar la randomización de los participantes, el uso de grupos de control activo que entrenen en condiciones similares a los participantes del grupo experimental, el registro de los ensayos clínicos, y el control del efecto placebo debido principalmente a expectativas, motivación y concentración en el juego (Boot et al., 2013; Boot & Simons, 2012; Simons et al., 2016).

En los dos estudios que componen el presente trabajo hemos intentado seguir las directrices metodológicas arriba mencionadas. Hemos realizado dos intervenciones con videojuegos de no acción, una en adultos jóvenes y otra en mayores.

8.2. Objetivos

Nuestros objetivos fueron los siguientes:

- Estudiar los efectos del entrenamiento con videojuegos cognitivos de no acción adaptativos, en memoria de trabajo, atención selectiva y control cognitivo en adultos mayores de 50 años.

- Estudiar los efectos del entrenamiento con videojuegos cognitivos de no acción adaptativos en memoria de trabajo, atención selectiva y control cognitivo en jóvenes entre 18 y 35 años.

- Superar limitaciones metodológicas previas realizando intervenciones controladas aleatorizadas.

- Tanto en el estudio con adultos mayores como con el estudio con adultos jóvenes hemos comparado los resultados de los participantes del grupo experimental con los de un grupo de control activo que entrenó y fue evaluado en condiciones equivalentes al grupo experimental con videojuegos no adaptativos de simulación, superando una de las limitaciones más frecuentes en este tipo de intervenciones.

- Controlar el efecto placebo que pueda ser debido a motivación, concentración o expectativas, analizando estos parámetros durante el entrenamiento con videojuegos y durante las sesiones de evaluación.

8.3. Hipótesis

Nuestras hipótesis fueron las siguientes:

- En el estudio con adultos mayores, esperamos que el grupo experimental que entrene con videojuegos mentales adaptativos, muestre beneficios derivados del entrenamiento en las tareas de evaluación de memoria de trabajo, atención selectiva, distracción, y control cognitivo.

- En el estudio con adultos mayores, hipotetizamos que el grupo de control activo, que entrena con videojuegos de simulación no adaptativos, no mostrará diferencias significativas pre-post test en la ejecución de las tareas que miden las funciones cognitivas objeto de estudio (memoria de trabajo, atención selectiva, distracción, alerta y respuesta inhibitoria).

- En el estudio con jóvenes, hipotetizamos que los participantes del grupo experimental mejorarían su rendimiento tras el entrenamiento en tareas que evalúan las funciones cognitivas.

- En el estudio con jóvenes esperamos que los participantes del grupo control activo no muestren cambios significativos en las funciones cognitivas evaluadas como consecuencia del entrenamiento con videojuegos.

- Tanto en el estudio con adultos jóvenes como en el estudio con adultos mayores, pensamos que, de manera similar a otras investigaciones, los participantes mejorarán en los videojuegos entrenados a lo largo de las sesiones de entrenamiento, tanto en los grupos experimentales como en los grupos control.

- Hipotetizamos que, en ambos estudios, la motivación, la inmersión en el entrenamiento y en las sesiones de evaluación o las expectativas, serán similares en el grupo experimental y control, y no podrán explicar las diferencias significativas que se observen como resultado de la intervención.

8.4. Descripción de los estudios y resultados

8.4.1. Estudio 1

Título:

Efectos del entrenamiento con videojuegos en medidas de atención selectiva y memoria de trabajo en adultos mayores: resultados de un ensayo clínico aleatorizado (Ballesteros et al., 2017b).

Breve descripción del trabajo y principales resultados

El envejecimiento normal se caracteriza principalmente por un deterioro de la atención, la memoria, y las funciones ejecutivas. Sin embargo, los estudios realizados sobre entrenamiento de funciones cognitivas con videojuegos para prevenir el deterioro cognitivo aún no son conclusivos. En este estudio se han intentado superar algunas limitaciones metodológicas previas descritas en la literatura. Para ello, realizamos un ensayo clínico aleatorizado con 55 participantes sanos, mayores de 50 años distribuidos aleatoriamente en un grupo experimental, que entrenó con videojuegos de no acción adaptativos, desarrollados por Lumosity Inc. y un grupo de control activo, que entrenó con videojuegos no adaptativos de simulación (The Sims y SimCity BuildIt), desarrollados por Electronic Arts.

Los participantes de cada uno de estos grupos fueron entrenados y evaluados en condiciones similares. Los entrenamientos fueron supervisados por el mismo entrenador, realizados en grupos de entre 6 y 10 participantes con una duración de 15 sesiones aproximadamente de 30 minutos cada una, distribuidas en 2 meses, 2 sesiones por semana. Para medir la atención selectiva, la memoria de trabajo verbal y visuoespacial y la respuesta de inhibición, se utilizaron la Tarea Oddball, el Test de Bloques de Corsi, la Tarea NBack y la Tarea Stroop. Además, se controló que los posibles resultados pudieran deberse a la motivación, a la inmersión o a las expectativas.

Los resultados mostraron beneficios derivados del entrenamiento con videojuegos en memoria de trabajo, atención selectiva y distracción, pero no hubo cambios significativos en el control ejecutivo. Además, los resultados no parecen verse afectados por las variables de motivación, concentración y expectativas. Sin embargo, los resultados positivos no fueron exclusivos del grupo experimental, pues los participantes del grupo de control activo también mostraron beneficios moderados similares.

8.4.2. Estudio 2

Título:

Efectos del entrenamiento cognitivo con videojuegos de no acción en medidas de atención selectiva y memoria de trabajo en adultos jóvenes.

Descripción y resultados:

El presente estudio tuvo por objeto comprobar los posibles resultados cognitivos derivados del entrenamiento con videojuegos adaptativos en la memoria de trabajo, la atención selectiva y control cognitivo en adultos jóvenes. Para llevarlo a cabo, se distribuyó aleatoriamente a 48 participantes en un grupo experimental y un grupo de control activo. El grupo experimental entrenó con videojuegos mentales adaptativos desarrollados por Lumosity Inc., y el grupo de control activo entrenó con videojuegos de no acción adaptativos y de simulación (SimCity BuildIt and The Sims, desarrollados por Electronic Arts.). Ambos grupos entrenaron en condiciones similares organizados en grupos de entre 6 y 10 participantes, durante 3 semanas, 5 veces a la semana con un total de 15 sesiones aproximadamente de 30 minutos cada una.

Para medir los beneficios cognitivos en atención selectiva, memoria de trabajo visuoespacial y control mental, utilizamos la Tarea Oddball, el Test de Bloques de Corsi y la Tarea de Stroop. También evaluamos la motivación, la inmersión y las expectativas de los participantes para poder cuantificar cualquier influencia posible en los resultados asociados al Efecto Placebo.

Los resultados mostraron mejoras moderadas después del entrenamiento en atención selectiva, distracción y memoria de trabajo visuoespacial, pero no se observaron cambios en el control mental. No obstante, estos resultados no fueron exclusivos de los participantes del grupo experimental puesto que los participantes del grupo de control activo también mostraron beneficios similares. Además, no podemos afirmar rotundamente un efecto de mejora derivado del entrenamiento con videojuegos pues no tenemos un grupo de control pasivo.

Los resultados de este estudio nos llevan a concluir que los videojuegos de no acción adaptativos influyen moderada pero significativamente a nivel cognitivo en adultos jóvenes en funciones atencionales y mnésicas, pero no en la ejecución de tareas de inhibición de la respuesta. Sin embargo, otro tipo de videojuegos de no acción, como por ejemplo los juegos de simulación con los que entrenaron los participantes del grupo de control activo mostraron efectos similares. Sin embargo, en futuras intervenciones, sería necesario comparar los resultados del grupo experimental no sólo con un grupo de control activo sino también con un grupo de control pasivo.

8.5. Conclusiones generales

Con el presente trabajo hemos estudiado el efecto del entrenamiento con videojuegos de no acción en memoria, atención e inhibición de la respuesta a través de la realización de dos estudios, uno con adultos jóvenes y otro con adultos mayores.

Para intentar superar las limitaciones encontradas en estudios previos, seguimos las pautas metodológicas propuestas por algunos autores (Boot & Simons, 2012; Boot et al., 2013; C. Shawn Green et al., 2013; Simons et al., 2016) con el propósito de mejorar la calidad de este tipo de intervenciones, tales como el desarrollo de estudios controlados aleatorizados, la elección de un grupo de control activo que pudiera entrenar y ser evaluado en condiciones equivalentes al grupo experimental, y el control del Efecto Placebo dependiente de motivación, concentración y expectativas. Nuestros objetivos eran estudiar en dichas condiciones los posibles beneficios de la intervención con videojuegos en funciones cognitivas, principalmente: memoria y atención.

Tanto en adultos mayores como en jóvenes se observaron beneficios derivados de los videojuegos en memoria de trabajo, atención selectiva y distracción, pero los beneficios no fueron exclusivos del grupo experimental.

También es relevante mencionar que los resultados en la Tarea de Stroop no fueron positivos en ninguno de nuestros estudios. Este resultado concuerda con otras investigaciones previas. Son escasos los estudios que han mostrado efectos en la inhibición de la respuesta, por lo que sería importante en el futuro, desarrollar investigaciones en esta línea y especificar los factores que están asociados a la realización de esta tarea, así como las posibilidades de transferencia del aprendizaje cercano y lejano.

En el estudio de esta Tesis realizado con adultos jóvenes, tanto los participantes entrenados con videojuegos cognitivos como los participantes del grupo control que jugaron con videojuegos de simulación mostraron resultados positivos en la tarea Oddball, una disminución del Efecto de Distracción, mientras que, en adultos mayores, tan solo el grupo que entrenó con videojuegos de simulación mostró un beneficio significativo. De acuerdo a la literatura, los adultos mayores se distraen más que los jóvenes, lo que dificulta el recuerdo y la adquisición de nueva información. En el futuro, sería importante estudiar más a fondo este fenómeno y cómo la modalidad de la tarea puede influir en los resultados.

En conclusión, los trabajos incluidos en esta Tesis muestran que los videojuegos adaptativos y otros videojuegos pueden contribuir a la mejora del rendimiento cognitivo en memoria visuoespacial, atención selectiva y distracción, en adultos jóvenes y mayores, lo que puede ayudar a frenar el deterioro asociado al envejecimiento cognitivo, sin embargo, en el futuro se debe contemplar la posibilidad de efectos resultantes de entrenamientos con videojuegos de no acción no adaptativos, y añadir a los estudios además del grupo de control activo adecuado, un grupo de no intervención.

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