

## The Use of Games in Paediatric Cognitive Intervention: A Systematic Review

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### Abstract

**Objectives:** Games that purport to stimulate cognition are increasingly used in intervention, leading to a need for comprehensive information regarding the putative benefits of game-based approaches for remediating cognitive functioning.

**Methods:** A systematic search of MEDLINE, ERIC, PsycInfo, CINAHL was conducted to document the methodology and outcome of game-based cognitive interventions, leading to 448 references. Titles and abstracts were initially screened with respect to inclusion and exclusion criteria and 396 studies were rejected. The 52 remaining articles were read in full and 14 were retained for review.

**Results:** Most studies found positive outcomes suggesting that using games is effective for improving language, attention, executive functions, reasoning, and face processing. Games and protocols varied greatly within and across domains.

**Conclusion:** While game-based cognitive intervention is a promising approach in paediatrics, lack of methodological precision can limit reproducibility and applicability. Recommendations for the design and reporting of game-based cognitive interventions are proposed.

**Keywords:** Rehabilitation; Recovery; Paediatric; Child; Games; Cognition

### Introduction

Cognitive deficits are inherent consequences of a large number of developmental (ex: attention deficit hyperactivity disorder, language disorders, Tourette's syndrome), acquired (ex: traumatic brain injury, brain tumours, stroke), genetic (ex: neurofibromatosis) and psychiatric (ex: depression) disorders of childhood and adolescence [1-6]. Their impact on everyday functioning is typically addressed through cognitive intervention and rehabilitation programs offered in the context of research protocols evaluating their efficacy and validity, or by clinicians, such as neuropsychologists, speech therapists, and occupational therapists [7]. Cognitive intervention or rehabilitation can be defined as a method to treat or improve cognitive functioning including oral and written language, reasoning, attention and executive functions and perceptual processing. This can occur in one of two ways, either through compensation (i.e., using strategies to avoid using the impaired function), or by directly addressing the damaged function. Intervention can take the form of pharmacological treatment [8], stimulation of the biological substrates of cognitive functioning, for example using transcranial magnetic stimulation [9-11] or neuro feedback [12,13], or be performed through repeated exposure, practice and training of target skills, and dispensed either in group therapy [14] or individually [15]. Individually tailored approaches are often used in clinical settings and are known to produce improvements in cognitive functioning. However, little

information is available in the scientific literature on the structure and standardization of such protocols.

Methodological approaches use both "paper-pencil" and computer exercises to stimulate cognitive functioning [16-18]. More recently, improvements in the technology and design of video games targeting 'brain training' [19-21] and their increased accessibility have led a growing number of health practitioners to turn to game-based formats for the delivery of cognitive remediation programs in a variety of age groups, clinical populations and settings [22,23]. However some studies suggest that game trainings might not lead to real cognitive transfer [22] or improved cognitive functions [24]. The use of games carries numerous advantages. First, they are generally accessible, not only for health practitioners and scientists, but also for parents and educators. Second, their cost is relatively low, especially compared to biofeedback and psychophysical techniques requiring cutting-edge technology and advanced training. Third, they can be used in different settings (clinic, home, school) and can be practised in individual or group sessions. Fourth, they can be based on a variety of media depending on the desired level of interaction and exposure and the cost trade-offs, including traditional board games [25], storytelling approaches [26], computer games [23], console and handheld gaming devices [27], and virtual reality [28]. Lastly, and perhaps most significantly, games are popular among youth and may offer added appeal and engagement compared to classical therapeutic approaches, thus enhancing motivation during intervention in child and adolescent populations.

There is emerging evidence for the effectiveness of gaming approaches for the improvement of cognitive skills, such as processing

speed and executive skills [20,23,29]. However, while this medium for intervention delivery shows promise, there is relatively little information available on the efficacy of game-based protocols and methodologies vary widely. Further, there is no consensual framework for the way in which game-based programs should be delivered and reported. The goal of this systematic review was therefore to document empirical studies using game-based cognitive interventions in children and adolescents, to assess their methodology and study design [30] and to provide considerations for scientists and clinicians when using games to remediate cognitive functions.

## Methods

### Literature search

Studies providing information on cognitive interventions using games with a paediatric population were identified. To do so, databases of interest, i.e. PsycInfo, Medline, ERIC and CINAHL, were searched for English and French articles published between 1992 and 2014. Studies published prior to 1992 were not considered because of the rapid technological evolution in gaming since then. The literature review methodology was conducted in accordance with the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) recommendations [31]. PsycInfo, ERIC and Medline were searched together using OVID, and CINAHL was searched separately. No contact was made with authors. Duplicates were then removed when found between the two separate searches (OVID and CINAHL). Bibliographies of articles respecting our inclusion and exclusion criteria were also reviewed and pertinent articles were added. Details on fields searched and keywords used to perform the systematic search are presented in Figure 1.

### Article selection criteria

Articles that matched our keywords were then screened according to the following inclusion and exclusion criteria.

#### Inclusion criteria:

- Human subjects
- Paediatric population (at least a portion of the sample consists of children and adolescents between 18 years and under)
- Experimental studies (randomized control trials, case reports, and empirical studies)
- Intervention protocol uses games that were explicitly defined as such to remediate function (computer games, board games, storytelling and listening associated with games, games with virtual reality)
- Intervention aims to improve complex cognitive functions (attention, memory, language, reading, reasoning, processing speed, working memory, executive functions, face processing)
- Full abstract available, original article, peer reviewed, English- or French-language publication

#### Exclusion criteria:

- Full abstract not available for review
- Adult only population (2)
- Did not use games in their methodology (7)
- Interventions focusing on psychotherapy, motor functions, visuo-motor functions, health, academics, dietary or sexual education (31)

- Language other than English or French
- If the information provided in the title or abstract was not sufficient to determine whether the article met our criteria, the article was read in full (stage 2).

### Data extraction

Articles were reviewed independently by two authors (M.N-C, C.G.) and all data were recorded in a priori designed summary table including the following information: authors, titles, year of publication, research setting, population, age, sample size, type of games used for intervention, measures used to assess the efficiency of intervention, experimental design, duration of the intervention, content of sessions, outcome, and main conclusions drawn by the authors.

### Study quality assessment

The PEDro scale [30] was completed to assess the methodological quality of each of the 14 studies reviewed. The items in this scale were established by a panel of experts [30,32] and although the scale was not primarily designed for neuropsychological studies, it has previously been used successfully in such studies [33] and the criteria were deemed pertinent for the purpose of this review.

## Results

### Overview

Details of the search results are presented in Figure 1. The initial search retrieved a total of 448 articles from which 15 duplicates were removed. 433 titles and abstracts were screened for inclusion and exclusion criteria (stage 1), after which 381 were excluded. The remaining 52 articles were read in-full (stage 2) and 40 articles were subsequently removed because they did not meet the review criteria: 2 reported on adult participants, 7 did not use game-based interventions and 31 reported on interventions that were not focused on complex cognitive processes. The 12 remaining articles were retained and two relevant articles were retrieved from a bibliography, for a final count of 14 articles for systematic review. The last search was conducted on September 14th, 2014.

There was a large variation in the type of games used. Studies included computer games, board games, virtual reality-based games, Wii, story listening supplemented with computer games, and games requiring social interaction. Intervention duration ranged from 1 to 45 hours (M=15.60, SD=14.22) taking place over the course of 2 to 35 weeks (M=13.54, SD=10.56). Only five studies [34-38] included a follow-up evaluation and this ranged from 1 to 6 months post-intervention (M=3.01, SD=2.01)[34-38]. In the 14 studies retained for review, the age of the study participants varied substantially, ranging from 4 to 29 years. For the purposes of this review, we chose to group studies according to the cognitive processes that were targeted in each intervention: oral language (4), written language (4), attention and executive functions (3), reasoning (2) and face processing (1). Improvements are reported for studies in which the results were found to be significant at the  $p < .05$  level.

### Methodological quality

The results of the PEDro scale are reported in Table 1. Most criteria included in the PEDro scale, were applicable to the studies reviewed.

Only two items were not relevant to the studies reviewed here: “blinding of the therapist” (since therapists had to be active during the intervention) and “concealed allocation”, which did not apply to the studies reported here. In some cases, information was not available in the manuscripts to address some of the criteria and these were then scored as negative. In sum, 57.14% of the studies were scored as average, 35.71% were scored as above average (+1 to +2 standard deviations) and 7.14% were scored as below average (-1 to -2 standard deviations). One of the criteria that was not well respected pertained to the equivalence of groups at baseline (9 studies out of 14), though in

five of those studies, this information was not specified, so it is possible that this refers to a reporting issue rather than a methodological one. Also, seven studies did not report that the assessors at post-test were blinded to the condition of attribution, though again this information was missing in four studies. Most studies used a variety of validated neuropsychological measures to assess functioning via pre- and post-test designs and used a control group allowing authors to take into account possible re-test effects. Of note, no study reported on statistical power, limiting the conclusions that can be drawn regarding the strength of the effects observed.

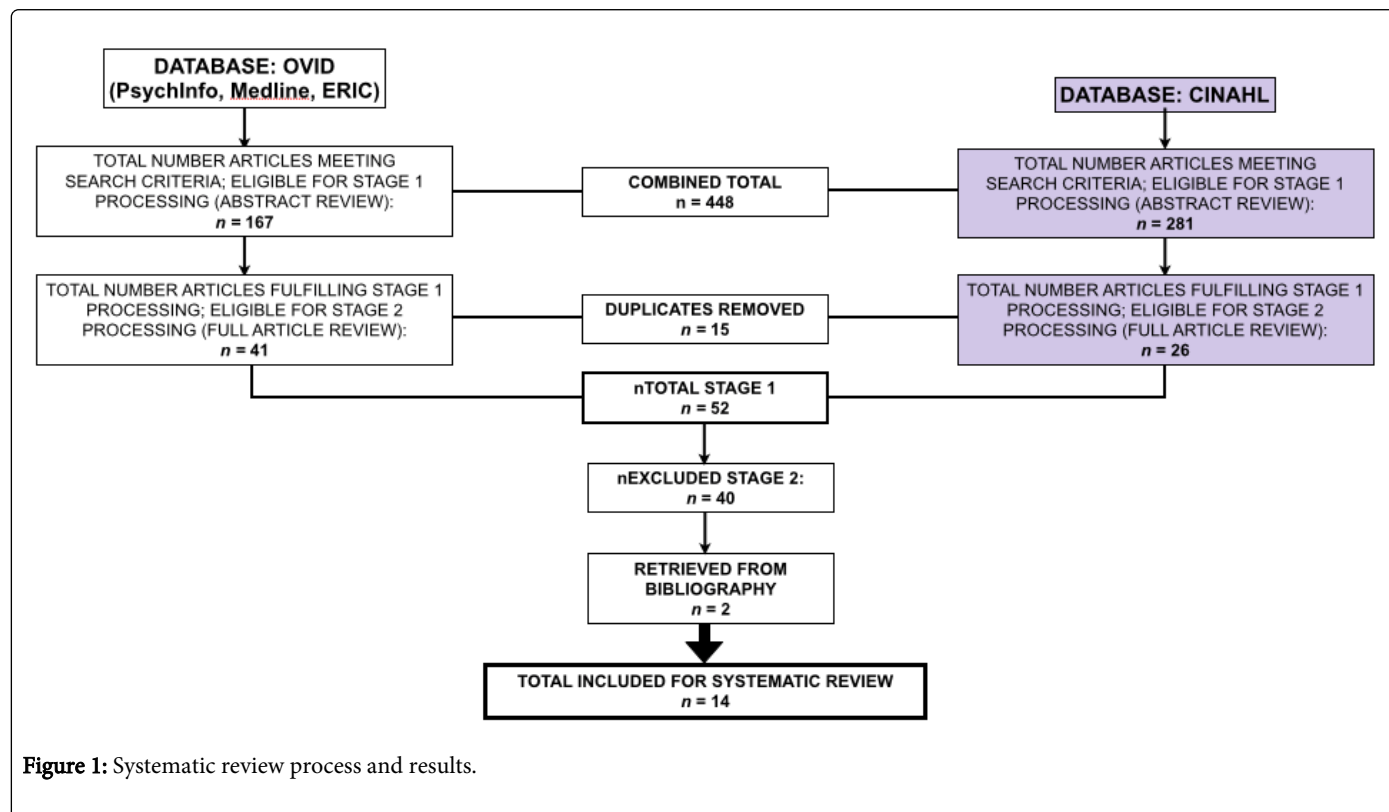


Figure 1: Systematic review process and results.

	Schneiderman, 1995	Cohen, 2005	Seegers, 2006	Munro, 2008	Brennan, 1997	Seegers, 2005	Craig, 2006	Wren, 2008	Rezaiyan, 2007	De Kloet, 2012	Staiano, 2012	Mackey, 2011	Passing, 2000	Tanaka, 2010
1. Eligibility criteria were specified														
2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received)														
3. Allocation was concealed														
4. Groups were similar at baseline regarding the most important prognostic indicators														
5. There was blinding of all subjects														
6. There was blinding of all therapists who administered the therapy														
7. There was blinding of all assessors who measured at least one key outcome														

8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups																				
9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by "intention to treat"																				
10. The results of between-group statistical comparisons are reported for at least one																				
11. The study provides both point measures and measures of variability for at least one key outcome																				
Total /11																				

**Table 1:** Assessment of studies according to criteria of the PEDro scale.

### Oral Language

References	Material	Participants	Age	Intervention	Study Design	Outcome Measures	Results	Follow up
Schneiderman, 1995	Picture toy matching game targeting sentences making	20 deaf or hard of hearing children	11–14	2 30 minutes sessions a week for 6 weeks, playing picture toy matching game or control group working with traditional vocabulary sheets	Randomized, control	Production of sentences depicting given image and rating of the correctness of their syntax	The intervention group wrote more syntactically correct sentences than the control group (92%CR against 27%)	No
Cohen, 2005	Computer games designed to rehabilitate language abilities	77 children with SLI (23 experimental group, 27 control computer group, 27 waitlist control)	m=7	90 minutes a day, 5 days a week for 6 weeks playing Fast For Word (FFW) computer game vs. Computer game control group, vs. Control group doing nothing	Randomized, control	Non-verbal IQ, CELF-3, TOLD-P:3, PhAB, Bus Story	All groups improved overtime, no effect of FFW game	6 months
Segers, 2006	Stories read by a computer then supplemented with games to help enhance vocabulary	18 children with multiple cognitive and physical disabilities with Performance IQ over 80 (9 experimental, 9 control)	4–7	3 20 minutes sessions over 2 weeks listening to stories read by a computer and playing games or listening to stories read by teacher (control group)	Randomized, control	The Active Vocabulary Task from the Dutch Language Test for children	Both groups improved but no difference was found at immediate post-test though there was a better vocabulary retention since they had better retention on long term post-test	1 month
Munro, 2008	Oral narrative, storybook telling and drill-based game	17 kindergarten children with SLI	4–6	One session of one hour a week for 6 weeks	No control group for ethical and practical reasons	Token test for children, Hundred Picture naming test, Bus Story, Preschool and primary inventory of Phonological awareness, Beery- VMI	Children improved on clinical measures of phonological awareness, spoken vocabulary, and oral narration	No

**Table 2:** Oral language interventions.

Of the four studies that intervened on oral language, Cohen et al. [39] and Segers et al. [36] used computer approaches to improve oral language and to help improve vocabulary, respectively. Munro et al. [26] used either card or board games to practise verbal concepts, while Schneiderman [40] used a picture-toy matching game. Participants were from diverse clinical groups, including those with specific

language impairment [26,34], children with multiple cognitive disorders [36], and deaf children [39]. Munro et al. [26], Schneiderman et al. [39] and Segers et al. [36] had a moderate number of participants (n=17-20), while Cohen et al. [39] had a larger number of participants (n=77) [34], which could be due to the fact that they used a computer game intervention and therefore did not require as

many human resources to conduct the remediation sessions. Munro et al. [26] and Schneiderman et al. [39] conducted interventions for one hour a week over six weeks. Cohen's intervention [34] also lasted six weeks, but was administered for 90 minutes every weekday by using a computer game. Segers et al.[36] intervention was shorter and lasted for one hour a week over a two week period [36]. All studies except Munro et al. [26] were randomized and controlled. All authors reported significant improvements as compared to baseline after the interventions, but, only Schneiderman et al. [39] and Segers et al. [36]

showed better results for the experimental group compared to the control group. Finally, only Cohen et al. [34] and Segers et al. [36] included a longitudinal follow-up. Interestingly, the latter detected a positive outcome (better retention) in the experimental group one month after the end of the intervention, whereas no positive effects were found immediately after the intervention.

### Written Language

References	Material	Participants	Age	Intervention	Study Design	Outcome measures	Results	Follow up
Brennan, 1997	Rhyming, clapping, listening to sounds games	38 children (12 experimental, 14 following the SKRW program and 12 control group)	4-6	15 to 20 minutes a day, every week for a whole school year for experimental group or success in school program while control group followed regular curriculum	Randomized, control	ITBS vocabulary, word reading (Schonell), tests developed by the researchers focusing on letter knowledge, word reading, metaphonological test, mathematics	Experimental group showed greater improvement than SKRW group than control group on reading and spelling measures	No
Segers, 2005	Computer games targeting phonological awareness	100 children (42 experimental group, 58 control group) both native and immigrant children	m=5;6	15 minutes session once a week for 35 weeks playing either experimental computer games or commercially available computer games (control group)	Randomized, control by native/immigrants	Tasks developed by Verhoeven (1987) testing rhyming, phonemic segmentation, auditory blending, decoding task	Immigrants in experimental group caught up on the native speakers for rhyming, experimental group improved on grapheme knowledge but not on auditory blending and phonemic segmentation	Yes
Craig, 2006	Rhyming games, story listening or interactive writing process (experimental)	87 kindergarten children (43 experimental, 44 control)	Not specified	4 20 minutes sessions a week for 16 weeks, participating in the experimental group or playing Metalinguistic Games-Plus Program (control)	Partly randomized, control	Snider's (1997) Test of Phonemic Awareness, Hearing Sounds in Words (Clay, 1993), Developmental Spelling Test Woodcock Reading Mastery Test—Revised	Improvement in both groups for phonological awareness, spelling, pseudo-word reading but experimental group showed greater progress on measures of real word identification, passage comprehension and word reading development	No
Wren, 2008	Computer game or countertop therapy using games	33 children with SLI (11 experimental group, 11 countertop therapy, 11 control group)	4-8	30 minutes a week for 8 weeks for both computer and tabletop therapy or control group doing nothing	Randomized, control	GFTA tasks, Speech processing task, Attention Level Rating scale, Phoneme stimulability	No effect of intervention since improvements on phonological knowledge were equivalent in all 3 groups	Yes

**Table 3:** Written language interventions.

Segers et al. [37] and Wren et al. [38] used computer games to target phonological knowledge, Craig et al. [40] used rhyming and stories as a control condition for an interactive writing program, and Brennan et al. [41] used interactive activities such as rhyming, clapping and listening to sounds in a ludic context. Wren et al. [38] and Brennan et al. [38,41] had moderate experimental group sizes (n=11-12), while Segers et al. [37] and Craig et al. [40] had relatively large sample sizes (n=42-43). All focused on children aged between 4 and 8 years old, since this is the age at which children start to learn phonological awareness and reading [42], except for Craig et al. [40] who failed to mention the age of the participant sample. Populations targeted were typically developing children [40,41], children with specific language impairment[38], and immigrant children [37]. In Wren et al. study [38], children participated in the intervention

program for 30 minutes a week for only eight weeks, which was considerably less exposure time than Segers et al. [37] and Brennan et al. [41] whose interventions lasted a full school-year, with weekly 15-minute sessions or daily 15-minute sessions, respectively. The intervention duration for the Craig et al. study [40] fell in between, with 16 weeks of four weekly 20-minute sessions. All studies found positive intervention effects, except Wren et al. [38] who did not find any. All studies used a control group and were randomized. Positive lasting intervention effects were found at follow-up for Segers et al. [37], but not in the study conducted by Wren et al. [38].

### Attention and executive functions

References	Material	Participants	Age	Intervention	Study Design	Outcome measures	Results	Follow up
Rezaiyan, 2007	35 sets of computer games targeting visual stimulus selective filtration	60 males with intellectual disability (50>IQ/70)	Not specified	Playing for 35 sessions of 20 to 30 minutes (experimental group) or doing nothing (control group)	Randomized, control	Attention Scale of Toulouse Pieron	Average attention scores were better in the experimental group compared to the control group right after the intervention, which was no longer the case 5 weeks after the intervention	Yes
De Kloet, 2012	3 Wii games that were chosen according to patients' objectives (different according to every patient)	50 patients with ABI	6–29	Playing on average 2 hours a week for 12 weeks	No control group	Amsterdamse Neuropsychologische Taken (ANT)	Improvements were made on processing speed for figure identification, shifting attention, visual motor coordination, inhibition, but not on accuracy, compared to baseline scores (since there was no control group)	No
Staiano, 2012	Nintendo Wii EA Sports Active exergames	54 obese, low-income African American adolescents	15-19	10 sessions of 30 minutes within a 10 week period during which participants played either competitive exergame or cooperative exergame or did not play (control group)	Randomized, control	Delis-Kaplan Executive Functions System (D-KEFS)	Adolescents who played the exergames competitively had greater improvement in executive skills compared to the cooperative exergame condition and control condition	No

**Table 4:** Attention and executive functions interventions.

Of the three studies targeting attention and executive functioning abilities, Rezaiyan et al. [35] used computer games targeting visual attention skills, while de Kloet et al. [43] used commercially available Nintendo Wii games to train attention. Staiano et al. [44] used exergames to target executive functions by having adolescents train competitively. The sample sizes were similar in all studies and included a large number of participants (N=50-60) who were between 6 and 29 years of age. Populations targeted were individuals with intellectual disability [35], acquired brain injury [43], and low-income African American adolescents [44]. Total program duration varied across studies from 10 x 30-minute sessions [44], to 35 20 to 30 minute

sessions [35] and up to weekly 2-hour sessions for 12 weeks [43]. All studies included a control group except de Kloet et al. [51] who acknowledge this as a major limitation preventing clear ascertainment of positive outcome. Though all studies found beneficial outcomes after the intervention on several of the measures, Rezaiyan et al. [35] were the only group to include a follow-up, but did not find lasting effects.

### Reasoning

References	Material	Participants	Age	Intervention	Study Design	Outcomes measures	Main outcomes	Follow up
Mackey, 2011	Board games and computer games	28 children from low socioeconomic backgrounds (17 for reasoning group and 11 for processing speed)	7 to 10	2 1 hour sessions a week for 8 weeks playing either games aiming at reasoning or processing speed	Randomized, control	TONI-4, Cross-out (Woodcock-Johnson), Coding (WISC-IV)	The intervention led to large improvements on standard cognitive tests of fluid reasoning or speed processing according to group	No
Passig, 2000	Virtual reality games in 2D or 3D	44 deaf and hard of hearing children and 16 controls with normal audition	8 to 10	Sessions of 15 minutes, once a week for 3 months playing either a 3D condition, 2D condition and control group doing nothing	Randomized, control	Structural Sequences of Cattell & Cattell	Deaf and hard of hearing were weaker than control group on pretest induction processes abilities. Deaf and hard of hearing participants playing 3D games performed as well as controls, while those playing 2D games did not	No

**Table 5:** Reasoning interventions.

Only two studies focused on reasoning abilities, Mackey et al. [45] used commercially-available board and computer games with 17 children from low socio-economic background, while Passig et al. [46] used a virtual reality version of the Tetris game in 2D and 3D with 44 deaf and hard-of-hearing children. All children were aged between 7 and 10 years old. Mackey et al. [55] intervention was more intensive with two hours of training a week for eight weeks, while Passig et al.

[46] lasted over three months, but with only 15 minutes of intervention per week. Both studies were controlled and randomized and both found positive outcomes, though neither study included a follow-up assessment.

### Face processing

Reference	Material	Participants	Age	Intervention	Study Design	Outcome Measure	Results	Follow up
Tanaka, 2010	Computer games Let's face it! skills battery	75 children, adolescents and young adults with autism spectrum disorder (wait-list control group)	Not specified	20 hours over a period of 19 weeks playing computer games or doing nothing	Randomized, control	Let's Face It Skills Battery	Children in the experimental group demonstrated improvements in their analytic recognition of mouth features and holistic recognition of face based on the eyes	No

**Table 6:** Information reported for a study regarding face recognition intervention.

Tanaka et al. [47] were the only group that used computer games to remediate face recognition and processing abilities. 75 children, adolescents and young adults with autism took part in the study and were attributed to either the experimental group or a wait-list control group. The mean age and age group breakdown was not specified. The intervention lasted for an average of 20 hours over the course of 19 weeks. Positive outcomes were found after the intervention, but there was no follow-up.

### Discussion

This systematic literature review focused on identifying experimental studies that used game-based approaches to remediate cognitive processes including oral and written language, attention and executive function, reasoning, and face processing in children and adolescents. Using games in intervention settings allows for a large choice of tools and programs and the studies reported here show this diversity. The most common media were computer games [6] and games where children and adolescents were required to interact with adults (rhyming, clapping, imitating tasks performed by adults) [3]. Few studies used board games [2], console/Wii games [2] or virtual reality [1], and surprisingly none used tablet interfaces, such as iPad. However, it is likely given the rapidly increasing accessibility and popularity of Wii, virtual reality and tablets that intervention studies will emerge using these interfaces in the coming years. The use of tablets and virtual reality has been shown to be effective in recent studies of adults with aphasia, adults with motor control deficits after stroke [28,48,49], and in children with autism, though not for cognitive intervention purposes [27]. An assessment of methodological quality using the PEDro Scale [30] showed that more than half of the studies demonstrated a moderate to high quality design with randomized control trial, blind attribution and blind post-testing. Of the 12 randomized controlled studies reviewed here, 10 reported significant effects after the intervention compared to control groups that did not use games. In summary, this review generally suggests that game-based approaches may be beneficial in the context of cognitive rehabilitation and for future research in paediatric populations. These results do not allow any conclusions to be drawn regarding the putative benefit of game-based interventions over more traditional non-game based paradigms. Future work could more

specifically address the potential advantages or disadvantages of electronic and non-electronic games.

Despite overall positive findings, some methodological limitations were present in many of the studies. Regarding game choice, it is important to keep in mind the inherent advantages, shortcoming and confounds of some games in the context of cognitive intervention. For example, interactive games such as board games include social interaction and use of language among peers, and are thus more relevant and useful when assessing oral language skills [34,39]. Computer games, on the other hand, appear to be efficient when addressing written language, attention and executive functions, reasoning and face processing abilities, since they are not as clearly bound to communication skills. Moreover, computer games do not necessitate as many qualified people to conduct interventions since one individual can often supervise several participants at a time [45]. Furthermore, computers (as well as tablets) are very accessible and can be used in clinical and academic facilities. They are also typically available in home environments where they can be used under parental supervision, allowing for greater parental involvement in child recovery, which may also diminish costs and allow for shorter treatment waiting times. Conversely, it is important to keep in mind the limits of computer-based approaches, for instance in the context of the remediation of cognitive functions related to language, communication, social information processing, and adaptive skills, which inherently require social interaction [50].

The way games are presented also appears to play a role in outcome. Using games in a competitive way rather than a cooperative way allowed for improvements in executive functions in one of the study presented [44]. According to Staiano et al. [51], when playing competitively children need to apply perspective taking and mentalizing abilities to both themselves and others in order to predict others' actions and maximize their chances of winning. Thus, it is important to keep in mind the way games are practised-and not only their content-can also influence which cognitive domains are stimulated.

Regarding the reporting of information in the methodology section, some information was often missing. First, details on the population were sometimes insufficient and future research should systematically report basic descriptive information, such as age of participants,

number of individuals in each group, inclusion and exclusion criteria, intellectual level prior to intervention, and, in the case of acquired brain injury, the average time since injury, as this is known to affect recuperation [52,53]. The baseline level on outcome measures between groups should also be reported to assess for any differences before intervention since this could influence how each group (experimental vs. control) could benefit from intervention. Second, no studies reported on statistical power or multiple comparisons in relation to the number of variables tested and sample size, yet it is known that increasing the number of neuropsychological tests in an assessment battery increases the rate of false positive findings [54]. Finally, when reporting the intervention itself, procedural and methodological details were often missing from the manuscripts reviewed, despite the fact that such details constitute the core of information necessary for study reproducibility. The most common missing information was the number of individuals dispensing the intervention and their qualifications, the setting in which the intervention took place, the time of the day, and details pertaining to how the educators/facilitators intervened when children were stuck on a problem (strategy learning and use, feedback). This information is essential to reader comprehension and assessment of the feasibility of intervention programs. Brennan et al. [41] indicate that using a step-by-step approach ranging from easier tasks to more difficult ones with children working in groups allowed for greater improvements than when their program was not as precise in its construction and intervention. The absence of specific program and protocol details hinders reproducibility of results and correct applications in clinical settings. Intervention research would benefit from greater specificity in this regard, so that future teams might better apply methodologies reported to be effective or attempt to change methodological aspects to improve previous results.

The duration of interventions and exposure varied substantially across studies, from two hours [36] to more than 40 hours [41] over the course of two weeks to an entire school year. Segers and colleagues [37] showed that the amount of time children spent playing correlated with their improvements, suggesting that this is an important factor. In most efficacious studies, interventions lasted for approximately two to three months and ranged from thirty minutes to two hours a week [26,39,43-46], though some were longer [47] and some shorter [36]. It also appeared from the studies reviewed here that a weekly two-month intervention may be sufficient for most cognitive processes, or at least for showing immediate effects, and this is confirmed by rehabilitation programs targeting more general cognitive functioning [56]. Their effectiveness suggests that there is a delicate balance between feasibility, time allotted to the intervention, and minimal time needed to have positive and lasting outcomes.

Most of the studies (12 out of 14) had a control group but these varied in their composition. Some used a control group that did not receive any intervention, such as in Seger's research [37] where children in the control group played commercially available entertainment computer games instead of the targeted rehabilitation games used in the experimental group, while other control groups followed classical therapy [38] or were offered the intervention at a later date (waitlist control groups) [47]. Using both a control group that does not receive any intervention, as well as one following classic therapy seems to be the strongest way of assessing intervention effectiveness. For instance, in Wren et al. study of individuals with specific language impairment [38], all groups improved (experimental group and control group doing occupational therapy) preventing them from concluding clearly whether their program was just as efficient as classical therapy, or

whether positive outcomes were due to expected developmental improvements over time in this population. Establishing that their computer intervention was just as effective as classical therapy may have allowed clinical application of their program since its administration is less costly and demanding (children practised computer games on their own rather than individual sessions with a health professional). Some studies did not include a control group for ethical reasons and though their methodology was promising it did not allow for generalization of the results [26,43]. It would be beneficial in future work to include follow-up evaluations to account for lasting effects of the intervention. Only 5 out of 14 studies reviewed here included a follow-up. In Seger et al. Study [36], experimental and control groups showed similar results right after the intervention, while experimental groups had more positive outcomes at follow-up after one month due to better retention compared to the control group. Though follow-ups can help show improvements after intervention, they can also reveal the opposite effect: Rezeiyan et al. showed that positive outcomes were no longer present at the five week follow-up assessment [35], suggesting that longer term evaluation of the efficacy of intervention studies can also speak to the maintenance (or lack thereof) of cognitive gains. In sum, regardless of the quality of the intervention development and design, the absence of a control group or issues concerning the type of control best suited to the study can undermine research protocols and may diminish the applicability of remediation programs. Including a follow-up strengthens the research design and allows clinicians and researchers to establish whether positive outcomes will last.

Based on this review, it appears that having multiple variables to assess efficiency is important to account for improvements. In most studies, greater positive effects were found for the experimental group on some variables tested but not on all the variables included. Of course, researchers must be wary to balance this with the problem of multiple comparisons, as the inclusion of too many variables weakens statistical power [55].

## Conclusions

Fourteen studies reporting game-based cognitive interventions were reviewed and their outcome and methodological quality was reported. Despite the presence of some methodological limitations, the overall findings of the review indicate that games are generally effective in improving oral and written language, attention and executive functioning, reasoning abilities and face processing, in paediatric populations. When reporting results, studies would benefit from referring to a common nomenclature so as not to omit methodological information and to optimize reproducibility and application of the intervention paradigms presented. Clinical and research applications are likely to benefit from using these media in remediation settings given their versatility (board games, computer game, Wii, etc.), accessibility, relatively low cost, and flexibility in different settings (clinic, home, school). Perhaps most importantly, game-based tools have a high potential engaging and motivating children and adolescents. Suggestions regarding game choice, participants, duration, program/protocol design, and assessment measures may help improve the comparability and ease of interpretation in future game-based intervention research.



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