Cognitive decline is one of the most feared aspects of growing older and is also the most costly in terms of financial, personal, and societal burdens. Cognitive decline has serious consequences for older adults’ independence and quality of life. It is associated with decreased ability to perform everyday tasks required for functional independence, such as the ability to drive a car and to manage personal finances. When older adults’ cognitive function declines to the point of inability to manage daily life, they experience significant neuropathology in the form of dementia, illness, or even death. Therefore, it is increasingly important to understand and find ways to improve their cognitive function. An approach that has been gaining researchers’ attention is digital games.

Although cognitive decline is a normal part of aging, the human brain appears to be capable of changing its structure and developing new skills over the course of a lifetime. By challenging their brains and strengthening cognitive skills, older adults can drive plasticity and improve brain function – the “use it or lose it” phenomenon. Digital games can be complex, flexible activities that use multiple cognitive abilities, and recent empirical research has demonstrated improvements of digital gameplay on older adults’ cognitive function, such as executive control and processing speed. These improvements suggest that digital game-based cognitive training has potential for combating cognitive decline associated with advancing age.

Cognitive training seems to be most effective when participants are pushed to the limits of their abilities, which can be frustrating and discouraging. To counter frustration, digital games can incorporate elements that are important to older adults’ enjoyment, including mental exercise, competition, and, for social games, a sense of belonging. Compared to other types of cognitive training, digital gameplay may be ideal for increasing intervention compliance, as it is inherently engaging and motivating, a state that can be described in terms of Csikszentmihalyi’s flow experience. Flow describes a mental state of complete absorption, accompanied by positive feelings. It is associated with characteristics such as challenge, concentration, direct feedback, clear goals, control over the activity, intrinsic rewards, loss of self-consciousness, time distortion, and a merging of action and awareness.

These factors have come together to stimulate growing research interest in exploring the cognitive effects of digital games on older adults. Researchers have employed a variety of games, research designs, and outcome measures, and there is a corresponding variety in the pattern of reported results. This review collects and summarizes work to date on theoretical foundations, design and development projects, and evidence of the effectiveness of digital games as tools for mitigating cognitive decline in older adults, with the goal of identifying existing evidence, gaps, and promising paths for future work.

F. Zhang, D. Kaufman. Cognitive benefits of older adults’ digital game play: A critical review. Gerontechnology 2016;15(1):3-16; doi:10.4017/gt.2016.15.1.002.00. There is growing research interest in the cognitive effects of digital games on older adults. This review systematically analyzed 34 published studies exploring the theoretical foundations, design guidelines, and empirical evidence regarding the potential of digital games to improve older adults’ cognitive function. Results indicate that while researchers are actively exploring games’ potential for cognitive intervention, (i) little work has been done to date to establish a strong theoretical foundation for this research; (ii) design and development of games for older adults have concentrated on usability and could be improved by a stronger focus on older adults’ engagement and motivation for gameplay; and (iii) evidence about their impact on cognitive functions is inconsistent, partly due to wide variations in experimental methods. Taking into account limitations of the studies, future research is recommended.

Keywords: cognitive benefits, cognitive decline, critical review, digital games, older adults
BACKGROUND

Older adults and cognitive change

Older adults’ cognitive and psychological health is important to the family and society. There are many risk factors influencing cognitive decline, such as a predisposing genetic polymorphism, vascular risk factors (e.g., hypertension, obesity and type II diabetes), biomarkers (e.g., inflammation) and lifestyle (e.g., exercise and diet), but age is the main factor associated with cognitive decline. Deary et al. stated that within the range of normal cognitive aging, people differ greatly in the degree to which their brains decline with age. These authors highlighted that although not all cognitive domains are equally affected by age, some declines are notable in older adults, such as information processing speed, reasoning, memory, and executive functions. These ‘fluid’ mental abilities are important for people to carry out everyday activities and live an independent and fulfilling life. Fluid intelligence relates to a person’s reasoning and problem solving skills. It peaks in early adulthood and then decreases over a lifetime.

While cognitive decline is generally thought to be a natural trend of aging, our increasing knowledge of cognition and aging indicates that cognition is not a fixed event, but dynamic and plastic in nature. Plasticity is the brain’s ability to change and reorganize neural networks in response to external stimulation. It is the foundation of our ability to learn and adapt, and in turn, to survive. This is how individuals are able to learn and change ideas and understanding. As individuals age, neural plasticity declines; however, it does not disappear completely. The ability for the brain to adapt and reshape thoughts is crucial for coping with the changes that occur in life and aging.

Many researchers have explored the possibility that targeted interventions may help to improve cognition and slow or prevent cognitive decline. There is some evidence to suggest that effective cognitive training has positive effects on cognitive function. Ball et al. examined the effectiveness of three cognitive training interventions on the mental abilities and daily functioning of independent-living older adults. In comparison to baseline performance, participants in their experimental group exhibited immediate improvements in processing speed, reasoning, and verbal episodic memory after a 19-month intervention period; these were maintained at a two-year follow-up. Uchida and Kawashima performed a single-blind, randomized controlled trial on cognitive intervention in community-dwelling older adults aged between 70 and 86. Participants in the experimental group were asked to solve systematized basic problems in reading and arithmetic every day for six months; results showed immediate beneficial effects on the speed of processing and executive function, and the improvements were maintained in six months of follow-up tests.

Digital games for older adults

Games often offer particularly striking examples of highly motivating activities. There are some features of games that intrinsically motivate players to engage in gaming activities, including challenge, fantasy, and stimulation of curiosity. Digital games provide players with new ways of interaction that are more natural in terms of affordances and engage the whole body. In an independent cross-genre research study on why people play digital games, Lazzaro and her XEODesign team concluded that people play digital games not only for the game itself, but also for the moment-to-moment experience accompanying gaming activities: the joy and sense of achievement from overcoming a difficult game task, interacting with other gamers inside or outside the game, and escaping from real-life work or school.

In addition to the gaming experience of fun and enjoyment, scholars in the digital games area have stated that digital gameplay activates cognitive skills as players explore dynamic and rich environments, adapt to changing scenarios, make quick decisions, and construct mental representations of space to move among screens. Games can drive positive neurological changes in brain systems when they require progressively more accurate, challenging, and faster judgments along with suppression of irrelevant information. Also, most digital games require resource processing, hand-eye coordination, sustained attention to the task, and the ability to quickly locate a particular screen area. As players practice and become proficient at these tasks, it is expected that their visual-spatial skills will be improved. Belchior et al. claimed that digital games might work to improve (i) basic speed of cognitive processing, (ii) executive control, (iii) attentional control, including both the spatial and temporal operation of attention, (iv) the ability to quickly perceive the relations between multiple objects and events, and (v) selective visual attention.

Since the mid-1980s, digital games have been used for psychological, cognitive, and neuropsychological rehabilitation in older adults. Digital games have some practical advantages compared to physical exercise intervention and traditional cognitive interventions supervised by therapists (for examples, see Ball et al.’s study) in that they are less expensive, more entertaining, and more highly motivating. However, due to their perceptual, motor, and cognitive changes and a lack of technological skills, older adults...
face more and different usability problems than younger users, and digital game design for older adults is an area that needs significant research. The methods used to make digital games usable for older adults may also differ from those needed for other information technologies because of the different natures of games and productivity-oriented software. In addition, games designed for cognitively therapeutic effect need to balance engagement and frustration more tightly than games for general population. A mismatch between game characteristics and the abilities and demands of older users may lead to poor performance and negative experiences.

Several reviews have assessed the impact of computer- and game-based interventions on older adults’ cognitive function. Kueider et al. reviewed studies examining the efficacy of computer-based cognitive interventions in healthy older adults, concluding that computerized training is effective and less labor-intensive than traditional paper-and-pencil-based approaches. Bleakley et al. analyzed the physical and cognitive effects of physically-based interactive computer games on older adults, found some evidence that they are safe and effective, although they questioned the quality of many of the studies reviewed. Toril et al.’s meta-analysis found evidence of positive effects on reaction time, attention, memory, and global cognition, with effects moderated by training duration and age. Cota and Ishitani reviewed studies of older adults’ motivation for and benefits of playing digital games and claimed that digital games can be low-cost, home-based tools for treating cognitive and psychosocial problems. Zhang and Kaufman, in a meta-analysis to examine the physical and cognitive impacts of digital games on older adults, found some empirical evidence for their effectiveness in improving executive function and processing speed. However, none of these reviews have specifically analyzed theoretical and methodological issues as well as empirical evidence regarding the cognitive effects of digital games on older adults.

**Research objectives**

Given that this field is expanding rapidly, this study addressed three objectives: (i) to describe theoretical rationales for the effectiveness of digital gameplay on older adults; (ii) to provide a summary of recent research projects that specifically target the design and development of digital games for older adults; and (iii) to identify existing evidence of the cognitive effects of digital gameplay on older adults.

**Methods**

**Search criteria and article selection**

The authors searched CENTRAL, PubMed, ERIC, Medline, PsycInfo, SSCI, and Google Scholar as well as article reference lists for original articles that described either intervention or non-intervention studies with a focus on cognitive effects of digital gameplay on older adults. The searches covered articles published between 1980 and 2015. Search keywords were: (Computer or video or digital) and gam* and (cogniti* or mental) and (senior* or old* or elderly or age*).

Park and Bischof argued that in order to improve cognitive function, the aging brain must have plasticity. Understanding the mechanisms that enhance neural plasticity is thus one foundation for the design and application of older adults’ digital games. Two types of articles were therefore included about theoretical rationales for the cognitive effects of digital games: (i) those describing basic concepts and mechanisms of plasticity, and (ii) those describing basic concepts, experiences and opinions related to the cognitive benefits of digital gameplay. Other inclusion criteria were: (iii) articles discussing the design, development and evaluation of digital games for older adults; and (iv) articles measuring the cognitive impacts of digital-game training on older adults.

Given the purpose of this review, we did not include the growing literature on the effects of digital gameplay on intergenerational relationships between older adults and grandchildren. Empirical studies were also excluded that evaluated cognitive benefits by retrospectively examining lives in early and middle adulthood to identify effects in later life.

After the database search and selection process, a total of 34 studies were included, of which nine studies are about theoretical rationales, 10 are studies focusing on game design and development, and 15 are empirical studies associated with outcome measures of cognitive abilities. All of the included articles were completely read. Information extracted from the 10 studies associated with game design and development includes: (i) game type; (ii) targeted users; (iii) usability test performance; and (iv) design recommendations. The 15 empirical studies were coded for several key methodological characteristics: (i) sample size; (ii) game type; (iii) study design (pre-post designs or random controlled trials); (iv) control group treatment; (v) time of game training; (vi) measures of cognitive abilities; and (vii) key findings.

**Results**

**Theoretical foundations**

To accomplish learning, growth, and development, the human brain is molded dynamically by environmental changes and pressures, physiologic modifications, and experiences. Neuroplasticity (also referred to as brain plasticity,
cortical plasticity or cortical re-mapping) has been widely studied in the last decade, since the development of functional neuroimaging. The literature has discussed neuroplasticity mechanisms at different levels: from structural, functional, and pathophysiological to molecular and cellular levels, and from microscopic to macroscopic, demonstrating the phenomenon's complexity. However, the consensus is that human brain is very capable of reorganization over a lifespan. Even after brain injury, such as stroke, neuroplasticity is possible due to "the existence of significant diffuse and redundant connectivity within the central nervous system, as well as the ability of new circuits to form through remapping".

Park and Bishof pointed out that the human brain can regulate cognitive function by increasing neural activity and developing neural scaffolding. Based on the scaffolding theory of aging and cognition (STAC), scaffolding can be understood as the recruitment of additional circuitry supporting brain function that has become noisy, inefficient, or both. Therefore, in order to protect cognitive function, cognitive training should be able to increase and enhance the development of compensatory scaffolding. This can be achieved by sustained engagement in novel training tasks or environments. In addition, Park and Bishof noted that contextual press or demand is an important factor affecting the access and use of any neural plasticity that exists in the aging brain. It is only when a task or environment consistently makes demands on core cognitive processes (e.g., respond speed, memory or reasoning) that cognitive change occurs. Individuals' past experience, expertise and cognitive status are all important for identifying tasks that provide them with optimal challenges and the potential to effect change in their neural structure and function.

Pascual-Leone et al. argued that plasticity is a consequence of all neural activity, responding to environmental pressures, functional need, and experience. They also identified two steps of plasticity: initial short-term flexible modification of existing neural pathways and eventual longer-term structural changes. Reviewing plasticity research, Jäncke observed that intensive practice stimulates cortical adaptations, and experience-dependent anatomical changes can disappear when practicing stops. This corresponds to the "use it or lose it" metaphor. Similarly, Kerr et al. noted that training intensity impacts both the rate of behavioral gains and the neural changes associated with skill acquisition. Repeated practice of a new skill over time also enhances the likelihood that the skill will be well established and enduring.

Zelinski and Reyes related the principles of brain plasticity effects, including extended practice, to the mechanics of digital action games. Digital gameplay requires time investment and continual repetition in order to progress and win. To achieve success, players must remember control schemes, adapt to changes in game challenges, and make decisions at high speeds. This drives them to engage in rapid information processing in order respond quickly and accurately. Thus, abilities such as memory, decision-making, speed, and hand-eye coordination are practiced and developed. Learning from mistakes, and using clues and strategies to reach higher levels, promote greater use of attention and reasoning in working memory in order to survey the environment, retrieve from memory elements seen earlier in the game, and predict which possible tasks require completion. Zelinski and Reyes also suggested that these gameplay mechanics "have the important added feature of producing the experiences of presence, engagement, and flow, the subjective elements of game play that are likely to sustain interest and emotional investment in the practiced skills", as demonstrated in studies with younger players.

Design and development

Ten of the included studies addressed, from different perspectives, issues related to digital game design for older adults. These focused on the creation of digital games that are adapted to older adults' physical and cognitive abilities while providing enjoyable gaming experiences. IJsselsteijn et al. recommended four design objectives: (i) relaxation and entertainment, (ii) social interaction with others, (iii) motivation for sharpening players' minds, and (iv) physical engagement. They claimed that interface design guidelines for older adults could also be usefully applied to game design, in particular minimizing the burden on functions that may have suffered decline and compensating for particular functional limitations. These two guidelines are in line with Mubin, Shahid and Mahmud’s statement that "the target for any game for the elderly should be minimum rules and maximum fun". To compensate for possible motor or cognitive decline, it is important to create adjustable difficulty levels and meaningful themes that relate to the real world in order to encourage older adults to enter into the game. Digital games for older adults should be easy to set up in order to minimize the burden for nursing staff and reduce access barriers. However, the baseline is that playing game should always be a fun and enjoyable activity.

This review also identified six digital games specifically designed for older adults, including two
Cognitive benefits of gameplay

physical games, a maze game, a mobile card game, a tablet-based card game, and a tabletop-based board game. The majority of these games can be played by multiple players and used in different contexts, such as full-care nursing homes, community centers, and private homes.

In terms of the design process used, the identified projects began with requirement gathering, either by examining literature to identify age-related changes and game characteristics that can provide enjoyable experiences to older users, or by gathering older adults’ game preferences and requirements through interviews and/or field observations. For example, Vasconcelos et al. developed a tablet-based gaming platform that provides an enjoyable experience while integrating cognitive training mechanisms. To understand the contexts of older adults’ gameplay, and to better assess their preferences and difficulties regarding cognitive games, they visited typical gathering places for older adults as well as an adult day care center. Through natural observation and interviews, they found that older adults prefer games that promote social interaction, competition, and a variety of choices but do not require great effort to play.

Even when games are adapted to accommodate common age-related changes, players may experience difficulties engaging in game activities. To address this issue, Gerling et al. recommended a participatory and iterative design approach, which allows older players to test and comment on early prototypes in order to improve game accessibility. Vasconcelos et al. used low-to-high-fidelity prototypes to support the development and evaluation of their tablet-based gaming platform, starting with the design of a paper prototype to evaluate concepts and ideas such as font size, icons and navigation. Later medium- and high-fidelity prototypes, running on the tablet, were tested to validate previous choices and assess older adults’ acceptance and interaction with the platform. Prototypes were iteratively improved after each testing based on test results. Vasconcelos et al. indicated that each prototype identified different design problems. For example, the low-fidelity prototypes showed how to improve the game concept, while the high-fidelity model revealed potential problems regarding interaction with the device itself. Mubin et al. applied a user-centered approach to design and evaluate a mobile game for older adults. The end users (older adults in community centers) participated in the process of requirement capture and game evaluation.

Evaluations of the identified games predominantly focused on usability. Evaluation methods were mainly questionnaires about players’ experience, observations or videotapes of in-game behaviors, and interviews. The Game Experience Scale was often used to measure dimensions of players’ experience, including challenge, competence, flow, immersion, and negative and positive affect. For example, Zwartkruis-Pelgrim and de Ruyter evaluated the enjoyment of a maze game in real-life settings: a total of 14 older adults living independently played the game during a two-week period, and evaluation used logs of participants’ playing behavior (i.e., frequency and timing of playing the game, and performance), diaries about participants’ day-to-day experience, a questionnaire, and interviews. However, the evaluation process for most games lasted for a shorter period of time, such as one or two game sessions.

Empirical studies with outcome measures

Description of the studies

Table 1 summarizes the 15 empirical studies that included outcome measures. The majority of participants in these studies were non-gamers who had no prior experience of digital games or who reported playing digital games less than one hour per week over the past two years. Although patients with a diagnosis of Parkinson’s disease were targeted in one experiment, all participants had good visual and auditory acuity and were cognitively healthy according to norms for the Mini Mental Status Exam (MMSE) (e.g., MMSE >26). In 12 studies participants were community-dwelling older adults. In others, they were drawn from nursing homes, assisted living centers, and senior centers.

The types of game used for cognitive training included sports, strategy, brain training, MMORPGs (Massive Multiplayer Online Role Playing Games) and biofeedback. The Big Brain Academy and Brain Age released by Nintendo present quick activities to train players’ brains, such as math calculation, character recognition, and puzzle solving. NeuroRacer is a 3D digital game designed by a team of researchers at the University of California, San Francisco. It works to enhance perceptual discrimination in the setting of challenges in visuomotor tracking, measured by the percentage of time spent on the road without hitting road and speed boundaries. Quick Battle is a strategy game in the Rise of Nations. The core gameplay involves building new cities, improving city infrastructure, and expanding one’s national borders. Its strategies include establishing diplomacy, acquiring technologies, building wonders, expanding territories, and espionage. Nintendo Super Tetris is a console game consisting of seven differently-shaped blocks that descend from the top of the screen and must be rotated rapidly to
<table>
<thead>
<tr>
<th>Participants</th>
<th>Game Study design</th>
<th>Treatment of CG</th>
<th>Training time</th>
<th>Outcome measures</th>
<th>Key findings</th>
<th>Source</th>
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<tr>
<td>n=78 aged 50-71 MA=60.7</td>
<td>Wii® Big Brain Academy OGPPT</td>
<td>20 hrs</td>
<td>Intellectual abilities</td>
<td>DG improved substantially compared to CG in tasks, no significant transfer to cognition and perceptual speed abilities</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>n=16 in EG n=15 in CG</td>
<td>NeuroRacer RCT</td>
<td>No treatment 12 hrs, follow-up</td>
<td>Fluid intellectual abilities</td>
<td>Cognitive control</td>
<td>Cognitive speed abilities</td>
<td>50</td>
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<tr>
<td>n=18 in EG MA=69.89 n=16 in CG MA=68.88 n=14 in EG n=15 in placebo CG n=13 in CG n=16 in UFOV n=7 in EG MA=70.0 n=7 in CG MA=74 n=20 in EG n=20 in movie n=20 in CG</td>
<td>Quick Battle RCT</td>
<td>No treatment 23.5 hrs</td>
<td>Perceptual speed abilities</td>
<td>Cognitive control</td>
<td>Visuospatial skills</td>
<td>51</td>
</tr>
<tr>
<td>n=14 in EG n=15 in placebo CG n=13 in CG n=16 in UFOV n=7 in EG MA=70.0 n=7 in CG MA=74 n=20 in EG n=20 in movie n=20 in CG</td>
<td>Medal of Honor® RCT</td>
<td>No treatment 9 hrs</td>
<td>Executive control</td>
<td>UFOV speed, Selective attention</td>
<td>Visuospatial skills</td>
<td>52</td>
</tr>
<tr>
<td>n=14 in EG n=15 in placebo CG n=13 in CG n=16 in UFOV n=7 in EG MA=70.0 n=7 in CG MA=74 n=20 in EG n=20 in movie n=20 in CG</td>
<td>Pac Man Donkey Kong RCT</td>
<td>No treatment 14 hrs</td>
<td>Reaction time</td>
<td>Executive function</td>
<td>Visuospatial skills</td>
<td>53</td>
</tr>
<tr>
<td>n=20 in EG n=20 in movie n=20 in CG</td>
<td>Breakout® RCT</td>
<td>No treatment 33 hrs</td>
<td>Visual sensitivity</td>
<td>Cognitive control</td>
<td>Emotional well-being</td>
<td>54</td>
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<tr>
<td>n=10 in EG n=12 in CG n=16 in EG MA=73.47 n=16 in CG MA=73.47 n=54 in EG aged 60-77 n=20 in CG aged 61-73</td>
<td>Nintendo Super Tetris® RCT</td>
<td>No treatment 31 hrs</td>
<td>Cognitive adaptability</td>
<td>Emotional well-being</td>
<td>Cognitive adaptability</td>
<td>55</td>
</tr>
<tr>
<td>n=16 in EG MA=73.47 n=16 in CG MA=73.47</td>
<td>Nintendo Wii® RCT</td>
<td>No treatment 24 hrs</td>
<td>Cognitive control</td>
<td>Executive function</td>
<td>Visuospatial skills</td>
<td>25</td>
</tr>
<tr>
<td>n=16 in EG MA=73.47 n=16 in CG MA=73.47</td>
<td>Anagram Falling Bricks Telling Time, etc. RCT</td>
<td>Answer quiz 24.5 hrs questions</td>
<td>Cognitive control</td>
<td>Visuospatial skills</td>
<td>Cognitive control</td>
<td>25</td>
</tr>
<tr>
<td>Study</td>
<td>Condition</td>
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<td>Intervention</td>
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<tr>
<td>Parkinson's patients</td>
<td>n=14 in EG&lt;br&gt;MA=68.86&lt;br&gt;n=14 in CG&lt;br&gt;MA=69.31</td>
<td>RCT</td>
<td>Play Tetris</td>
<td>5 hrs</td>
<td>Global cognitive status&lt;br&gt;Executive function&lt;br&gt;Attention&lt;br&gt;Processing speed</td>
<td>EG improved executive functions and processing speed, not global cognitive status nor attention</td>
</tr>
<tr>
<td>Community-dwelling older adults</td>
<td>n=16 in EG&lt;br&gt;n=16 in CG</td>
<td>RCT</td>
<td>Balance exercise</td>
<td>7 hrs</td>
<td>Montreal Cognitive Assessment (visuospatial skill, executive function, naming, memory, attention, language, abstraction, delayed recall)</td>
<td>No improvement difference compared to balance exercise therapy</td>
</tr>
<tr>
<td>Nintendo Wii Fit®</td>
<td>RCT</td>
<td>OGPPT</td>
<td>Balance exercise</td>
<td>7 hrs, follow-up</td>
<td>Mood&lt;br&gt;Health-related quality of life&lt;br&gt;Global cognitive functioning Speed&lt;br&gt;Visual construction&lt;br&gt;Memory&lt;br&gt;Language&lt;br&gt;Executive functions&lt;br&gt;Alzheimer’s, self-concept Life quality</td>
<td>CG significantly improved depressive symptoms, mental health-related quality of life, and cognitive performance Only EG improved executive control and letter-number sequencing</td>
</tr>
<tr>
<td>Space Fortress</td>
<td>RCT</td>
<td>No treatment</td>
<td>36 hrs, follow-up</td>
<td>Speed&lt;br&gt;Visual construction&lt;br&gt;Memory&lt;br&gt;Language&lt;br&gt;Executive functions&lt;br&gt;Alzheimer’s, self-concept Life quality</td>
<td>EG improved cognitive functioning and maintained players’ self-concepts and quality of life EG Improved attention compared to CG</td>
<td></td>
</tr>
<tr>
<td>65+ n=15 in EG&lt;br&gt;n=17 relaxation&lt;br&gt;n=11 in CG&lt;br&gt;n=19 in EG&lt;br&gt;n=20 in CG aged 60-77</td>
<td>RCT</td>
<td>No treatment</td>
<td>8 hrs</td>
<td>Attentional control&lt;br&gt;Spatial orientation&lt;br&gt;Mental rotation, etc.</td>
<td>EG improved cognitive functioning and maintained players’ self-concepts and quality of life EG Improved attention compared to CG</td>
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<td>56</td>
<td>48</td>
<td>57</td>
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form a solid wall. Nintendo Wii® Balance Board, Wii® Fit and Wii® Sports are physical games using motion-sensitive technology. The mini-games used in the studies of Muijden et al.25 and Torres59 are brain training tools. For example, in the Telling Time game players need to indicate what time it will be after a variable number of hours and minutes, given the current time depicted on the clock. Space Fortress was originally developed to help young adults acquire complex skills; players must shoot missiles and destroy a space fortress while protecting their spaceship against damage and also need to defend themselves against two types of mines that intermittently appear on the screen. World of Warcraft is a popular MMORPG in which players are pushed to complete more difficult and challenging quests and collaborate with other players in order to ‘level up’ and receive rewards.

In the game studies, interventions were usually conducted for at least one session per week for one or two weeks. Each session lasted 15 to 60 minutes. The mean time of game training was 17.87 hours. However, in Nouchi et al.’s study56, participants played for 15 minutes per day during a period of 20 days, for a total of five hours. In terms of game selection criteria, four studies described expected cognitive benefits underlying selected games. Two studies conducted preliminary investigations to select games suitable for older adults’ cognitive abilities and individual preferences. Whitlock et al.6 was the only article discussing the game mechanisms used for cognitive intervention. They pointed out that any game chosen for cognitive training should include multi-tasking and switching between multiple cognitive abilities (e.g., memory, spatial manipulation and reasoning) to be effective. A game that fulfills this requirement is World of Warcraft.

Study design
Thirteen of the identified empirical studies were randomized controlled trials, one of which had two experiment groups (EGs) and one control group (CG); three had one EG, one active and one passive CG; and one had two EGs in different conditions as well as one active and one passive CG. The other two studies compared pre-post scores in one group. For the passive control group, ten studies used no treatment and three used alternative treatments. For example, Muijden et al.25 examined whether playing online cognitive training games could improve cognitive control in healthy older adults. The experiment group played five randomly alternating digital games, while the control group watched documentaries, followed by answering three to five multiple-choice quiz questions about the documentary. All participants completed their 30-minute interventions daily for a period of seven weeks.

In terms of test administration, twelve studies conducted only one post-test, and the post-test was administered immediately following cessation of the treatment. For the other three studies, follow-up effects were measured at the sixth month58, the 20-24th week57, and the fourth and 24th weeks50.

Outcome measures
Careful inspection of Table 1 shows a wide variability in outcome measures. The majority of studies examined several cognitive benefits, each measured by various scales or tasks. For example, Maillot et al.55 conducted an experiment to evaluate the effects of playing interactive physical-activity digital games on cognitive function in older adults. Participants completed a battery of cognitive tests divided into three categories: executive control tasks, visuospatial function tasks, and processing speed tasks. Each category was further divided into several subtests. In Stern et al.’s study58, five tests were used to assess executive control ability, and each test was performed under two conditions (congruent vs. incongruent and compatible vs. incompatible).

In addition, the same outcome measure was often tested using different scales or tasks. For instance, Maillot et al.55 measured processing speed ability by a cancellation test, a number comparison test, a reaction time test, and a plate-tapping test, while Nouchi et al.56 tested this ability using a completing a Digital Symbol Coding task and a Symbol Search task. The outcomes from the same test were at times reported differently; for example, in one study the mean reaction time difference between the incongruent and congruent conditions of the Stroop Color-Word Test was used as a dependent variable to measure inhibition25, while in another study the reaction time in each condition was reported separately58.

Six articles described the details of the cognitive scales used, including the abilities measured, test administration, scoring, and interpretation. However, only one reported scale reliability. Goldstein et al.54 used the Sternberg test and the Stroop Color Word Test to measure reaction time and cognitive adaptability. The Spearman-Brown reliability coefficients for these two scales were 0.90 and 0.89 respectively. Other studies did not explain why a specific task was used, what it tested for, or how it was administered. Thus, it is difficult to draw conclusions about whether the outcome measures used in these studies were appropriate for testing the study hypotheses.
Evidence of effectiveness

The studies used different types of ANOVA analysis (e.g., mixed ANOVA, repeated ANOVA, MANOVA, and MANCOVA) to examine the treatment and interaction effects of the interventions and the effects of demographics (e.g., age and education). Study results suggested that playing digital games could improve older adults’ executive control, reaction time, attention, and reasoning. However, the positive findings of the majority of studies were based on behavioral improvement - the change in pre-post scores on paper or computer-based cognitive tests.

This review only identified one study that both provided behavioral evidence of the positive effects of video game training on older adults’ cognitive control abilities and evaluated underlying neural mechanisms. Anguera et al. assessed the effects of digital gameplay on the aging mind by having 16 healthy older adults play NeuroRacer on laptops at home, three times per week for a month. The participants then returned to the lab to play the game wearing electroencephalography caps that read electrical activity in their brains. There were improvements in their multitasking skills, response speed, and sustained attention. Furthermore, as measured with electroencephalography, the participants showed changes in the rhythmic firing of neurons in the part of the brain known as midline frontal theta, suggesting that NeuroRacer multitasking training remediated age-related deficits in neural signatures of cognitive control.

In contrast to these encouraging findings, some contradictory ones were also reported. For example, Ackerman et al. compared the cognitive effects of two training approaches in 78 older adults aged between 50 and 71. Participants first played Wii® Big Brain Academy for 20 one-hour sessions, then completed 20 sessions of reading training. Results showed that there was no significant transfer effect from the Wii® practice to cognitive and perceptual speed abilities. One problem with this study is that the reading training might have had a negative impact on the effectiveness of game training.

Three studies investigated the long-term effects of digital gameplay on older adults. Anguera et al. found that playing an adaptive version of NeuroRacer in multitasking training mode reduced older adults’ multitasking costs, with gains persisting for six months. However, in Stern et al.’s study, which investigated the feasibility of using Space Fortress to improve executive control processes in cognitive healthy older adults, participants showed improvement on one measure of executive control and on WAIS-III letter-numbering sequencing at the end of training in altering the focus of play to different aspects of the game (such as controlling the spaceship or manipulating mines), but the benefit was not maintained after six months without gameplay. Rosenberg et al. assessed the feasibility, acceptability, and short-term efficacy and safety of Nintendo’s Wii® Sports, finding that there was a significant improvement on cognitive performance after a 12-week intervention, but the cognitive improvement was not maintained at a 20-24 week follow-up.

Studies examining whether training results are extended to untrained abilities also produced conflicting results. Anguera et al. found that their training resulted in performance benefits that extended to untrained cognitive control abilities such as sustained attention and working memory. Muijden et al.’s study tested whether playing online cognitive training games could improve cognitive control in healthy older adults. Compared to the control group, participants in the game-playing experimental group showed improvements in response inhibition, inductive reasoning, and selective attention, which were not targeted by the intervention. Muijden et al. were not confident about their results because of potential baseline differences between the groups. Although it is desirable and important to show improvement on trained and untrained cognitive abilities, and over longer periods of time, it is difficult to assess how durable training effects are over time, and whether training results can be extended to untargeted abilities.

Discussion

This study has reviewed the theoretical support for game-based interventions to enhance older adults’ cognitive function, summarized relevant game design and development guidelines, and confirmed that there is promising, although somewhat conflicting, evidence that digital gameplay can provide older adults with cognitive benefits. In each of these areas, results also suggest ways in which new research directions could help to improve digital games as vehicles for enhancing older adults’ cognitive capacities.

Need for more theoretical support

There is evidence that the aging brain is plastic, maintaining its ability to change in neural structure, connectivity, and function. Our experience and behavior corresponding to the activity of all relevant neurons through the brain make our dynamic plastic cortex possible. Cognitive function can be facilitated through cognitive training and through engagement in demanding tasks that provide sustained cognitive challenge. Intensity and repetition of practice, contextual press,
past experiences, expertise and cognitive status all play important roles in designing tasks that provide optimal challenges to older adults and thus effect change in neural structure or function. This knowledge, based on brain research, provides possible ways to design digital games aimed at older adults and enhance intervention effects in gamed training.

However, only Zelinski and Reyes\textsuperscript{41} examined the cognitive benefits of digital gameplay for older adults from the principles of brain plasticity. They related the improvement of specific cognitive abilities to types of game genres, arguing that role-playing games involve reasoning, working, and long-term memory, while playing first-person shooting games requires hand-eye coordination, mental rotation, response speed and visual attention. However, their study investigated only action games and did not consider whether these principles could be applied to other type of digital games (strategy games, MMORPGs, etc.). More theoretical support for the cognitive effects of different types of gameplay on older adults could provide guidance for the design and development of digital games for older adults’ general cognitive training, as well as for the use of digital games for rehabilitating cognitive impairments.

Usability tests

Designing and developing digital games for older users’ cognitive training pose unique challenges, due to factors such as (i) older adults’ functional limitations, (ii) their limited technology experience, (iii) the need to respond to and challenge individual cognitive limits, and (iv) the need to motivate and engage older users to stay with gameplay challenges for enough time to realize potential benefits. In order to offer a demanding, yet enjoyable gaming experience to older adults regardless of age-related impairments, researchers and developers need to not only examine evidence-based design guidelines in the literature, but also to iteratively test game prototypes with older adults. Game researchers in the reviewed studies were aware of basic game design issues for an older population, such as challenge, flow, competence levels, accessibility for required physical movements, potential problems regarding the game interface design, navigation, in-game behavior, and game performance. Participatory game design or user-centered design has successfully been implemented to create user-friendly digital games for older adults. By understanding older adults’ various ability levels, interests, and motivations, and then incorporating these considerations into the design process, digital game designers can better address the usability issue for older users. This will allow them to appeal to and benefit more from the potential cognitive enrichment offered by digital games\textsuperscript{28}.

However, IJsselsteijn et al.\textsuperscript{24} argued that researchers should look beyond the usability requirements imposed by age-related functional limitations towards the creation of digital games that offer engaging content and adaptable interfaces for older users. All of the identified design studies focused primarily on design requirements to make sure that games are usable for older adults. None of them measured the broader benefits of the games for older adults. Usability in itself is not a sufficient motivation for older adults to use digital games; it is equally and perhaps more important to make sure that “there are substantial perceived benefits for older users so that they are willing to invest their valuable time and energy in what could potentially be a rich and rewarding experience”\textsuperscript{21,55}. As McLaughlin et al.\textsuperscript{60,21} pointed out, “When the qualities of a video game provide benefit, seniors will play that game”. Therefore, in addition to ensuring usability of games for older adults, researchers need to understand how digital games can offer cognitive benefits through play, how players’ needs can be adequately addressed, and which aspects make games appealing and special for them.

Game interventions

In the reviewed studies, four types of outcomes were measured for game interventions with older adults. Most projects focused on training specific cognitive skills through practice, measuring improvement at the end of a training period. The improvement was typically behavioral, such as improvement in executive control ability. Some studies also examined whether the observed improvement transferred to untargeted abilities. A few assessed how long the improvements were maintained after the training ended. Finally, a few studies focused on actually changing neural activity with training.

Although these studies are promising with regard to the cognitive improvements in older adults, some methodological limitations were identified. First of all, the research findings are inconsistent. Conclusions are difficult to draw because of inconsistency associated with a number of factors, such as the baseline difference between experimental and control groups, the wide variety of study designs, and differences in analytic approaches and outcome measures. For example, Goldstein et al.\textsuperscript{54} had experimental group participants play Super Tetris\textsuperscript{®} to test its cognitive effects, whereas in Nouchi et al.’s study\textsuperscript{56}, Tetris\textsuperscript{®} was used by participants in a control group because Goldstein et al. had found that playing Tetris\textsuperscript{®} did not exert transfer effects on cognitive
functions. Although Nouchi et al.\textsuperscript{56} determined that the effect size for the outcome measure of executive function after playing Brain Age\textsuperscript{®} (the game used in the experiment group) over four weeks was 0.773, it is possible that the true effect of playing Brain Age\textsuperscript{®} was underestimated because the ‘no effect’ conclusion of playing Tetris\textsuperscript{®} itself is arbitrary. Another reason is that Goldstein et al.’s study\textsuperscript{54} did find that playing Tetris\textsuperscript{®} improved reaction time, and those who played Tetris\textsuperscript{®} felt more positive than those who did not. Thus, the internal validity of Nouchi et al.’s study\textsuperscript{56} is questionable.

Although these studies remained promising with regard to cognitive improvements in older adults, some additional limitations were identified. First, older adults showed immediate improvement on sets of cognitive measures, but long-term effects remained uncertain because there were only three studies analyzing effect retention after game training. It was also unclear whether improvements transferred to everyday life tasks such as driving safely, as no study assessed the practical value of cognitive gains from digital gameplay. The retention effect of digital games on older adults’ everyday life is important, because for a cognitive training program to be effective, benefits should remain and translate into real-world behavioral changes\textsuperscript{12}.

In addition, it is questionable whether some training plans were sufficiently long to build up effects. For example, in Nouchi et al.’s (2012) study\textsuperscript{56}, the total training time was five hours, which is much less than the mean training time (17.87 hours) of all included studies. Although there is no evidence indicating that five hours is too short a period to build up effects, previous studies have concluded that successful gameplay requires both adequate time and emotional investment from users\textsuperscript{61}. Thus, the outcome measures in this study may not reflect the true impact of the game interventions. Kerr et al.\textsuperscript{40}, reviewing findings on the role of experience in reorganizing the adult damaged brain, concluded that training intensity impacts both the rate of behavioral gains and the neural changes associated with skill acquisition, and it may be most important for the rehabilitative training to be long enough to effectively translate regained functions into everyday activities. However, we do not sufficiently understand the impact of levels of gameplay intensity.

The evidence for cognitive effects of digital gameplay on older adults has primarily been based on behavioral measures. However, the diversity of cognitive tests used to assess cognitive function leads to uncertainty about the nature of the abilities tested. Also, long-term effects are uncertain because only three studies analyzed the retention of effects after game training. It is also unclear whether those improvements transfer to everyday life tasks such as driving safely, as no study has assessed the pragmatic value of digital games. The retention effect of digital game on older adults’ everyday life is important, because for a cognitive training program to be effective, benefits should remain and translate into real-world behavioral changes. Park and Bischof\textsuperscript{12} emphasized that the gain to participants is slight if the primary gain is just becoming more efficient at the training task. Reviewing studies in cognitive training, Vinogradov, Fisher and de Villers-Sidani\textsuperscript{62,64} noted that: “…if a cognitive intervention is to be successful, it must have a well-articulated theoretical rationale and clearly understood, specific mechanisms of action that are grounded in the neuroscience of learning and cognition; it must induce a specific, robust, and enduring change in a well-defined set of cognitive/socio-affective functions and neurological outcome measures when studied under rigorously controlled conditions; and it must generalize beyond the trained task and result in meaningful behavioral improvements that affect real-world functioning”.

Digital games are promising tools for cognitive training because they are designed to be fun to play\textsuperscript{6}. While some of the mini-games used in the empirical studies (such as Telling Time) can be defined as cognitive tools to train the aging brain, they do not include the key elements of game, such as fun, curiosity stimulation, competition, and flow. Some digital interventions only involve simple bio-feedback or computer-based drill-and-practice training. Digital games have some practical advantages compared to other cognitive interventions (e.g., they are less expensive but more entertaining and motivating), and thus should not be dismissed as cognitive training tools\textsuperscript{25}. Ackerman et al.\textsuperscript{49} found that the majority of their participants did not enjoy the Wii task practice. This raises the question: how will digital game training have enduring and meaningful impacts on older adults’ cognitive function if they do not enjoy the training?

**Future research**

The limitations found in studies exploring the design and evaluation of digital games for older adults may lead to skepticism about their ultimate usefulness and efficiency for cognitive enhancement. To address these limitations, we offer a list of recommendations for future research: (i) Aim for greater understanding of the fundamental mechanisms of how different digital games influence older adults’ cognitive func-
Cognitive benefits of gameplay

in order to design more effective and efficient digital games and training plans.
(ii) Conduct both usability tests and empirical studies to develop and evaluate digital games that are usable for older adults and have the potential to improve their cognitive function.
(iii) Offer both neural and behavioral evidence of the cognitive benefits of digital games for older adults. This would allow researchers to determine which neural systems are engaged and adapted during gameplay. This could also provide information with respect to issues such as long-term effects of gameplay and factors such as timing and intensity that could affect training results.
(iv) Assess the sustained effects of digital game training in order to better understand how cognitive gains from gameplay translate to older adults’ everyday lives and to determine how games can be used to treat neurodegenerative diseases.

CONCLUSION

Digital games are entertaining and motivating tools to engage players in challenging activities that require multiple perceptions and skills, providing the potential to improve older adults’ cognitive function. This review has identified core themes and gaps in research to date. Evidence from brain and neural science research suggest that the aging brain is capable of reorganization in response to experience and behavior. We suggest that game mechanics should be based on our knowledge of the human brain, should be designed to meet the special requirements of older adults, and should consider their motivations for spending time and effort on digital gameplay. Consistent with this, usability tests of game design should be combined with evaluation of the potential benefits for the target population. Although the findings of the empirical studies pertaining to the cognitive effects of digital game training are encouraging, it is difficult to reconcile inconsistent findings because the methodological differences among the identified studies are substantial. Therefore, more research is needed in order to create and develop efficient and successful digital game training for cognitive impact on older adults.

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