Video Game Training Enhances Cognition of Older Adults: A Meta-Analytic Study

Pilar Toril, José M. Reales, and Soledad Ballesteros
The National University of Distance Education

It has been suggested that video game training enhances cognitive functions in young and older adults. However, effects across studies are mixed. We conducted a meta-analysis to examine the hypothesis that training healthy older adults with video games enhances their cognitive functioning. The studies included in the meta-analysis were video game training interventions with pre- and posttraining measures. Twenty experimental studies published between 1986 and 2013, involving 474 trained and 439 healthy older controls, met the inclusion criteria. The results indicate that video game training produces positive effects on several cognitive functions, including reaction time (RT), attention, memory, and global cognition. The heterogeneity test did not show a significant heterogeneity ($I^2 = 20.69\%$) but this did not preclude a further examination of moderator variables. The magnitude of this effect was moderated by methodological and personal factors, including the age of the trainees and the duration of the intervention. The findings suggest that cognitive and neural plasticity is maintained to a certain extent in old age. Training older adults with video games enhances several aspects of cognition and might be a valuable intervention for cognitive enhancement.

Keywords: aging, cognitive functions, meta-analysis, moderating factors, video game training

The proportion of people aged over 65 is increasing worldwide (United Nations, 2010). Given this increasing longevity and the cognitive and physical declines that occur with aging, researchers are investigating ways to promote independent living, delaying cognitive decline as much as possible (for reviews see Hertzog, Kramer, Wilson, & Lindenbergen, 2008; Park & Reuter-Lorenz, 2009). To this end, efforts are being made to investigate the potential of new information and communication technologies (ICT) to improve cognitive functioning (Bond, Wolf-Wilets, Fiedler, & Burr, 2001) and quality of life in older adults (Ballesteros, Toril, Mayas, Reales, & Waterworth, 2014; Leung & Lee, 2005; Peter et al., 2013). The reduction in the number of social relations, the deterioration of physical abilities and the decline of cognitive functioning are important burdens in old age (Meijer, Van Boxtel, Van Gerven, Van Hooren, & Jolles, 2009).

Aging is associated with declines in many cognitive processes. However, current findings from longitudinal studies have found older age a time of decline, stability, and even growth (Baltes & Lindenberger, 1997; Rönnlund, Lövden, & Nilsson, 2008). Specifically, declines occur with age in several processes including processing speed, attention, executive control, working memory, and episodic memory (e.g., Hoyer & Verhaeghen, 2006; Nilsson, 2003; Rönnlund, Nyberg, Bäckman, & Nilsson, 2005; Salthouse, 1996). In contrast, other crystalized cognitive functions as general knowledge, verbal abilities (e.g., Bialystok & Craik, 2006; Hedden & Gabrieli, 2004) and implicit memory (e.g., Ballesteros, Bischof, Goh, & Park, 2013; Ballesteros & Reales, 2004; Mitchell & Bruss, 2003; Wiggs, Weisberg, & Martin, 2006) are mostly preserved or even improve.

A number of recent studies have shown that positive changes in older adults′ cognition can occur after training with video games (Anguera et al., 2013; Buschkuehl et al., 2008; Nouchi et al., 2012). Although findings on this topic are sparse, evidence suggests that the older brain retains considerable plasticity. In other words, it has the ability to increase its capacity in response to experience. The observed increase in neural volume in response to cognitive training is an important indicator of brain change (see Boyke, Driemeyer, Gaser, Büchel, & May, 2008; Park & Bischof, 2013). Encouraged by previous findings showing that cognitive training interventions can improve cognition in healthy older adults (Ball et al., 2002; Basak, Boot, Voss, & Kramer, 2008; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Willis et al., 2006), there is a growing interest in video game training as an effective way of enhancing important aspects of cognition and neural plasticity in older adults (e.g., Anguera et al., 2013; Boot, Blakely, & Simmons, 2011; Nouchi et al., 2012; Prakash et al., 2012). Cognitive training can be defined as an intervention that provides structured practice on tasks relevant to different aspects

of cognitive functioning, such as memory, attention, language, or executive functions. Theoretically, these studies suggest that the older human brain maintains some neural plasticity (e.g., Pascual-Leone, Amedi, Fregni, & Merabet, 2005; Raz et al., 2005) although not to the same degree as young adults (e.g., Bialystok & Craik, 2006; Lee et al., 2008; Li, Brehmer, Shing, Werkle-Bergner, & Lindenberger, 2006).

In our technological society, computer-based training programs and video games have interested researchers as a tool for improving and/or maintaining perceptual and cognitive functions in older adults. However, so far, scientific evidence of the potential of these interventions is mixed, as reviewed below.

Effects of Training With Video Games on Cognitive Functions in Older Adults

A video game is an electronic game that involves human interaction with a computer by means of a user interface that generates visual and auditory feedback. Video games can be classified in different nonoverlapping categories. The first category is "serious games" (Gopher, Weil, & Bareket, 1994), primarily designed to convey information or a learning experience of some sort to the game player. A second category comprises "educational games," such as *Brain Age* and *Brain Training* (McDougall & House, 2012). Video games can also be classified as simple or non-action games and complex games.

The use of video games as a way to enhance cognitive functioning in healthy older adults has an advantage over traditional cognitive training programs in that they are relatively inexpensive, enjoyable, and fun (Zelinski & Reyes, 2009). Video games include images, movement, sound, and feedback. All these characteristics are more attractive and rewarding than printing materials. Moreover, a recent study (Allaire, McLaughlin, Trujillo, Whitlock, & Laporte, 2013) showed that regular and occasional video game players reported significantly higher levels of wellbeing and less depression than nonvideo game players. For these reasons, video games have been used as a tool for training young and older adults, and are considered to provide a good context for cognitive enrichment (Achtman, Green, & Bavelier, 2008; Green & Bavelier, 2008). Early studies with older adults revealed improvements in several cognitive functions after video game training, including processing speed (Clark, Lamphear, & Riddick, 1987; Dustman, Emmerson, Steinhaus, Shearer, & Dustman, 1992; Goldstein et al., 1997), intelligence (Drew & Waters, 1986), visuomotor coordination (Drew & Waters, 1986), attention (Belchior, 2008), and global cognitive function (Torres, 2008). However, other studies did not find a significant transfer of training to measures of cognitive and perceptual functioning (e.g., Ackerman, Kanfer, & Calderwood, 2010; Boot et al., 2013; Owen et al., 2010). The transfer of video game training to untrained cognitive functions is critical and has important practical significance.

Recently, Kueider, Parisi, Gross, and Rebok (2012) conducted a systematic review (SR) to examine the effectiveness of computer-based cognitive interventions in cognitively healthy older adults. The SR method attempts to answer a theoretical question by analyzing empirical published studies in the field of interest to obtain a summary of the results in terms of effect size. Meta-analysis, however, provides a better way of analyzing the results of several individual studies. The main advantage of meta-analysis

over SR is that it involves statistical tests on individual effect sizes producing, among other things, significance statistics, confidence intervals, and heterogeneity indexes that enhance the information provided by the analysis. For example, Kueider et al. (2012) outlined the difficulties posed by the variability and length of video game interventions in the results obtained. Meta-analysis is thus an appropriate tool to elucidate the conflicting results published so far in this field. The existence of several outcomes and moderator variables in the original studies does not preclude the possibility of conducting a meta-analysis. Borenstein, Hedges, Higgins, and Rothstein (2009) suggested that this kind of meta-analysis is feasible although it involves great complexity. The present meta-analytic study is thus intended as a refinement and an extension of the SR conducted by Kueider et al. (2012).

One of the main difficulties in obtaining a clear picture of the effects of video game training is the great variability of several key features of the intervention studies, including the type of video game used, the type of cognitive process assessed, the way in which these cognitive processes were evaluated, and personal characteristics of the trainees. Presumably, the mixed results reported in the literature can be attributed to this variability. For example, some studies reported positive results (e.g., Anguera et al., 2013; Goldstein et al., 1997; Torres, 2008), whereas others did not find any cognitive improvement (e.g., Ackerman et al., 2010; Owen et al., 2010). Meta-analysis is a good tool to determine the variables responsible for the discrepancies reported in the intervention studies (Hertzog et al., 2008).

Scope, Aims, and Hypotheses of the Meta-Analysis

The main aim of this meta-analytic study was to investigate the extent to which cognitive training with video games enhances cognitive functions in healthy older adults. It synthesizes the effect sizes obtained in video game training studies conducted to investigate transfer effects. Furthermore, we were interested to find out which training variables might explain the wide variability of results reported in the literature. We also tried to identify the specific variables involved in the modulation of the effect sizes obtained in the intervention studies. The first step was to review the published literature in order to identify the main variables that modulate the effect. We selected six main variables thought to contribute to the results: (a) the type of video game used, (b) the duration of the training program, (c) the number of games used in the training program, (d) the type of program, (e) the type of control group, and (f) the age of the participants. These variables were coded for each study and introduced as covariates in the analysis. The dependent variables used to compute the effect sizes are known as outcomes. In the literature on video game intervention studies, there are a variety of outcomes related to cognitive processes. We combined the outcomes to compute a single effect size for each study. To examine the effect of the moderator variables, the outcomes were classified into five broad cognitive categories: memory, attention, RT, executive functions, and global cognitive function.

To code the type of video game used in each study, we attempted to classify them. This was not an easy task as there has been a spectacular development in this field during the last decade. Briefly, the first video games were simple or non-action games (e.g., *Pac-Man* or *Donkey Kong*). Their use as cognitive training

tools improved performance on speed of processing tasks but not on executive function or working memory tasks (Clark et al., 1987; Dustman et al., 1992; Goldstein et al., 1997). Later, more complex action games were developed in which planning and strategic factors played a predominant role. Video games such as *Medal of Honor* and *Space Fortress* are classified as complex games that activate many perceptual and cognitive skills. Some studies have used this type of video game in their interventions with older adults (e.g., Basak et al., 2008; Stern et al., 2011). The type of video game used to train older adults is thus an important variable in video game training studies. Zelinski and Reyes (2009) classified video games as simple versus complex. The former does not involve complex cognitive demands, yet the latter requires the concurrent recruitment of many perceptual and cognitive skills. We followed this approach when classifying the types of video game used in the intervention studies. Two complementary moderators were also considered in our analysis: duration of training, and number of games used in the intervention. The amount of training, as well as the diversity of skills involved, might also explain some of the variance of the results even when the type of video game is the same. We also included in the meta-analysis other two moderator variables, type of program (commercial video games vs. "brain training" programs designed specifically to improve cognitive functions) and type of control group (active control group vs. passive control group). Finally, the age of the participants as a moderator variable is also important as older adults vary considerably in their cognitive abilities and health status. People aged between 60 and 70 might have preserved their functionalities but people older than that might experience the burdens of aging more profoundly.

We hypothesized that there would be an overall cognitive improvement after training, with some variance in the amount of improvement depending on the cognitive processes assessed (outcomes). Moreover, with regard to the combined effect size of the individual studies, we hypothesized that complex games would yield greater improvement than simple games because the former involve a broader range of skills. Our second hypothesis was that there would be a positive relationship between the overall cognitive improvement and the number of training sessions. The third hypothesis was that there would also be a positive relationship between the number of video games the participants were trained to play and improvements in cognition. The fourth hypothesis was that the interaction with the experimenter would be beneficial. We tested this hypothesis by assessing the effect of the type of control group included in the study. The fifth hypothesis was that brain training specifically designed to improve cognition would be more effective than commercial video games. Finally, we hypothesized that cognitive improvements, while remaining significant, would decrease with age. Consequently, the age covariant would have a detrimental effect on cognitive improvement.

Method

Literature Search

A systematic search strategy was used to identify relevant studies to be included in this meta-analysis. The MEDLINE, Psyc-Info, and Google Scholar databases were searched to identify relevant studies. Periodic searches of these databases were conducted between 1986 and 2013 using several combinations of the following keywords: "aging," "older adults," "video game training," "memory," and "cognitive function." We also performed a manual search and cross-referencing of original articles. We restricted the search to articles written in English. As the video game business developed with the computer industry in the late 1980s, the first article found was published in 1986. After reading the articles obtained from the electronic search, we found additional related papers not obtained in the previous step. The titles and abstracts of the original articles were screened for potential inclusion in the study.

Selection criteria.   Studies were included if they met the following criteria: (a) they involved only healthy older adults; (b) they reported pre- and postevaluation results of the same cognitive outcomes; (c) the trained group received only video game training; and (d) the studies reported all the descriptive statistics necessary to compute the d effect size index and its confidence interval. The electronic and manual search yielded a total of 60 articles, but only 20 fulfilled the inclusion criteria and were included in the meta-analysis. Figure 1 shows the flow diagram with the search characteristics and the inclusion criteria.

Of the 20 articles included in the present study, two (Ackerman et al., 2010 and Cassavaugh & Kramer, 2009) did not include a control group. However, it was possible to compute the effect size indexes corresponding to these two studies using the formula for a prepost design without a control group (see Equation 1).

$$d = c(n-1)\frac{\overline{Y}_{Pre} - \overline{Y}_{Post}}{S_{Pre}} = \left(1 - \frac{3}{4n-5}\right)\frac{\overline{Y}_{Pre} - \overline{Y}_{Post}}{S_{Pre}} \quad (1)$$

Equation 1 has the c term included multiplicatively to correct bias in Cohen's d (Carlson & Schmidt, 1999; Hedges & Olkin, 1985), n is the number of participants, $\overline{Y}$ is the mean of the dependent variable with the subscript signaling the phase (Pre: pretest, Post: posttest) and S is the standard deviation of the same dependent variable.

The other 18 studies were coded using Equation 2 (prepost experimental design with two groups, experimental and control, and a continuous dependent variable).

$$d = \left(1 - \frac{3}{4(n_{Exp} + n_{Cont})}\right)\frac{\left(\overline{Y}_{Pre}^{Exp} - \overline{Y}_{Post}^{Exp}\right) - \left(\overline{Y}_{Pre}^{Cont} - \overline{Y}_{Post}^{Cont}\right)}{\sqrt{\dfrac{n_{Exp}\left(S_{Pre}^{Exp}\right)^2 + n_{Cont}\left(S_{Pre}^{Cont}\right)^2}{n_{Exp} + n_{Cont} - 2}}}$$

$$(2)$$

Equation 2 has the same meaning as Equation 1 in the subscripts, superscripts, and the symbols used. So, the first multiplicative term between brackets is a bias correction of Cohen's d (Hedges & Olkin, 1985), n is the number of participants on each group (signaled by their subscripts) and superscripts *Exp* and *Cont* meaning "Experimental group" and "Control Group," respectively. Standardized Cohen's d statistics were computed from the pre- and postintervention means and standard deviations of each group for each outcome variable using the formulas outlined above (Hedges & Olkin, 1985). The characteristics of these studies are presented in Table 1.

Characteristics of training interventions.   As expected, the video games used as training platforms in the 20 studies included
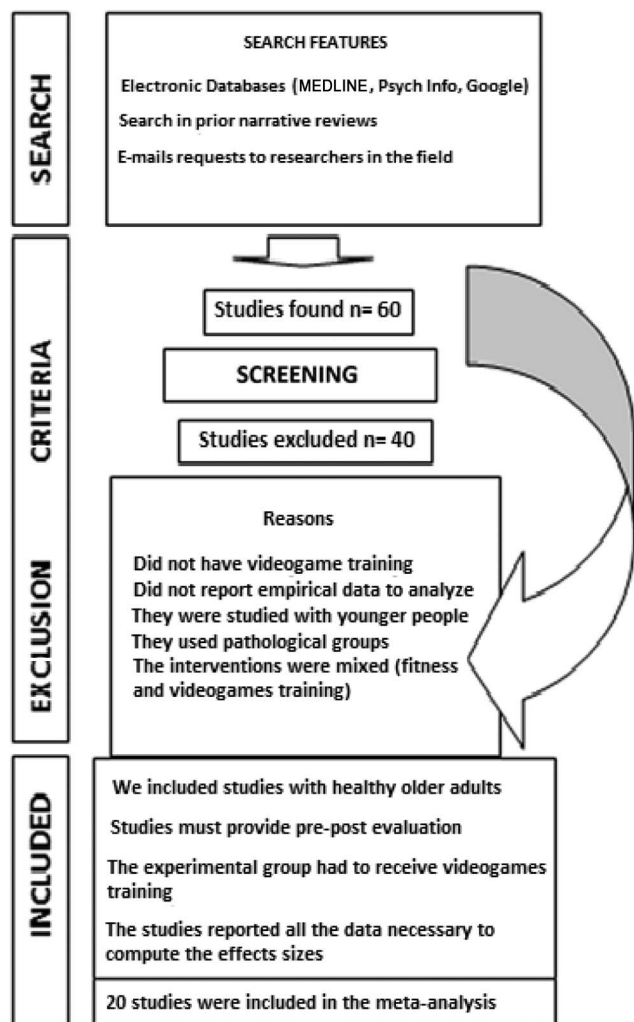
Figure 1. Flow diagram of studies considered and ultimately included in the meta-analysis.

in the present investigation differed in several characteristics. It is important to note that none of the video games used in these intervention studies, except those used in Anguera et al.'s (2013) study, were originally designed to improve cognition in older adults. The studies used a wide range of video game genres (see Table 1); some used commercial video games such as *Medal of Honor*, *Pac Man*, *Donkey Kong*, *Tetris*, *Crystal Castle*, and so forth, while others used a combination of classic cognitive tasks taken from commercial packages (e.g., *Nintendo Brain Training, Brain Age*, *Big Brain Academy*, etc.). This implies that the individual studies trained different cognitive processes as an unavoidable consequence. Two other relevant differences were the number of training sessions and the number of video games used in the same intervention study. These two characteristics are likely to affect the intensity of the training program. We coded these characteristics (type of video game, duration or number of training sessions, type of program, type of control group and number of video games included in the training program) as moderator variables.

With regard to the type of video game, these were classified as simple versus complex. A game was coded as complex if it involved multiple cognitive processes and complex cognitive demands. The number of video games was also classified with two categories: few (one to six games) and many (seven to 12 games). Another factor considered in the present study was the duration of the intervention; two levels were selected: short (between 1 and 6 weeks) and long (between 7 and 12 weeks). Type of program was coded with two levels ("brain training" program and video games). The variable type of control group was also coded with two levels (active and passive). The last variable was the age of the participants. Unfortunately, the published studies did not provide consistent information about the age of the participants, some reporting the age range and others the mean age of participants. Consequently, we decided to code age as a categorical variable with two levels: (a) from 60 to 70 years of age, and (b) from 71 to 80 years of age (when the mean age or the half-split range point reported was within these ranges). Finally, we coded the outcome measures of the studies as cognitive processes (RT, executive functions, memory, attention, and global cognitive functioning) based on the category of tests used at prepost assessment.

Table 2 displays the moderator variables and their coded levels in the present study.

Outcomes

The 20 studies included in this meta-analysis reported multiple outcomes on several cognitive functions that we classified as memory, attention, RT, executive functions, and overall cognitive function, although not all of them reported the same cognitive functions. Moreover, even when studies assessed the same cognitive functions, they used different tests to evaluate them. The difficulty of comparing different measures of the same cognitive function using different tests was overcome by converting the raw statistics to Cohen's *d* using a common metric for all the outcomes.

To evaluate interrater agreement, the first author (P.T.) and the second author (J.M.R) coded the data from the 20 original studies using the same codebook. There was no disagreement regarding the moderator variables (Pearson's correlation $r = 1$). The level of agreement between the two coders for outcomes (memory, attention, RT, global cognitive function, and executive functions) was computed as the correlation between the effect sizes (*d*) for the outcomes between the two assessments. The interrater correlation for the main outcomes was $r = .97$ ($p < .001$), indicating that the agreement between the coders was very high, both for moderator and outcome variables.

Meta-Analytic Procedure

The analyses were conducted using the Comprehensive Meta-Analysis software (Borenstein, Hedges, Higgins, & Rothstein, 2005). Effect sizes were computed for each individual study and test using Cohen's *d* for experimental designs with pre- and posttests and experimental and control groups. As mentioned above, the only exceptions were the studies by Cassavaugh and Kramer (2009) and by Ackerman, Kanfer, and Calderwood (2010) in which we used only the treatment group. As all the studies reported data on more than one individual test in the same cognitive area, we computed the mean. The effect size and its standard deviation (*SD*) for each

Table 1
Characteristics of the Studies Included in the Meta-Analysis

STUDY	AGE	Control	N	Video games	Duration (training)	Significant findings
Ackerman et al., 2010	50–71	--------------	78	Wii Big Brain Academy	4 weeks: 5x/weeks	No significant transfer of training from Wii practice or reading tasks to measures of cognitive and perceptual speed abilities.
Anguera et al., 2013	M = 67	Active/nonactive	46	Neuroracer	4 weeks	Training enhanced cognitive control in older adults. These benefits were extended to untrained abilities.
Basak et al., 2008	63–75	No contact	39	Rise of Nations	4–5 weeks: 3x/weeks	EG improved memory, executive function, and visuospatial abilities.
Belchior, 2008	67–84	Tetris or no contact	58	UFOV or Medal of Honor	2 weeks: 2–3/week	EG improved processing speed more than control group.
Boot, 2013	M = 74	No contact	40	Brain Age	12 weeks	Cognitive abilities did not improve.
Boot, 2013	M = 74	No contact	34	Mario Kart	12 weeks	Cognitive abilities did not improve.
Bozoki et al., 2013	60–80	Online activities	60	Online video games	6 weeks	Overall analysis did not show transfer effects. The effect sizes were relatively small.
Cassavaugh & Kramer, 2009	M = 71.7	--------------	21	Computer training program	2–3 weeks: 8 sessions	EG improved reaction time.
Clark et al., 1987	57–83	No contact	14	Pac Man or Donkey Kong	7 weeks: 120 min/ week	EG improved reaction time.
Drew & Waters, 1986	61–78	Contact	13	Atari Crystal Castle	8 weeks: 12x/week	EG improved psychomotor speed and global cognition.
Dustman et al., 1992	62–71	Movie or no contact	60	Breakout, Galaxian Frogger Kaboom, PacMan, . . .	11 weeks: 3x/week	EG improved reaction time.
Goldstein et al., 1997	72–85	No contact	22	SuperTetris	5 weeks: 300 min/ week	EG improved reaction time. EG and CG also improved executive functions but there were no differences between groups.
Maillot et al., 2012	65–75	No contact	32	Nintendo Wii	12 weeks	EG group improved more than CG on measures of physical function, executive control, and processing speed functions, but not on visuospatial measures.
McDougall & House, 2012	M = 74	No contact	41	Nintendo Brain Training	6 weeks	EG improved in Digit Span Test and other tests.
Nouchi et al., 2012	M = 69	Tetris	28	Brain Age	4 weeks	EG improved executive functions and processing speed.
Peretz et al., 2011	60–77	Computer games	121	C. Personal Coach	12 weeks: 3x/week	EG and CG improved focused and saturated attention, memory recognition, and mental flexibility.
Sosa, 2011	M = 74	Nonactive	31	Brain Age	5 weeks: 1/week	EG improved syllable (time), arithmetic (time), and Stroop tests.
Stern et al., 2011	M = 66	Active or nonactive control	60	Space Fortress	12 weeks: 36 hr	One measure of executive control showed improvements in EG.
Torres, 2008	60–86	Muscle relaxation/no contact	43	Super Granny, Zoo Keeper, Penguin Push, Bricks, memory games	8 weeks: 1/week	EG showed less cognitive decline than CG
Van Muijden et al., 2012	60–77	Documentary group	72	Anagram, Falling bricks	7 weeks/24.5 hr	Modest support for the potential of video game training to improve cognitive functions in older people.

Note. EG = experimental group; CG = control group; UFOV = useful field of view; Control refers to the control group activity.

Table 2
Variables Analyzed

Variables	Levels	
Age of participants	60–70 years	71–80 years
Training duration	Short (1–6 weeks)	Long (7–12 weeks)
Type of video game	Simple	Complex
Number of games	Few (1–6)	Many (7–12)
Type of control group	Active	Passive
Type of program	Brain training	Video games

study and each cognitive function were calculated. Finally, we combined the effect sizes of the same cognitive function in each study to overcome the statistical problem of assigning more weight to studies with more individual outcomes. We used these mean scores for each cognitive function as outcomes instead of raw effect sizes computed for each individual test in each study. Moreover, five of the 20 final individual studies included in the meta-analysis had subgroups within the study. In all cases, the subgroups compared the same experimental (trained) group with different control groups. As not all the studies reported data on the same subgroups, we treated each subgroup as a separate study.

Mean effect sizes and confidence intervals were estimated using the fixed effect model. By convention, an absolute effect size of 0.2 or less is considered small, an absolute value between 0.2 and 0.6 is considered moderate, and an estimated value equal to or greater than 0.6 is considered large. A 95% confidence interval (CI) was calculated for each effect size to establish whether it was statistically different from zero. We examined the variation in effect sizes between studies using a standardized scale, based on the Q index of homogeneity (Hedges & Olkin, 1985). To estimate the proportion of the observed variance that reflects real differences among studies, we calculated I^2.

Thus, a total of 20 studies contributed data to this meta-analysis, comprising 474 trained older adults and 439 control participants. Full details of all the studies included in this meta-analysis are provided in the References section, marked with an asterisk. A major concern in meta-analytic studies is the existence of publication bias. We used funnel plots to assess the relationship between sample size and effect size (Egger, Smith, Schneider, & Minder, 1997). As shown below, publication bias does not seem to affect the validity of the overall effect size obtained in the present study.

Results

Effect Size Estimates: Mean Effects and Test of Heterogeneity

An overall effect size was calculated incorporating all effect sizes. The mean effect size was calculated incorporating all effects sizes. The mean effect size was 0.37 (ET = 0.05) with a 95% confidence interval of between 0.26 and 0.48. Effect sizes showed no significant heterogeneity, Q (19) = 23.95, $p > .05$, I^2 = 20.69%. The forest plot is shown in Figure 2.

Although we obtained a nonsignificant p value for heterogeneity and did not therefore reject the null hypothesis, we are aware that

this result could be due to a low power (Borenstein et al., 2009). For this reason, we calculated the effect of the moderator variables.

Regarding the type of video game (simple vs. complex), the heterogeneity between groups was not significant, Q (1) = 0.55, $p > .05$. The mean effect size for simple video games was 0.42, 95% CI [0.25, 0.58], Z = 5.00, $p < .01$, and for complex games it was 0.33, 95% CI [0.18, 0.48], Z = 4.38, $p < .01$.

The second variable was the duration of training with two levels (short vs. long). The heterogeneity between groups was significant, Q (1) = 3.73, $p = .05$, I^2 = 73.19%. The mean effect size for short training was 0.49, 95% CI [0.32, 0.67], Z = 5.59, $p < .01$; and for long training it was 0.26, 95% CI [0.09, 0.43], Z = 3.03, $p < .01$.

The third moderator variable analyzed in the present meta-analysis was the number of video games (few vs. many) used in the interventions. The heterogeneity between groups was not significant, Q (1) = 0.37, $p > .05$. The mean effect size for many games was 0.30, 95% CI [0.07, 0.54], Z = 2.56, $p < .05$, and for few games it was 0.39, 95% CI [0.26, 0.51], Z = 6.12, $p < .01$.

The fourth variable analyzed was type of program (brain training vs. video game). The heterogeneity between groups was not significant, Q (1) = 0.27, $p > .05$. The mean effect size for brain training was 0.34, 95% CI [0.17, 0.50], Z = 4.04, $p < .01$, and for video games was 0.40, 95% CI [0.25, 0.55], Z = 5.25, $p < .01$.

The next moderator variable analyzed was type of control group (active vs. passive). We analyzed this variable in two ways: (a) including all the studies that had a control group, excluding only those without control group (two studies); and (2) analyzing the effect sizes of those studies that used both an active and a passive control group, excluding those studies that had just a passive control or no control group. The results of the first analysis showed that the heterogeneity between groups was not significant, Q (1) = 0.54, $p > .05$. The mean effect size for active control was 0.27, 95% CI [0.09, 0.45], Z = 3.03, $p < .01$, and for passive control was 0.37, 95% CI [0.19, 0.55], Z = 4.0, $p < .01$ The results corresponding to the second analysis showed that the heterogeneity between groups was not significant, Q(1) = 0.004, $p > .05$. The mean effect size for active control was 0.36, 95% CI [0.06, 0.66], Z = 2.40, $p < .05$, and for passive control 0.37, 95% CI [0,07, 0.68], $p < .05$. The difference between active and passive control
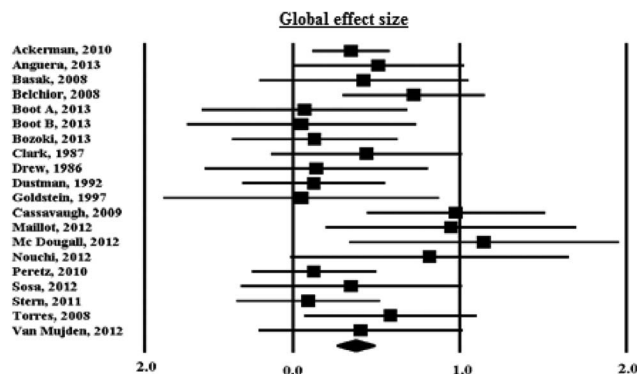

Figure 2. Mean global effect size (*d*) and 95% CI corresponding to the 20 individual studies combining effect sizes within each study. On the left are shown the articles identified by the first author's name and publication year.

was not statistically significant but they were significantly different from zero.

Finally, the last moderator variable was age. The heterogeneity of effect sizes for both age groups was highly significant, Q (1) = 4.50, $p < .01$, $I^2 = 77.77\%$. The mean effect size for the 60- to 70-year-old group was 0.30, 95% CI [0.16, 0.44], Z = 4.27, $p < .01$, and for the 71- to 80-year-old group 0.57, 95% CI [0.34, 0.79], Z = 4.98, $p < .01$. Table 3 summarizes these results.

To assess the interaction between age and duration of training, we computed the correlation between these two variables. The result showed that the association between these variables was not statistically significant ($r = -0.12$, $p = .60$). This suggests that grouping certain levels of training duration with certain levels of participants′ age did not bias the results obtained in this meta-analysis.

Next, we present the results of the analysis of the combined outcomes for each cognitive function. The heterogeneity between cognitive functions was significant, Q (5) = 13.20, $p < .05$, and we therefore report the analysis using the random effect model for outcomes. We give below the statistics for those cognitive functions that showed a significant treatment effect. The effect size for RT, $d = 0.63$, 95% CI [0.42, 0.84], Z = 5.93, $p < .01$; memory, $d = 0.39$, 95% CI [0.01, 0.64], Z = 3.08, $p < .05$; attention, $d = 0.37$, 95% CI [0.17, 0.57], Z = 3.67, $p < .01$; and overall cognitive function, $d = 0.38$, 95% CI [0.13, 0.62], Z = 3.07, $p < .05$, were all significant. Only executive functions did not reach statistical significance ($p > .05$). These results are displayed in Table 4.

The present results suggest that the effects of the interventions depend on variables such as the age of the participants and the duration (number of sessions) of the intervention. Specifically, this analysis suggests that short interventions (from 1 to 6 weeks) are more effective than long interventions (from 7 to 12 weeks). Furthermore, age has a significant effect, suggesting that the oldest adults (71–80 years) benefit more from video game training than younger participants (60–70 years).

Evaluation of Publication Bias

To evaluate possible publication bias, we performed a funnel plot (see Figure 3). The symmetry of the graph suggests the absence of publication bias. The interpretation of a funnel plot is subjective, so we performed other quantitative tests of publication bias (Begg & Mazumbar, 1994; Egger et al., 1997). First, we applied the Egger test (Egger et al., 1997). This test is an unweighted regression that takes the precision of each study as the independent variable and effect size as the dependent variable. The Egger test was not significant for the intercept of the regression model, intercept = 0.74; $t(8) = 1.03$, $p = 0.31$. The t test for the null hypothesis of an intercept equal to zero showed a statistically nonsignificant result. We can therefore assume that publication bias is not a threat to the validity of the overall effect size. Second, we calculated the fail-safe N_{fs} index (Becker, 2005). The result of this analysis suggests that in order to cancel the global mean effect obtained in our meta-analysis ($d = 0.37$), it would be necessary to have 207 nonpublished studies with null effects not included in the meta-analysis. These results also suggest that the effect obtained in the present study is not affected by publication bias. Thus, combined results from these methods suggest that the likelihood of publication bias is minimal.

Discussion

As far as we know, this is the first meta-analysis of the effects of video game training on improving cognitive functioning in healthy older adults. The present meta-analytic study investigated whether video game training enhances cognitive functions in older adults by reanalyzing individual studies published on this topic since 1986. The overall meta-analysis unambiguously revealed that training older adults with video games improves cognition. The main findings can be summarized as follows: (a) video game training in older adults produces positive effects on several cognitive functions that decline with aging; (b) several methodological and personal factors have moderator effects; (c) among the analyzed variables, the age of the participants and the number of sessions in the training program were significant in modifying the effect size of the interventions. These moderator variables may explain, in part, the variability of the results reported so far in the literature on this topic.

Overall, the results of this meta-analysis confirm our main hypothesis that video game training improves cognitive functioning in older adults. However, the present results do not confirm the specific hypotheses regarding age, duration of training, type of program, number, and type of video games. In fact, we predicted greater improvement with longer training interventions, but the results showed that short training is a better option for this type of intervention with older adults. Moreover, cognitive improvements

Table 3
Results of the Significant Moderator Variables

Variable	Level	d (SE)	Q	I^2	Z	95% CI
Age	60–70	0.30 (0.07)	Q(1) = 4,50, $p < .01$	77.77 %	4.27, $p < .01$	[0.16, 0.44]
	71–80	0.57 (0.11)			4.98, $p < .01$	[0.34, 0.79]
Training duration	Short	0.49 (0.08)	Q(1) = 3.73, $p = .05$	73.19 %	5.59, $p < .01$	[0.32, 0.67]
	Long	0.26 (0.08)			3.03, $p < .01$	[0.09, 0.43]
Type of game	Simple	0.42 (0.08)	Q(1) = 0.55, $p > .05$		5.00, $p < .01$	[0.25, 0.58]
	Complex	0.33 (0.07)			4.38, $p < .01$	[0.18, 0.48]
Number of games	Few	0.39 (0.06)	Q(1) = 0.37, $p > .05$		6.12, $p < .01$	[0.26, 0.51]
	Many	0.30 (0.12)			2.56, $p < .01$	[0.07, 0.54]
Type of program	Video games	0.40 (0.07)	Q(1) = 0.27, $p > .05$		5.25, $p < .01$	[0.25, 0.55]
	Brain training	0.34 (0.08)			4.04, $p < .01$	[0.17, 0.50]
Type of control group	Active	0.27 (0.09)	Q(1) = 0.54, $p > .05$		3.03, $p < .01$	[0.09, 0.45]
	Passive	0.37 (0.09)			4.00, $p < .01$	[0.19, 0.55]

Table 4
Effect Sizes (D), Z, and CI Corresponding to Each Cognitive Process (Outcomes)

Outcomes	d (SE)	Z	95% CI
Memory	0.39 (0.12)	3.08, $p < .01$	[0.01, 0.64]
Attention	0.37 (0.10)	3.67, $p < .01$	[0.17, 0.57]
Reaction time	0.63 (0.10)	5.93, $p < .01$	[0.42, 0.84]
Cognitive function	0.38 (0.12)	3.07, $p < .01$	[0.13, 0.62]
Executive functions	0.16 (0.13)	1.20, $p > .05$	[−0.10, 0.42]

due to video game training increased rather than decreased with age; the oldest adults (71–80 years) improved more after training than younger participants (60–70 years). We also predicted greater cognitive improvements with complex games than with simple games. The results, however, showed no significant differences between simple and complex games. Similar results emerged for the number of video games used in the intervention.

The current results have both theoretical and practical implications. First, duration of training was a significant variable. Our results indicate that the training effects are greater when training is of short duration (1–6 weeks) than when it is long (7–12 weeks). This finding has practical implications as many intervention programs spend a great amount of time training older participants on the assumption that longer training will produce better results. The results of this meta-analysis do not support this assumption. Our own experimental work with senior citizens (Ballesteros et al., in press; Mayas, Andrés, Parmentier, & Ballesteros, 2014) suggests that long training schedules lead to loss of motivation. Training sessions may be quite exciting at first but older adults get tired and bored in the last sessions. It seems that what motivates older participants to practice the games in the later sessions is not the training per se but the affective link or personal relationship established with the experimenter. Moreover, despite evidence suggesting a significant effect size of training on cognitive functioning, older people do not seem to perceive its functionality in their daily life. Apart from the motivational factors outlined above, the present results might be explained in terms of the *Temporal Discounting Hypothesis*. Temporal discounting (Green, Fry, & Myerson, 1994) refers to the phenomenon that future rewards are less valuable than immediate rewards. This temporal discounting is greater in elderly participants whose expected life-time is shorter. This means that the effort put into learning a new task must be balanced with the expected reward of acquiring the new skill. When the time needed to learn and improve in the video game task begins to be relatively long with respect to the expected reward, the motivation to continue training decreases. The reason may be that the anticipated rewards are small compared with the immediate cost of attending the training sessions.

The second significant moderator variable that appeared in our analysis was the age of the trainees. The results suggest that the benefits of training increases as participants get older. This result is relevant for applied purposes and could be explained by the larger training gains in people with lower baseline scores. In other words, the oldest adults (71–80 years) start the training program with lower cognitive functioning scores, but they show greater improvement after training than the younger participants (60–70 years of age). The combination of these two effects may produce

a greater effect size in the oldest adults (71–80 years). Our results do not rule out the possibility that the performance of younger participants (60–70 years) may be relatively high at the start of the training program. Notwithstanding, it is worth stressing that although older people may benefit extensively from video game training, they use new technologies and video games in particular less than other members of the population, even when they can obtain a greater benefit.

The results of the current study show that there are no significant differences between few and many video games used in the training phase, although there is a nonsignificant trend indicating that few games are better than many. In relation to the social interaction between experimenter and trainee that occurs in the experimental group and in the active control group but not in the passive control group, the results suggest a minor, although nonsignificant beneficial effect on cognition. This effect might be due to motivational factors. This result, however, must be taken with caution due to the small number of studies (five studies) that included passive and active control groups in the same study. Future investigation in this field should include at least these two types of control groups (active and passive) as a better control. It should be noted that the means showed in Table 3 for the variable type of control group correspond to standardized mean differences of the experimental versus active control group and the experimental versus passive control group. This implies that if the active control group had an effect, the computed *d* for the first contrast will be lower than that of the second contrast. The reason is that the performance of the active control group will be closer to the experimental group than to the passive control group. The present results show that there are no significant differences between "brain training" programs and video games. The same happened with type of game. There are no significant differences between simple and complex games, although there is a nonsignificant trend indicating that simple games produce more benefits than complex games.

So far, we have considered the moderator variables included in the meta-analysis. An important issue, however, is whether the effects of training older people with video games are transferable to untrained tasks. This is the so-called "transfer effect." The question is whether the effects of training with video games transfer to cognitive processes such as memory, attention, execu-
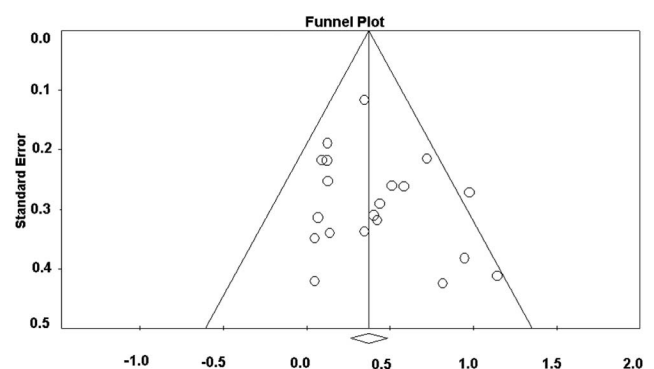

Figure 3. Funnel plot of standard errors and effect sizes (*g*) of the 20 studies of healthy older adults trained with video games included in the meta-analysis.

tive functions, RT, and global cognitive function. Excluding executive functions that did not show a significant effect different from zero, effect sizes revealed an interesting pattern in the other cognitive functions. The results of this meta-analytic study suggest that attention is perhaps the cognitive function that improved most following training. This finding is in agreement with the results of a recent study (Mayas et al., 2014). In this study, the trained group, but not the control group, received 20 1-hr training sessions with non-action video games and were evaluated before and after the intervention using a cross-modal visual-auditory oddball task measuring alertness and distraction. The results showed that training reduced distractibility by improving attention filtering (a function that declines with age and is largely dependent on frontal regions) and also improved alertness supported by a larger brain network.

The present study also showed that speed of processing, assessed by RT tasks, improved significantly after training. This finding is in line with a recent review (Bavelier, Green, Pouget, & Schrater, 2012). Most video games demand rapid responses and the maintenance in long-term memory of information relevant to the task at hand ready to be used when required. This is reflected in the significant effect of video game training on memory. The significant effect of training on global cognitive function also shows, although to a lesser extent, that some components of training transfer to general cognitive processes as assessed by standardized psychometric intelligence tests.

Interestingly, executive functions did not show a significant effect of training (although there was a trend in this direction). This result is in agreement with the study of Dahlin, Nyberg, Bäckman, and Neely (2008), who found that the transfer of computer training to the updating of information in working memory was limited to young participants. They concluded that older participants have more limited neural plasticity, reducing their ability to generalize an executive skill (information updating). The results of the present meta-analysis are also congruent with those of a study from our laboratory (Ballesteros et al., in press). A recent meta-analysis conducted with children, young adults, adults, and older adults also yielded negligible effects for executive functions (Powers, Brooks, Aldrich, Palladino, & Alfieri, 2013).

Overall, our results are in line with those of Kueider et al. (2012) who also found that video game training improved RT and global cognition but that it was less efficient for improving executive functions. This meta-analysis extends the systematic review carried out by Kueider et al. (2012) by including a greater number of studies. In order to ascertain the consistency of our results, we compared them with those obtained by Kueider and colleagues in the meta-analytic review. The mean effect sizes of both studies are similar. For instance, our mean effect size for RT was $d = 0.63$ versus $d = 0.77$ reported by Kueider and colleagues. These results suggest that video game training improves memory and other cognitive functions in healthy older adults and have important practical implications. Helping older adults to maintain cognitive health may reduce the risk of dependency. However, the video game industry should create attractive and useful games specifically designed for the elderly, in other words, video games that meet their perceived needs and which may not be the same as those that young people find attractive and engaging.

Future Research

More research is needed to study effective ways of maintaining cognition and of improving the quality of life of older adults. The findings regarding the moderating effects of the age of the trainees and the duration of the training program suggest that these factors require further investigation. However, the main issue for future research is how to improve the transfer effects of video games on cognitive functioning in older adults, especially executive functions. A fruitful new approach is the incorporation of neuroimaging data to identify the mental processes that operate in multiple task domains (Anguera et al., 2013; Basak, Voss, Erickson, Boot, & Kramer, 2011; Lustig, Shah, & Reuter-Lorenz, 2009; Prakash et al., 2012). These mental processes might be targeted with specific cognitive tasks directed at these processes and evaluating their performance on another task (Dahlin et al., 2008; Persson & Reuter-Lorenz, 2008).

Limitations

It is important to stress that publication bias is a potentially serious threat to the validity of the meta-analysis. Publication bias concerns the issue of missing data. However, the statistical analysis suggests that the results of this meta-analysis are reasonably good and that the likelihood of publication bias is minimal.

Finally, it should be noted other possible limitations, including the lack of documented effects on latent factors, which makes it difficult to rule out effects due to specific strategies, the lack of reported effects on abilities related to daily life, and the difficulty to rule out possible effects due to motivational factors rather than neurocognitive plasticity.

Conclusion

In summary, although video game training has positive effects for older adults, the benefits do not transfer to all cognitive functions. Moreover, the positive effects are moderated by personal and methodological factors. For instance, the age of the trainee and the duration of the training program are important factors that have to be considered in this type of intervention and should be the focus of future research. The results of this meta-analytic study suggest neurocognitive plasticity in the aging human brain, as training with video games is found to enhance cognitive performance on several untrained functions.

References marked with an asterisk indicate studies included in the meta-analysis.

References

References marked with an asterisk indicates studies included in the meta-analysis.

Achtman, R. L., Green, C. S., & Bavelier, D. (2008). Video games as a tool to train visual skills. *Restorative Neurology and Neuroscience, 26,* 435–446.

*Ackerman, P. L., Kanfer, R., & Calderwood, C. (2010). Use or lose it? Wii brain exercise practice and reading for domain knowledge. *Psychology and Aging, 25,* 753–766. doi:10.1037/a0019277

Allaire, J. C., McLaughlin, A. C., Trujillo, A., Whitlock, L., & Laporte, L. (2013). Successful aging through digital games: Socioemotional differences between older adult gamers and non gamers. *Computers in Human Behaviour, 29,* 1302–1306. doi:10.1016/j.chb.2013.01.014

*Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., . . . Gazzaley, A. (2013). Video game training enhances cognitive control in older adults. *Nature, 501,* 97–101. doi:10.1038/nature12486

Ball, K., Berch, D. B., Helmer, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., . . . Willis, S. L. (2002). Effects of cognitive training interventions with older adults: A randomized controlled trial. *Journal of the American Medical Association, 288,* 2271–2281. doi:10.1001/jama.288.18.2271

Ballesteros, S., Bischof, G. N., Goh, J. O., & Park, D. C. (2013). Neural correlates of conceptual object priming in young and older adults: An event related functional magnetic resonance imaging study. *Neurobiology of Aging, 34,* 1254–1264. doi:10.1016/j.neurobiolaging.2012.09.019

Ballesteros, S., Prieto, A., Mayas, J., Toril, P., Pita, C., Ponce de León, L., Reales, J. M., & Waterworth, J. A. (in press). Training older adults with non-action video games enhances cognitive functions that decline with aging: A randomized controlled trial. *Frontiers in Aging Neuroscience.*

Ballesteros, S., & Reales, J. M. (2004). Intact haptic priming in normal aging and Alzheimer's disease. Evidence for dissociable memory systems. *Neuropsychologia, 42,* 1063–1070. doi:10.1016/j.neuropsychologia.2003.12.008

Ballesteros, S., Toril, P., Mayas, J., Reales, J. M., & Waterworth, J. A. (2014). The role of a new ICT in supporting successful aging. *Gerontechnology, 13,* 39–48.

Baltes, P. B., & Lindenberger, U. (1997). Emergence of a powerful connection between sensory and cognitive functions across the adult life span: A new window to the study of cognitive aging? *Psychology and Aging, 12,* 12–21. doi:10.1037/0882-7974.12.1.12

*Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real time strategy video game attenuate cognitive decline in older adults? *Psychology and Aging, 23,* 765–777. doi:10.1037/a0013494

Basak, C., Voss, M. W., Erickson, K., Boot, W. R., & Kramer, A. F. (2011). Regional differences in brain volume predict the acquisition of skill in a complex real-time strategy video game. *Brain and Cognition, 76,* 407–414. doi:10.1016/j.bandc.2011.03.017

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity through the life span: Learning to learn and action video games. *Annual Review of Neuroscience, 35,* 391–416. doi:10.1146/annurev-neuro-060909-152832

Becker, B. J. (2005). Failsafe N or file drawer number. In H. R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment and adjustments* (pp. 111–125). Chichester, UK: Wiley.

Begg, C. B., & Mazumbar, M. (1994). Operating characteristics of a rank correlation test for publication bias. *Biometrics, 50,* 1088–1101. doi:10.2307/2533446

*Belchior, P. D. C. (2008). Cognitive training with video games to improve driving skills and driving safety among older adults [dissertation]. *Dissertation Abstract International: The Sciences and Engineering, 68*(9–B).

Bialystok, E., & Craik, F. I. M. (2006). *Lifespan cognition: Mechanisms of change.* Oxford, UK: Oxford University Press. doi:10.1093/acprof:oso/9780195169539.001.0001

Bond, G. E., Wolf-Wilets, V., Fiedler, F. E., & Burr, R. L. (2001). Computer aided cognitive training of the aged: A pilot study. *Clinical Gerontologist, 22,* 19–42. doi:10.1300/J018v22n02_03

Boot, W. R., Blakely, D. P., & Simmons, D. (2011). Do action video games improve perception and cognition? *Frontiers in Psychology, 2,* 1–6.

*Boot, W. R., Champion, M., Blakely, D. P., Wright, T., Souders, D. J., & Charness, N. (2013). Video games as a means to reduce age-related cognitive decline: Attitudes, compliance, and effectiveness. *Frontiers in Psychology, 4,* 31. doi:10.3389/fpsyg.2013.00031

Boot, W. R., Kramer, A., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory and executive control. *Acta Psychologica, 129,* 387–398. doi:10.1016/j.actpsy.2008.09.005

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. (2005). *Comprehensive meta-analysis (Version 2.0).* [Computer software]. Englewood, NJ: Biostat.

Borenstein, M., Hedges, L. V., Higgins, J. P. T., & Rothstein, H. (2009). *Introduction to meta-analysis.* Chichester, UK: Wiley. doi:10.1002/9780470743386

Boyke, J., Driemeyer, J., Gaser, C., Büchel, C., & May, A. (2008). Training induced brain structure changes in the elderly. *The Journal of Neuroscience, 28,* 7031–7035. doi:10.1523/JNEUROSCI.0742-08.2008

*Bozoki, A., Radovanovic, M., Winn, B., Heeter, C., & Anthony, J. (2013). Effects of a computer based cognitive exercise program on age related cognitive decline. *Archives of Gerontology and Geriatrics, 57,* 1–7. doi:10.1016/j.archger.2013.02.009

Buschkuehl, M., Jaeggi, S. M., Hutchison, S., Perrig-Chiello, P., Däpp, C., Müller, M., . . . Perrig, W. J. (2008). Impact of working memory training on memory performance in old-old adults. *Psychology and Aging, 23,* 743–753. doi:10.1037/a0014342

Carlson, K. D., & Schmidt, F. L. (1999). Impact of experimental design on effect size: Findings from the research literature on training. *Journal of Applied Psychology, 84,* 851–862. doi:10.1037/0021-9010.84.6.851

*Cassavaugh, N. D., & Kramer, A. F. (2009). Transfer of computer based training to simulated driving in older adults. *Applied Ergonomics, 40,* 943–952. doi:10.1016/j.apergo.2009.02.001

*Clark, J. E., Lamphear, A. K., & Riddick, C. C. (1987). The effects of videogame playing on the response selection processing of elderly adults. *Journal of Gerontology, 42,* 82–85. doi:10.1093/geronj/42.1.82

Dahlin, E., Nyberg, L., Bäckman, L., & Neely, A. (2008). Plasticity of executive functions in young and older adults: Immediate training gains, transfer and long term maintenance. *Psychology and Aging, 23,* 720–730. doi:10.1037/a0014296

*Drew, B., & Waters, J. (1986). Video games: Utilization of a novel strategy to improve perceptual motors skills and cognitive functioning in the no institutionalized elderly. *Cognitive Rehabilitation, 4,* 26–31.

*Dustman, R. E., Emmerson, R. Y., Steinhaus, L. A., Shearer, D. E., & Dustman, T. J. (1992). The effects of videogame playing on neuropsychological performance of elderly individuals. *Journal of Gerontology, 47,* 168–171. doi:10.1093/geronj/47.3.P168

Egger, M., Smith, G. D., Schneider, M., & Minder, C. (1997). Bias in meta-analysis detected by simple, graphical test. *British Medical Journal, 315,* 629–634. doi:10.1136/bmj.315.7109.629

*Goldstein, J., Cajko, L., Oosterbroek, M., Michielsen, M., Van Houten, O., & Saavedra, F. (1997). Videogame and elderly. *Social Behavior and Personality, 25,* 345–352. doi:10.2224/sbp.1997.25.4.345

Gopher, D., Weil, M., & Bareket, T. (1994). Transfer of skill from a computer game trainer to flight. *Human Factors, 36,* 387–405.

Green, C. S., & Bavelier, D. (2008). Exercising your brain: A review of human brain plasticity and training induced learning. *Psychology and Aging, 23,* 692–701. doi:10.1037/a0014345

Green, L., Fry, A. F., & Myerson, J. (1994). Temporal discounting and preference reversals in choice between delayed outcome. *Psychonomic Bulletin and Review, 1,* 383–389. doi:10.3758/BF03213979

Hedden, T., & Gabrieli, J. D. E. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5,* 87–96. doi:10.1038/nrn1323

Hedges, L. V., & Olkin, I. (1985). *Statistical methods for meta-analysis.* Orlando, FL: Academic Press.

Hertzog, C., Kramer, A. F., Wilson, R., & Linderbergen, U. (2008). Enrichment effects on adult cognitive development. Can the functional capacity of older adults be preserved and enhanced? *Psychological Science in the Public Interest, 9,* 1–65.

Hoyer, W. J., & Verhaeghen, P. (2006). Memory aging. In J. Birren & W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 209–232).

Burlington, MA: Elsevier Academic Press. doi:10.1016/B978-012101264-9/50013-6

Kueider, A. M., Parisi, J., Gross, A. L., & Rebok, G. W. (2012). Computerized cognitive training with older adults: A systematic review. *PloS ONE, 7,* e40588.

Leung, L., & Lee, P. S. N. (2005). Multiple determinants of life quality: The role of internet activities, use of new media, social support and leisure activities. *Telematics and Informatics, 22,* 161–180. doi:10.1016/j.tele.2004.04.003

Li, S.-C., Brehmer, Y., Shing, Y. L., Werkle-Bergner, M., & Lindenberger, U. (2006). Neuromodulation of associative and organizational plasticity across the life span: Empirical evidence and neurocomputational modeling. *Neuroscience & Biobehavioral Reviews, 30,* 775–790. doi:10.1016/j.neubiorev.2006.06.004

Li, S.-C., Schmiedek, F., Huxhold, O., Röcke, C., Smith, J., & Lindenberger, U. (2008). Working memory plasticity in old age: Practice gain, transfer, and maintenance. *Psychology and Aging, 23,* 731–742. doi:10.1037/a0014343

Lustig, C., Shah, P., & Reuter-Lorenz, P. (2009). Aging, training and the brain: A review and future directions. *Neuropsychology Review, 19,* 504–522. doi:10.1007/s11065-009-9119-9

*Maillot, P., Perrot, A., & Hartley, A. (2012). Effects of interactive physical activity videogame training on physical and cognitive function in older adults. *Psychology and Aging, 27,* 589–600. doi:10.1037/a0026268

Mayas, J., Andrés, P., Parmentier, F., & Ballesteros, S. (2014). Plasticity of attentional functions in older adults after non-action video game training: A randomized controlled trial. *PloS ONE, 9,* e92269. doi:10.1371/journal.pone.0092269

*McDougall, S., & House, B. (2012). Brain training in older adults: Evidence of transfer to memory span performance and pseudo-Matthew effects. *Aging, Neuropsychology, and Cognition, 19,* 195–221. doi:10.1080/13825585.2011.640656

Meijer, W. A., Van Boxtel, M. P., Van Gerven, P. W., Van Hooren, S. A., & Jolles, J. (2009). Interaction effects of education and health status on cognitive change: A 6 years follow up of the Maastricht Aging Study. *Aging & Mental Health, 13,* 521–529. doi:10.1080/13607860902860821

Mitchell, D. B., & Bruss, P. J. (2003). Age differences in implicit memory: Conceptual, perceptual o methodological. *Psychology and Aging, 18,* 807–822. doi:10.1037/0882-7974.18.4.807

Nilsson, L.-G. (2003). Memory function in normal aging. *Acta Neurologica Scandinavica, 179,* 7–13. doi:10.1034/j.1600-0404.107.s179.5.x

*Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Akitsuki, Y., Shigemune, Y., . . . Kawashima, R. (2012). Brain training game improves executive functions and processing speed in the elderly: A randomized controlled trial. *PloS ONE, 7,* e29676. doi:10.1371/journal.pone.0029676

Owen, A. M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., . . . Ballard, C. G. (2010). Putting brain training to test. *Nature, 465,* 775–778. doi:10.1038/nature09042

Park, D. C., & Bischof, G. (2013). The aging mind: Neuroplasticity in response to cognitive training. *Dialogues in Clinical Neuroscience, 15,* 109–119.

Park, D. C., & Reuter-Lorenz, P. (2009). The adaptive brain: Aging and neurocognitive scaffolding. *Annual Review of Psychology, 60,* 173–196. doi:10.1146/annurev.psych.59.103006.093656

Pascual-Leone, A., Amedi, A., Fregni, F., & Merabet, L. B. (2005). The plastic human brain cortex. *Annual Review of Neuroscience, 28,* 377–401. doi:10.1146/annurev.neuro.27.070203.144216

*Peretz, C., Korczyn, A., Shatil, E., & Aharonson, V. (2011). Computer based personalized cognitive training versus classical computer games:

A randomized double-blind prospective trial cognitive stimulation. *Neuroepidemiology, 36,* 91–99. doi:10.1159/000323950

Persson, J., & Reuter-Lorenz, P. A. (2008). Gaining control training executive function and far transfer of the ability to resolve interference. *Psychological Science, 19,* 881–888. doi:10.1111/j.1467-9280.2008.02172.x

Peter, C., Kreisner, A., Schröter, M., Hyosun, K., Bieber, G., Öhberg, F., Hoshi, K., . . . Ballesteros, S. (2013). *AGNES*: Connecting people in a multimodal way. *Journal on Multimodal User Interactions, 7,* 229–245. doi:10.1007/s12193-013–0118-z

Powers, K. L., Brooks, P. J., Aldrich, N. J., Palladino, M., & Alfieri, L. (2013). Effects of video-game play on information processing: Meta-analytic investigation. *Psychonomic Bulletin & Review, 20,* 1055–1079.

Prakash, R. S., De León, A., Mourany, L., Lee, H., Voss, M. W., Boot, W. R., . . . Kramer, A. F. (2012). Examining neural correlates of skill acquisition in a complex videogame training program. *Frontiers in Human Neuroscience, 6,* 115, 1–11.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., . . . Acker, J. D. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex, 15,* 1676–1689. doi:10.1093/cercor/bhi044

Rönnlund, M., & Nilsson, L.-G. (2008). Cross-sectional versus longitudinal age gradients of Tower of Hanoi Performance: The role of practice effects and cohort differences in education. *Aging, Neuropsychology and Cognition, 15,* 40–67.

Rönnlund, M., Nyberg, L., Bäckman, L., & Nilsson, L.-G. (2005). Stability, growth and decline in adult life span development of declarative memory: Cross-sectional and longitudinal data from a population-based study. *Psychology and Aging, 20,* 3–18. doi:10.1037/0882-7974.20.1.3

Salthouse, T. A. (1996). The processing speed theory of adult age differences in cognition. *Psychological Review, 103,* 403–428. doi:10.1037/0033-295X.103.3.403

*Sosa, G. (2011). The impact of video game intervention in the cognitive functioning, self-efficacy, self-esteem and video games attitude of older adults. A final project. *CUG Theses and Dissertations.*

*Stern, Y., Blumen, H., Rich, L., Richards, A., Herzberg, G., & Gopher, D. (2011). Space Fortress game training and executive control in older adults: A pilot intervention. *Aging, Neuropsychology and Cognition, 18,* 653–677. doi:10.1080/13825585.2011.613450

*Torres, A. (2008). Cognitive effects of video games on older people. *ICDVRAT, 19,* 191–198.

United Nations, Department of Economic and Social Affairs. (2010). *World Population prospects: The 2010 revision, volume II: Demographic profiles.* ST/ESA/SER. A/317.

*Van Muijden, J., Band, G., & Hommel, B. (2012). Online games training aging brains: Limited transfer to cognitive control functions. *Frontiers in Human Neuroscience, 6,* 1–13.

Wiggs, C. L., Weisberg, J., & Martin, A. (2006). Repetition priming across the adult lifespan—The long and short of it. *Aging, Neuropsychology, and Cognition, 13,* 308–325. doi:10.1080/138255890968718

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., . . . Wright, E. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Journal of the American Medical Association, 296,* 2805–2814. doi:10.1001/jama.296.23.2805

Zelinski, E. M., & Reyes, R. (2009). Cognitive benefits of computer games for older adults. *Gerontechnology, 8,* 220–235. doi:10.4017/gt.2009.08.04.004.00