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A LITERATURE REVIEW ON EFFECTIVENESS OF COMPUTERIZED TRAINING PROGRAMS ON WORKING MEMORY CAPACITY AND READING ABILITY OF STUDENTS WITH DISABILITIES

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Abstract:
In this paper, a literature review is conducted to discuss the effectiveness of computerized training programs in improving Working Memory (WM) capacity and reading ability of students with disabilities. The methodology used in conducting this review is to systematically search internet resources and databases. This review examines mainly empirical studies published over the last 10 years. These studies focused on the effect of computerized training programs on working memory and reading in students with disabilities. Six selection criteria are used for the inclusion decisions. Twenty articles are included in the final review. This literature review indicates that working memory training can improve WM capacity among students with different types of disorders including learning disabilities, ADHD, intellectual disability, and low WM. Moreover, after WM training, improvements in reading skills are noted across some groups. It is noteworthy that among previous studies there are inconsistent findings regarding the far transfer effect of working memory training on other untrained executive functions. Also, the underlying mechanism of memory improvement following training is not always clear in the research reviewed. Further research is needed to determine the principles governing the type and amount of WM computerized training.

Keywords: working memory training, reading achievement, computer-based programs, executive functions, school performance

1. Introduction

According to Adams and Hitch; Gathercole; Durling; Evans; Jeffcock and Stone; and Wilhelm and Wittman, working memory is the cognitive system responsible for the

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temporary maintaining and manipulating of information during a short period of time (as cited in Dunning, Holmes, & Gathercole, 2013). This ability is needed to complete common classroom and everyday activities that require following multi-step instructions, mental arithmetic, problem-solving, language comprehension, and planning. Working memory plays a key role in learning since it is essential for performing complex mental tasks (Bennett, Holmes, & Buckley, 2013). Some students with reading difficulties have difficulty in using working memory which is responsible for interpreting, integrating and associating existing information with previously learned information that is intended to be stored and retained (Zayat, 2007). Numerous studies have examined the relationship between working memory and learning ability. Results of the studies by Ackerman and Dykman; Cohen, Netley and Clarke; Helland and Asbjørnsen; and Palmer indicated that students with low working memory typically make poor academic progress. Children and adults with reading disabilities showed significant difficulties in tasks involving working memory (as cited in Shiran & Breznitz, 2011). Therefore, it is important to be aware of how WM can act as a barrier to learning and what can be done to improve an individuals' WM.

According to the recent data by Klingberg; Olesen, Westerberg, and Klingberg, a certain plasticity in the neural system that underlies working memory can be improved by training. Neurobiological studies using the Functional Brain Imaging (fMRI) show that brain activity in the prefrontal cortex, the area associated with working memory, noticeably increased after WM training (as cited in Dahlin, 2010). Recent studies suggest that training cognitive skills could improve the brain activity and increases reading skills. "*Improve childhood cognitive ability may be an important influence on the development of reading skills in later childhood and into adult life*" (Shaywitz, 2005, p.1306). Studies by Gunther, Schafer, Holzner, and Kemmler (as cited in Dahlin, 2010) have found that working memory training may have a beneficial effect for both children and adults. These results lead to finding ways to provide interventions for stimulating the mental abilities associated with WM and then improving reading skills.

Interventions for training WM include certain software programs that consist of different tasks in the form of simple computer games. It has been claimed that computerized working memory training programs are effective way to enhance WM functions and reading ability (Diamond, 2012). Typically, computerized training programs for WM development require intensive training for a continuous period of tasks modified to current performance. Understanding the improvement of working memory performance and related reading tasks following a computerized training program is essential to determine effective intervention for students with poor academic achievement associated with working memory impairment.

A number of literature reviews have already been made on studying the effectiveness of WM training and their results are varied. For example, Shipstead, Redick, and Engle (2012) in their reviews suggested that there was not sufficient substantial evidence confirming that WM training significantly improves WM. While Melby-Lervåg & Hulme, (2013) conducted a review and found immediate positive effects of WM training but no evidence to support long-term effects. However, Shinaver, Entwistle and Söderqvist (2014) in their reviews found evidence that WM training can improve WM and this effect is maintained over time. The previous reviews addressed the general question whether WM training is effective or not, while others focused on one disability in order to assess the effect of WM training. For this reason, this review will focus on discussing the effectiveness of WM training on improving WM capacity and its transfer effects to other executive functions and reading ability in individuals with different disabilities.

In this regard, the importance of this review appears in determining the evidences of the efficacy of computerized training programs on students' working memory and understanding the importance of working memory training on improving reading skills. This review may stimulate educators to make a strong effort to develop computerized training programs to improve students' executive functions and academic achievement, and encourage teachers to take the advantages of using computer-based training programs and implement them with students with disabilities in regular school settings.

The aim of this review is to discuss the effectiveness of computerized training programs in improving working memory capacity and reading ability of students with disabilities. Thus, keeping up with their peers in inclusive classes.

This review tries to answer these key questions: Does computerized WM training programs improve WM capacity among students and adults with different disorders, and can that working memory training effect transfer on reading ability and other executive functions?

2. Method

This review aims to explore the effect of computerized training programs upon working memory and reading ability, and how this intervention can help students with disabilities in developing academic performance and social interaction, and keeping up with peers in inclusion classes. The review included a variety of papers with a number of different research questions, category of disability, and training methods. A comprehensive search was performed using databases to search for studies discussing the effect of computer programs on working memory and reading in students with disabilities who have impaired working memory and reading. A literature search was conducted in February 2018 using three online electronic databases; ProQuest, PubMed and ERIC. In these databases, the search "Computerized Training Programs for Working Memory and Reading" was used. (836) publications were found. (35) studies were screened for eligibility. Publications were first screened by title and then by abstract. The final 20 articles were screened for eligibility by analyzing the full text. For this study, only empirical studies were included and other types of publications, such as literature reviews, policy papers, chapters, and studies on segregated special education were excluded.

The authors used six selection criteria for study inclusion decisions; studies were included if (1) interventions are based on computerized programs for training working memory; (2) the study design included a pre-test/post-test and control group comparison; (3) the study addressed the effectiveness of training working memory (WM) on WM capacity and then on reading ability; (4) participants had previously been diagnosed with dyslexia, dawn syndrome, Attention deficits and hyper activity disorder, low active memory; (5) the study reported quantitative outcome data of mean/standard deviation (M/SD) or standardized measures of IQ, language, academic achievement, or adaptive behavior;(6) the study was published in English between 2007 and 2018.

3. Results

3.1 Effectiveness of Training Working Memory Capacity in Typically Developing Children

Students' academic achievement has been associated with their cognitive skills. Dealing with academic and social challenges requires them to successfully implement Executive Functions (EF). Therefore, a strong effort has been spent to develop EF training programs to improve students' EF and academic achievement. Results of many studies show the success of training WM in promoting working memory and academic skills in a large number of typically developmental groups.

Recently, in a study conducted by Sánchez-Pérez, Castillo, López-López, Pina, Puga, Campoy, González-Salinas & Fuentes (2017), the research group designed a computer-based training program which has two components, namely, working memory and mathematics tasks. They tested the effects of training on children's cognitive skills (WM, IQ) and their academic abilities and achievement in math and language grades and abilities. The final sample consisted of 104 children (56 boys) aged from 7 to 12 years old. The training period included two weekly 30-min sessions over 13 weeks. As a result, children in the training group showed a significant improvement in cognitive skills, such as non-verbal IQ and inhibition, better reading abilities, and math performance compared to children in the control group. Results also indicated that children's improvements in reading were significantly associated with their WM performance rather than to math activities. However, it has not been clarified which reading skills have improved after training.

Furthermore, the findings by Loosli et al., (2012) provided further evidence for shared processes between working memory and reading. The authors in their study conducted a computerized, adaptive WM intervention with a total of 20 typically developing children aged 9- 11 years over 2 consecutive weeks. Comparing to a matched control group, the children considerably enhanced their performance in the trained working memory task. Additionally, the experimental group significantly improved their reading performance particularly reading text. However, having transfer effects of WM after 2 weeks only is surprising. This amount of time (two weeks period) is considerably shorter than the training time used in other approaches, which usually takes 5 weeks as a minimum.

A different training approach is used by Nevo and Breznitz (2013) that involves a combination of two training programs: reading acceleration and WM training programs. Ninety-seven students in third grade (50 boys and 47 girls) were distributed into three study groups and one control group. Each group received a different program: one group was trained on reading acceleration program only, while the other two groups received WM program followed by reading acceleration program and reading acceleration followed by WM. In general, all training programs significantly improved reading skills and WM abilities more than the untrained control group abilities. The group trained with only the reading acceleration program improved word accuracy while the groups trained with a combination of reading and WM programs improved word and pseudo-word fluency. On the other hand, no improvement in reading comprehension has shown in any group. Furthermore, the data indicated that training program that combines reading acceleration program followed by the WM program is the most effective for improving the abilities most associated with scholastic achievement. Obviously, using the combination of the two training programs can create a strong intervention that could help to close the gap between the readers' abilities and performance in reading and WM. However, since each group was assigned to a different training program, there is possibility that other classroom characteristics influenced the gains in reading, such as classroom composition or teacher factors. Based on these successful results of training WM in typically developmental groups, several studies have been conducted the possibility of using computerized training programs to improve working memory and reading ability of students with disabilities (Bennett, Holmes, and Buckley, 2013).

3.2 Effectiveness of Training Working Memory Capacity in Students with Learning Disabilities

Poor working memory is associated with poor academic performance in reading, mathematics and language comprehension. The empirical evidence indicates that working memory performance is one source of data that can reliably differentiate between students with learning disability and those who are slow learners. Deficits in working memory functions are associated with developmental dyslexia and poor academic performance in reading skills. Studies showed that students with dyslexia have significantly lower working memory capacity compared to typical students (Horowitz-Kraus & Breznitz, 2009). The working memory deficits of those with learning disabilities seem to arise from neurobiological limitations in working memory and as well as inefficient use of working memory resources (Alloway, 2010). However, working memory abilities could be enhanced through computerized high-intensity working memory programs training (Wong & Chan, 2014). Several studies examined whether dyslexics' working memory can be enhanced by cognitive training software programs, and whether the training outcomes would affect the quality of their reading development.

One of these studies conducted by Shiran and Breznitz (2010) to examine the relationships between training working memory capacity and enhancement of reading skills in both skilled readers and readers who have dyslexia. In their study, they used the *CogniFit Personal Coach* the computer-training program that was designed to train cognitive skills, especially three different modules of working memory: auditory memory, visual memory and visuo-spatial memory. The participants consisted of 91 university students, 41 with dyslexia and 50 skilled readers. The experimental group underwent the working memory training by using *CogniFit Personal Coach* (CPC) for four sessions per week over 6 weeks. The level of reading and working memory were monitored before and after training. This training aims to affect the recall range and speed of processing in working memory of the readers with dyslexia and then improve reading ability. The result of this study indicated that after using CPC for working memory training, the performance of working memory in storing verbal and visual-spatial information improved and the speed of processing tasks in the working memory system increased. This improvement in the working memory performance increased the reading rate and accuracy, decoding process, and comprehension ability in the readers with dyslexia and the skilled readers in the experimental group. However, once can ask a question about the stability and continuity of that effectiveness, and if this training involves strategies to ensure the stability and continuity of current development in the working memory performance?

Similarly, Horowitz-Kraus and Breznitz (2009) in their study used CPC to investigate the effectiveness of the training on the capacity of dyslexic readers' working memory, and the impact of training on the error detection mechanism. University students, 27 with dyslexia and 34 controls participated in the study. Reading and memory measures were administered previous to, immediately after, and 6 months after the experiment. Both groups were provided with direct training of auditory, visual, and cross-modality working memory skills 3 times weekly over 6 weeks. Both groups exhibited improvement in WM measure and an increase in Error-related Negativity (ERN) size following the training. The number of words per minute read correctly significantly increased after the training by 14.73% in the dyslexic group. The readers with dyslexia gained significantly more of an ERN increase than the control. It would seem that the lower the students' starting point the higher they can go.

It may be worth mentioning that the CPC program includes adaptive tasks in which participants are provided with many memory trials to perform that are at or slightly above their current ability. However, the program does not appear to depend on any detailed task analysis or theoretical framework of the mechanisms by which such adaptive training regimes would be expected to improve working memory capacity.

Moreover, Gray, Chaban, Martinussen, Goldberg, Gotlieb, Kronitz, & Tannock, (2012) conducted a study to determine whether computerized WM training improves

WM in a hard-to-treat group of students with combined LD/ADHD, and to evaluate the transfer effects into academic achievement. A total of 60 students at the residential school, aged 12–17 who have a specific LD and ADHD received training by *Cogmed RoboMemo* a computerized program that includes 12 different training WM exercises. The average WM training time for each day was approximately 45 min. The major finding was that WM training had a beneficial effect on a measure of auditory-verbal and visual-spatial WM for those with a confirmed co-occurring ADHD diagnosis. Also, students showed some gains over the study period in the area of cognitive attention, reading and math. However, the study did not tell if the level of benefit from the training could allow students to return to regular schools.

3.3 Effectiveness of Training Working Memory Capacity in Students with Attention-Deficit Hyperactivity Disorder

According to Klingberg et al. (2005), the disorders in executive functions including working memory, response inhibition, and temporal processing have been showed to play an important role in Attention- Deficit/Hyperactivity Disorder (ADHD). ADHD affects working memory and other executive functions, and thereby negatively impacts academic achievement (Bigorra, Garolera, Guijarro, & Hervás, 2016). It was suggested by Olesen, Westerberg, and Klingberg (as cited in Dahlin, 2010) that working memory training programs are effective as treatments ADHD in children and adult.

A study by Dahlin (2010) expected high correlations between working memory and reading comprehension skills. The author hypothesized that WM training of children with ADHA would improve their working memory ability with a positive effect on their reading comprehension skills. To examine this hypothesis, Dahlin examined the effectiveness of the *RoboMemo* training program on the working memory, which is originally developed to improve working memory in children with ADHD, of 57 special education students with ADHD for 5 weeks of daily training. The results showed enhancement in WM and reading comprehension performance by comparing the scores between pre-test and post-test in literacy development as well as WM training. These results indicated that WM training to improve working memory functions may help children with special needs and ADHD become more skillful in reading comprehension. In order to evaluate the training effects, assessments were conducted after 7 months of the treatment. The results showed that the positive effects of the training program continued on reading comprehension tasks while these effects did not continue on the other reading tasks such as orthographic reading. It may be argued that the continuity of the effectiveness of the training on reading comprehension could be due to a good deal of extra help at school and/or at home, the treatment group may have received during the 7week post-test period. However, the results of this study were consistent with the previous study of Klingberg et al., (2005) which concluded that a 5 - week computerized WM training using *RoboMemo* program produces improvement on WM performance in children with ADHD.

The previous result contradicts with what the study of Bigorra, Garolera, Guijarro, & Hervás (2016) concluded. In their randomized, double-blind, placebo-controlled trial, the effect of *Cogmed Working Memory Training* (CWMT), a computerized WM training on ADHD symptoms, functional impairments and academic achievement was tested. The participants were 66 children with ADHD randomized (1:1) to an experimental group or a control group. Assessments were conducted at baseline (T0), 1–2 weeks (T1), and 6 months' post-intervention (T2). Parents and teachers who performed the cognitive assessments were blinded. Findings showed significant improvements in executive functions (EFs) scales-parent version, as well in EF scales-teacher version. There were also significant improvements in ADHD symptoms, and functional impairment. CWMT had a significant impact on ADHD deficits by achieving long-term far-transfer effects. However, no improvements were noted on learning when assessing with a measure of reading comprehension. The authors argued that the performance measure used in their study may lack enough sensitivity to discover subtle and developing changes. Plus, that the measure of reading comprehension is not an exhaustive measure of learning in general. And thus, no improvement in this measure does not necessarily reflect an improvement overall school performance. Thus, it would have been useful to use teachers' observation to the academic performance and reading skills of the subjects in the classroom.

Likewise, Chacko, Bedard, Marks, Feirsen, Uderman, Chimiklis, Rajwan, ….. & Ramon (2014) studied the benefits of *Cogmed* Working Memory Training (CWMT) utility of WM training to alleviate key symptoms of ADHD. Eighty-five 7- to 11-year old school-age children with ADHD were randomized to either standard CWMT (CWMT Active) or a well-controlled CWMT placebo condition (CWMT Placebo). Training period took 30– 45 min over 5 days per week (25 training-days total). Students were evaluated before and 3 weeks after intervention. CWMT shows effects on certain aspects of working memory in children with ADHD. In particular, verbal and nonverbal working memory storage, but there are no notable gains in working memory storage plus processing/manipulation. In addition, no treatment group differences were observed for reading, spelling, comprehension or mathematics outcome measures. The authors concluded that CWMT should not be considered as an effective treatment for children with ADHD! However, since the program has shown its usefulness in a number of studies, the trial procedures may need some adjustments in order to obtain maximum benefit from the program.

3.4 Effectiveness of Training Working Memory Capacity in Students with Intellectual Disability

Most of the studies we have reviewed so far showed the benefit of the computerized training programs on working memory and reading in typically children, children with learning disabilities, and with ADHD and memory impairments. However, many questions are raised regarding whether students with intellectual disability can manage the intensive system of cognitive training, and profit from the same training as expressed in other categories of disability, also if successful training in children with intellectual disability leads to improved performance on non-trained tasks.

In (2012) Söderqvist et al. tried to answer these questions by training students 6–12 years old with mild or moderate ID on visuospatial WM and non-verbal reasoning (NVR). The WM training program was provided by *Cogmed* Systems and consisted of visuo-spatial WM tasks. Students have been divided into two groups, both groups trained for 5 weeks, 5 days a week. The test group trained on an adaptive computerized training program ascending to more demanding levels due to the participants' correct answers on the given tasks. The control group used a program with the same kind of tasks, but remained at the easiest level throughout the entire training period. The main outcome of this study is that computer-based cognitive training is possible in students with ID and can help improve their cognitive performance. Findings of this study showed a little difference in the training performance and in the results of the assessments of the test group and the control group, which indicated that the transfer effects of the adaptive training to untrained abilities were insignificant. Training progress predicted improvements on both WM and language comprehension immediately following training, but not at a 1-year follow-up. Training progress was influenced by inter-individual differences and baseline capacities on verbal WM. particularly, females without an additional diagnosis and with higher baseline performance showed greater progress. No significant effects of training were observed at the 1-year follow-up. Therefore, the authors suggested that "training in children with intellectual disability needs to be more extended (e.g., 10 weeks instead of 5) or repeated (e.g., 5 weeks every 3 months) in order for effects to be maintained". Thus, based on Söderqvist et al. (2012) suggestion, Ottersen & Grill (2015) hypothesized that children with ID would benefit from an extended training period, and that the level of difficulty during training would affect the results. They trained 21 children with mild or moderate Intellectual Disability (ID) aged 8-13 years, through 37 and 50 training sessions with an adaptive computerized program on WM (Cogmed program). The duration of the training ranged from 10 to 23 weeks. The children were divided into two subgroups, an intervention group and an active control group with different difficulty levels during training. The level of difficulty was individually adapted by an algorithm. The group who started each exercise at a low level of difficulty by easily finding the correct answer reached higher levels of achievement and improved significantly more on a verbal WM task compared to children with more demanding tasks. Results showed that extended training leads to better results on untrained tasks, and that training intensity was not necessary for the outcome. One can say, that this study has confirmed the importance of manipulating training factors and procedures to make training more effective.

Compared with the training studies mentioned above, different results were found in a study conducted by Van der Molen, Van Luit, Van der Molen, Klugkist & Jongmans (2010). They provided the first demonstration that WM can be effectively trained in adolescents with mild to borderline intellectual disabilities, a group known for its low WM capacity. However, training transfer did not appear on the Reading test. The authors developed a computerized *'OddYellow'* training program based on the principle of the Odd-One-Out test by Henry (2001). They examined the effectiveness of the OddYellow program on WM memory, scholastic abilities and the recall of stories in adolescents with mild to borderline intellectual disabilities. Participants in the study were 95 adolescents with IQ score in the range 55–85. They randomly assigned to either a training adaptive to each child's progress in WM, a non-adaptive WM training, or to a control group. The participants trained three times a week, for 6 min, during a 5-week period. Following the training, the adolescents were tested twice within a 4-week period (post-test 1 in the first 2 weeks and post-test 2 in the last 2 weeks). Finally, they took the follow-up test 10 weeks after the training was done. Additionally, participants underwent two tests to tap scholastic abilities, one test for arithmetic and another one for reading abilities. The results demonstrated that the scores led by both the adaptive and non-adaptive WM training were greater at follow-up than those at post-intervention on visual and verbal STM, arithmetic and story recall compared with the control group. Scholastic abilities scores increased on the Arithmetic test but not on the Reading test for both group A and group B compared with the control group. However, the positive gains in this study occurred during a 5-week period, which normally used in most studies. Thus, results of this study do not emphasize the suggestion of Söderqvist et al. (2012) regarding expanding training time for ID students.

Furthermore, Downs' syndrome is associated with significant limitations and difficulties in the ability to store and manipulate information (short term and working memory). Past studies by Baddeley, Gathercole, & Papagno found that people with Down syndrome have more limited verbal and visuospatial working memory capacity than typically developing people of the same age. These components of WM play a critical role in language acquisition, mainly during new word learning and the development of grammar (Bennett, Holmes & Buckley, 2013). Improving working memory function might therefore be expected to have important effects on learning and language development of children with Down syndrome. Bennett, Holmes, and Buckley (2013) conducted the first study to test the impact of computerized WM training on children with Down syndrome. The study aimed to investigate whether WM training could be useful to reduce the short – term memory (STM) and working memory (WM) difficulties associated with Down syndrome, and whether it leads to improvements in non-trained tasks of both verbal and visuospatial STM and WM. The research team conducted a randomized controlled trial of Junior *Cogmed Working Memory Training* (JCWMT), the software program designed for typically developing pre- school children. The JCWMT program includes visuospatial memory training activities presented as engaging games. Twenty – one children were randomly assigned to an initial intervention group (A) and a waiting comparison group (B). Children in the intervention group received 25 training sessions over a period of 10 to 12 weeks. In using Automated Working Memory Assessment, group (A) were assessed before and after the intervention, and then assessed a third time after the comparison group (B) had received the intervention. After the training, results showed that the scores of 60% of the intervention group improved on the test of visuospatial short term memory. While, the scores of 27% among the comparison group improved over the same period without training. When the comparison group (B) next received the training, similar gains on the test of visual short term memory were noticed but the effect on visual working memory was not as clear.

Interestingly, the children in the initial intervention group (A) achieved important gains on the non-trained assessments of visuospatial short term memory and visuospatial working memory, but these gains did not transfer to verbal STM and verbal WM skills. After four months of completing the training, the initial intervention group maintained the gains observed on the visuospatial STM and visuospatial WM assessments. Overall, this study suggests that computerized working memory training could be a practical and useful intervention for children with Down syndrome. Arguably, the CWT program, which originally was designed for students with average IQ and was used in the study, could be a stringent training for children with Down syndrome. This increased the need to create special programs for the cognitive impairment category.

3.5 Effectiveness of Computerized Training program of Working Memory in Students with Poor Working Memory

Individuals differ in their WM capacity for several reasons, including limited capacity per se or limitations in the cognitive control mechanisms supporting WM (Loosli, Buschkuehl, Perrig & Jaeggi, 2012). In their studies, Alloway, Gathercole, Kirkwood, and Elliott; Pickering; Rapport, Scanlan, and Denney (as cited in Loosli et al., 2012) argued that WM capacity is a crucial factor for children's scholastic achievement in many domains including mathematical and reading ability. Therefore, children with low working memory typically make poor educational progress (Dunning et al., 2013). Cognitive functions such as executive functions and working memory change throughout life. In some cases, some of the cognitive functions of young adults at around 20 years of age do not reach the peak. However, the improvements of cognitive functions by cognitive training in both younger and older adults may be very beneficial (Nouchi et al., 2013).

There are number of studies have investigated whether WM training boosts WM capacity and improves reading processes in students with poor working memory. Generally, these studies have two main objectives. The first objective is to investigate whether WM training enhances both visual and verbal WM capacity. The second is to examine whether the effect of working memory training could be transferred to other non-trained functions. According to Shipstead, Redick, and Engle (as cited in Dahlin, 2010), transfer effects are the expected improvements occur to various untrained skills and tasks that children may be struggling with (e.g., improvements on IQ tests, word decoding, arithmetic, attentional control, behavioral inhibition, and language abilities following training on working memory tasks).

Wong and Chan (2014) examined the effectiveness of a computerized working memory intervention among the Chinese population. In their study, they used a WM computerized program that was designed by He and Chan (2009) and includes eight working memory tasks; five on visuospatial tasks and three on verbal working memory tasks. The training program was carried out in 20 to 25 days within five consecutive weeks on 1,557 elementary students aged between 6 and 12 years with poor working memory. The treatment group received high-intensity training in the school setting. The neuropsychological measure, General Linear Model Analysis, indicated that there was a significant improvement in visuospatial and verbal working memory in the treatment group as compared with the control group. However, no transfer of training effect to non-trained inhibitory task was found. Although the study showed that WM could be improved by computerized training programs, it did not indicate to any possible benefit of the WM training on learning tasks and academic achievement of the trained students.

Similar results were found in a study by Dunning et al. (2013). A total of 810 children with low WM aged 7–9 years were divided into three groups to receive either adaptive *Cogmed* working memory training, non-adaptive *Cogmed* working memory training or no training. After 6 weeks of the training, children who completed adaptive training made significantly greater improvements in verbal and visuo-spatial WM tasks than either children who completed a non-adaptive version of training or those who received no intervention. The gains made in working memory were partly sustained one year after training. Also, in this study, there was no evidence of transfer to other cognitive assessments or academic progress. In fact, the WM training did not significantly improve children's performance on standardized reading and mathematics tests.

Additionally, Roberts, Quach, Spencer-Smith, Anderson, Gathercole, Gold,... & Wake (2016) in their study, aimed to determine whether a computerized adaptive working memory intervention program improves long-term academic achievement of children with low working memory compared with usual classroom teaching. Participants were first graders students 6 to 7 years of age who were classified as having low working memory from 44 primary schools. These children were randomly assigned to either an intervention or a control group. 90.3% of the children in the intervention group completed at least 20 sessions. *Cogmed* working memory training has delivered over 5 to 7 weeks. Comparing with the children in the control group, children in the intervention group gained improvements in visual spatial short-term memory and verbal working memory. However, benefits on WM remained at 12 months, but not at 24 months. Moreover, there were no improvements to any other academic outcomes; in fact, scores of the children in the intervention group were worse in math and reading at 12 months and at 24 months than children in the control group. In sum, results from this study indicate that adaptive working memory training program may temporarily improve visuospatial short-term memory.

Surprisingly, the findings in the studies mentioned above do not indicate to any benefit of WM training on the learning or reading ability of the trained students, although the benefits were found with students with disabilities associated with low WM. That could be caused by taking students out of classroom regularly for several weeks to provide the training. Plus, the large size sample in some studies could negatively affect the result by screening the big number of children quickly.

Nevertheless, several studies suggested that WM training positively related with the improvement of reading and academic achievement children with low WM due to healthy circumstances. Children with Traumatic Brain Injury (TBI) who exhibit deficits in the WM appear to be most likely to benefit from computerized WM training programs. Phillips, Mandalis, Benson, Parry, Epps, Morrow, & Lah, (2016) conducted the first study to analyses the efficacy of adaptive WM training for children having traumatic brain injury with low WM. The purpose of the study was to determine whether WM training can improve WM and other cognitive and academic skills (reading and mathematics) in children with TBI. The researchers randomly divided twenty-seven children with moderate to severe TBI into adaptive (Cogmed; n = 13) or non-adaptive training (active placebo; n = 14). Participants underwent a neuropsychological assessment of WM, attention, and academic skills at pre-training, post-training, and 3-month follow-up. They were required to complete about 30 to 40 min of training (active time), 5 times per week, during 5 weeks (i.e., total of 25 training days). The adaptive training resulted in significantly greater gains on reading comprehension and reading accuracy. This outcome provides another evidence of the transfer WM training effects to academic skills. In spite of the limitations of this study like the small sample size and the inability to generalize the findings, this study gave encouraging results.

Additionally, Grunewaldt, Løhaugen, Austeng, Brubakk & Skranes (2013) examined whether a computerized working memory training would have a generalizing effect on memory, learning, attention, behavior, and anxiety on a group of very low birthweight (VLBW) preschoolers who have cognitive problems including deficits in working memory. The used program was *Cogmed JM* which designed for children aged 4 to 6 years. 20 VLBW preschoolers aged 5 to 6 years received training from 10 to 15 minutes, 5 days a week for 5 weeks under parental supervision. The main findings were that the VLBW preschoolers improved significantly on trained and non-trained working memory tasks, as well as phonological processing, phonological awareness which plays a central role in the pre-reading linguistic ability and sentence repetition. Therefore, this study speculates that preschool training may have a positive effect on later academic ability in reading for preterm born VLBW preschoolers. However, the training and test results may have a positive influence from parents who conducted the training. Two years later, Grunewaldt et al, (2016) investigated whether the computerized working memory training program *Cogmed JM* has long-term positive effects on memory, learning, and behavior in very-low-birthweight (VLBW) children at age 5 to 6 years. Children were divided into two groups: 20 VLBW children in the intervention group and 17 age-matched, non-training VLBW children in the comparison group. The intervention was daily for 5 weeks (25 training sessions). The children underwent neuropsychological test and parental questionnaires 4 weeks after intervention and at follow-up 7 months later. The result was that the intervention group had higher scores at follow-up than the comparison group. In sum, this study proves that computerized working memory training (CWMT) in very low birthweight preschool children has long-term positive effects on visual and verbal working memory. It also hypothesizes that WM training is useful to improving the ability to learn from both the teaching at school and for further cognitive development.

Furthermore, Boot, Blakely, and Simons (as cited in Nouchi et al., 2013) stated that commercial brain-training games has attracted much attention because results of previous studies indicated to the positive effects of playing certain types of video games on improving cognitive performances. In order to investigate the beneficial transfer effects of a commercial brain training game on cognitive functions, Nouchi et al. (2013) conducted a double-blinded intervention by using *Brain Age and Tetris games*. Brain Aga is the most popular brain training games in the world, and Tetris is one of the most popular video game. In this study, 32 young adults with low WM were randomly divided into two groups: a brain training group that used Brain Age and an active control group that used Tetris. The participants were asked to perform each type of video game training (Brain Age or Tetris) at least 5 training days over 4 weeks. The results demonstrated that playing the commercial brain training game (Brain Age) significantly improved executive functions, working memory and processing speed compared to playing the non-brain training game (Tetris). This result is consistent with those of an earlier study by Nouchi et al. (2012) that used brain exercise training for healthy elderly people. However, the study did not assess the long-term benefit of playing the brain training game and did not examine whether or not the brain training game can support educational and clinical activities.

4. Discussion

The articles subjected to full review are presented in Table 1. The purpose of this review was to notice the studies with different designs and different types of computerized-training programs, and their implications on students with different type of disability. All reviewed studies previously mentioned focused on the effectiveness of computerized training programs in improving working memory (WM). However, these studies had different aims and concluded with a variety of findings.

The purpose of some of the reviewed studies mentioned above was to examine directly the relationship between working memory and reading ability (Dahlin, 2010; Shiran, & Breznitz, 2011; Phillips et al., 2016; Nevo, Breznitz, 2013; Horowitz-Kraus, Breznitz, 2009). While some studies aimed to evaluate the effectiveness of a computerized working memory training on memory and academic achievement of the students (Van der Molen et al., 2010; Gray et al., 2012; Chacko et al., 2014; Bigorra et al., 2016; Sánchez-Pérez et al., 2017; Roberts et al., 2016). Some of the studies focused more on investigating whether the WM computerized trainings' effects can transfer to other non-trained skills (Loosli et al., 2012; Ottersen & Grill, 2015; Wong & Chan,2014; Smithet al., 2009; Nouchi et al., 2013; Bigorraet al., 2016; Grunewaldt et al., 2013). Other studies looked for the benefits of WM computerized training to alleviate some behavioral and cognitive symptoms of a disability (Bennettet al., 2013; Grunewaldt et al., 2013;2016; Van der Molen, et al., 2010). One of the included studies evaluated the long-term positive effects of computerized working memory training programs on memory and learning (Grunewaldt et al., 2016).

From another side, although most of the participants in the studies were school age children with average ages ranged from 6 to 17 (Dahlin, 2010; Bennettet al., 2013; Van der Molen, et al., 2010; Loosli et al., 2012; Ottersen & Grill, 2015; Wong & Chan,2014; Smithet al., 2009; Nouchi et al., 2013; Bigorraet al., 2016; Gray et al., 2012; Chacko et al., 2014; Sánchez-Pérez et al., 2017; Roberts et al., 2016), some were preschool students aged 5 to 6 years (Grunewaldtet al., 2013: 2016) and university students (Shiran & Breznitz, 2011; Horowitz-Kraus& Breznitz, 2009), and adults (Nouchi et al., 2013; Smith et al., 2009).

Most of the studies conducted on students who were determined through a variety of methods as special educational students. In studies of Shiran & Breznitz (2011) and Horowitz-Kraus & Breznitz, (2009), participants were diagnosed with dyslexia. Participants in a study by Gray (2012) were students with LD and comorbid ADHD. Participants in the other studies were students with ADHD (Bigorra et al., 2016; Chacko et al., 2014), students with intellectual disability (ID) (Ottersen & Grill, 2015; Bennett et al., 2013; Van der Molen et al., 2010; Söderqvist et al.,2012), students with poor working memory (Wong & Chan,2014; Roberts et al., 2016; Dahlin, 2010), children with VLBW and poor WM (Grunewaldt et al.,2013: 2016), or children with (TBI) and poor WM (Phillips et al.,2016). Also, three studies were conducted on typically developing children (Loosli et al, 2012; Nevo & Breznitz, 2013; Sánchez-Pérez et al., 2017). The sample sizes in the included studies differed considerably ranging from 20 (Grunewaldt et al., 2013) to 104 (Sánchez-Pérez et al., 2017). This can affect the generalization of results and the statistical power of the studies.

As for the research design of the studies, all of the included studies took a quantitative approach to assess differences in score pre and post intervention. All of the studies used a between participants' design, other than Dahlin (2010) used a within participants' design and Grunewaldt et al., (2015) who used a stepped wedge design. Moreover, most of the included studies used matched control groups, except three of the studies did not use matched control groups. Løhaugen et al., (2011) used a control group that consisted of children born at a healthy birthweight (comparing them to children born at very low birthweight). Shiran & Breznitz (2011) and Horowitz-Kraus& Breznitz (2009) used a control group that consisted of skilled readers (comparing them to students with of dyslexia). The non-matched group allocation in the studies means that the groups were not equivalent in some characteristics so any comparisons would be speculative.

In regard to the interventions, the majority of the included studies (9 studies) used the *Cogmed Working Memory Training program (CWMT)* (Nouchi et al., 2013; Ottersen & Grill, 2015; Bennett, Holmes & Buckley, 2013; Gray et al., 2012; Phillips et al., 2016; Bigorra et al., 2016; Söderqvist et al., 2012; Roberts et al., 2016; Chacko et al., 2014). Plus, two studies used the *Cogmed pre-school version* (Cogmed JM) (Grunewaldt et al., 2013; 2016). The *CogniFit Personal Coach* program was also used by two studies (Shiran & Breznitz, 2011; Horowitz-Kraus & Breznitz, 2009). The *RoboMemo* program designed for ADHD was used by Dahlin (2010).

Some of the computerized training programs were developed by the authors or have been taken from previous studies (Loosli et al., 2012; Wong& Chan, 2014; Horowitz-Kraus, Breznitz, 2009; Smith et al., 2009; Sánchez-Pérez et al., 2017; Van der Molenet al., 2010). However, all of the used programs were designed for training executive functions and particularly WM capacity.

The training period in the studies ranged from 20- 25 sessions over 5 to 7 weeks. However, in Ottersen & Grill (2015) study, the duration of the training ranged from 10 to 23 weeks in line with the hypothesis of providing children with ID an extended training period to gain the desired benefit. There is no information provided regarding the duration of each session. This raises a question of the required amount of the computerized training (length of intervention, number and duration of sessions, intensity) to reach the maximum benefits of the training.

Conclusively, the findings from the studies reviewed above report that computerized WM training can enhance visuospatial and verbal working memory (Shiran & Breznitz, 2011; Dahlin, 2010; Wong& Chan, 2014; Gray et al., 2012; Grunewaldt et al., 2015), visuospatial and verbal short-term memory (Van der Molenet al., 2010), or only verbal WM (Roberts et al., 2016; Chacko et al., 2014; Smith et al., 2009), or Visuo-Spatial WM (Phillips et al., 2016; Van der Molenet al., 2010), and Visuo-Spatial short-term memory (Roberts et al., 2016; Bennett, Holmes & Buckley, 2013; Smith et al., 2009).

Moreover, the findings report that WM training can improve reading skills. In particular, decoding, reading rate, reading correctly (Shiran & Breznitz, 2011; Loosli et al., 2012; Horowitz-Kraus, Breznitz; Nevo & Breznitz, 2013; Sánchez-Pérez et al., 2017), and reading comprehension (Dahlin, 2010; Shiran & Breznitz, 2011; Phillips et al.,2016). Results from Grunewaldt et al., (2015) showed that WM training of preschool children improves phonological processing which plays an important role in the pre-reading linguistic ability and sentence repetition. However, no transfer effects on reading has been noticed in some other studies (Bigorra et al., 2016; Roberts et al., 2016; Chacko et al., 2014). That may be due to insufficient training or inaccurate measurements. Thus, some adjustments in experiments' procedures may be needed.

Number of the studies not only showed a significant increase in the trained working memory tasks, but also in untrained measures, particularly, in other cognitive functions, behaviors or academic skills (Loosli et al., 2012; Nouchi et al., 2013; Ottersen & Grill, 2015; Grunewaldt et al., 2013) Söderqvist et al., 2012). However, some studies reported that there is no evidence of the transfer effects of WM training to other cognitive and/or academic abilities (Gray et al., 2012; He & Chan ,2009; Van der Molenet al., 2010; Bennett, Holmes & Buckley, 2013; Dunning et al. 2013; Söderqvist et al., 2012).

Thus, the results were inconsistent about the transfer of working memory training effect on other untrained executive functions even with the use of different intervention programs.

Reference	Research Question/Purpose	Design	Subjects	Findings	Computerized training program
1) Shiran, A., & Breznitz, Z. (2011). The effect of cognitive training on recall range and speed of information processing in the working memory of dyslexic and skilled readers. Journal of Neurolinguistics, 24(5), 524-537.	Examine the effect of the CogniFit Personal Coach computerized training program on the recall range and speed of processing in working memory of dyslexic readers, and whether it affects reading ability	Between participants	91 University students participated in the study, 41 dyslexics and 50 skilled readers. There were two experimental and two controls each contained one group of dyslexic's and one of skilled readers. The experimental groups included 26 dyslexics and 35 skilled readers and the control 15 dyslexics and 15 skilled readers.	- The ability to store verbal and visual-spatial information in working memory increased, and decoding, reading rate and comprehension scores improved in both groups. - A main effect of training was obtained for both groups, accuracy increased significantly and reaction time decreased significantly for the dyslexics and the skilled readers. - working memory training enlarges the working memory "supply," namely the capacity and speed of processing in the working memory system and enhanced the reading skills.	CogniFit Personal Coach

Reference	Research Question/Purpose	Design	Subjects	Findings	Computerized training program
2) Dahlin, K.I.E. (2010). Effects of working memory training on reading in children with special needs. Reading and Writing, 24, 479–491.	This study examined the relationship between working memory and reading achievement in primary-school children with special needs. It was examined whether children's working memory could be enhanced by a cognitive training program, and how the training outcomes would relate to their reading development.	Within participants	Fifty-seven children, 11 girls and 46 boys with special education needs, in grades 3–5, ages ranging from 9 to 12 years.	- The results show that the treatment group enhanced its results of working memory measures at Time 2 compared to Time 1. -Reading comprehension performance enhanced in the treatment group at time 2 and 3 compared to Time 1 and the control group. -The results show that working memory can be seen as a crucial factor in the reading development of literacy among children with special needs, and that interventions to improve working memory may help children becoming more proficient in reading comprehension.	RoboMemo

Reference	Research Question/Purpose	Design	Subjects	Findings	Computerized training program
3) Sandra V. Loosli, Martin Buschkuehl, Walter J. Perrig & Susanne M. Jaeggi (2012): Working memory training improves reading processes in typically developing children, Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence, 18:1, 62-78	This study investigates whether a brief cognitive training intervention results in a specific performance increase in the trained task, and whether there are transfer effects to other untrained measures.	Between participants	40 children aged 9 to 11 participated in the study. Children of the control group were matched one by one with a child of the experimental group.	- participants not only showed a significant gain in the trained working memory task, but also in untrained measures, in particular reading of single words and text.	WM span task using Windows-based computers
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized training program**
4) Nouchi R, Taki Y, Takeuchi H, Hashizume H, Nozawa T, et al. (2013) Brain Training Game Boosts Executive Functions, Working Memory and Processing Speed in the Young Adults: A Randomized Controlled Trial. PLoS ONE 8(2): e55518. doi:10.1371/journal.pone.0055518	Can brain game training, specifically that using commercial brain-training games, improve cognitive function in healthy young adults?	Between participants	Thirty-two volunteers were recruited through an advertisement in the local newspaper. Participants randomly assigned to either of two game groups (Brain Age, Tetris).	-Playing the commercial brain training game (Brain Age) significantly improved executive functions, working memory, and processing speed compared to playing the non-brain training game (Tetris) -The results demonstrated the beneficial transfer effects of the commercial brain training game on widely various cognitive	Brain Age

				functions in young adults.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized training program**
5) Ottersen, J., & Grill, K. M. (2015). Benefits of extending and adjusting the level of difficulty on computerized cognitive training for children with intellectual disabilities. Frontiers in psychology, 6, 1233.	Hypothesis 1: Children with ID will attain better transfer results on non-trained cognitive tests by extending the training period. Hypothesis 2: The level of difficulty on the training tasks will affect training results and transfer to untrained tasks for children with ID.	Between participants	21 children with mild or moderate Intellectual Disability (ID) aged 8-13 years. The children were divided into two subgroups, an intervention group and an active control group with different difficulty levels during training.	Results showed that extended training leads to better results on untrained tasks, and that training intensity was not necessary for the outcome	Cogmed Working Memory Training (CWMT).
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized training program**
6) Horowitz-Kraus T, Breznitz Z (2009) Can the Error Detection Mechanism Benefit from Training the Working Memory? A Comparison between Dyslexics and Controls — An ERP Study. PLoS ONE 4(9): e7141. doi: 10.1371/journal.pone.0007141	The study investigated the capacity of adult dyslexic readers' working memory to change as a result of training, and the impact of training on the error detection Mechanism.	Between participants	61 university students (27 dyslexics and 34 controls) participated in the study.	- Both groups of readers gained from the training program but the dyslexic readers gained significantly more. In the dyslexic group, working memory training significantly increased the number of words per minute read correctly by 14.73%. - Results indicated that the larger the working	CogniFit Personal Coach Program

				memory capacity, the higher the ERN amplitude. - Adult brain activity changed as a result of training, evidenced by an increase in both working memory capacity and the amplitude of the Error-related Negativity (ERN) component (24.71%). When ERN amplitudes increased, the percentage of errors on the Sternberg tests decreased.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized training program**
7) Wong, A. S., He, M. Y., & Chan, R. W. (2014). Effectiveness of Computerized Working Memory Training Program in Chinese Community Settings for Children with Poor Working Memory. Journal of attention disorders, 18(4), 318-330.	The effectiveness of computerized working memory intervention among Chinese population.	Between participants	Participants were 53 students recruited from the primary schools. age between 6 and 12 years with poor working memory. 27 participants (21 boys and 6 girls) were in experimental group and 26 participants (17 boys and 9 girls) were in control group	-The treatment group showed significant improvement in working memory reflected in neuropsychological measures as well as parent-rated behavioral measures as compared with the control group.	He and Chan (2009)

Reference	Research Question/Purpose	Design	Subjects	Findings	Computerized training program
8) Bennett, S. J., Holmes, J., & Buckley, S. (2013). Computerized memory training leads to sustained improvement in visuospatial short-term memory skills in children with down syndrome. American Journal on Intellectual and Developmental Disabilities, 118(3), 179-92. Retrieved from http://ezproxy.emich.edu/login?url=http://search.proquest.com/docview/1431279154?accountid=10650	To evaluate the impact of a computerized visuospatial memory training intervention on the memory and behavioral skills of children with Down syndrome.	Between participants	Twenty-one children aged 7-12 years with Down syndrome were randomly allocated to either an intervention or waiting list control group.	-Following training, performance on trained and untrained visuospatial short-term memory tasks was significantly enhanced for children in the intervention group. -This improvement was sustained four months later. - These gains did not transfer to verbal STM skills.	Cogmed Working Memory Training (CWMT).
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
9) Nevo, E., & Breznitz, Z. (2013). Effects of working memory and reading acceleration training on improving working memory abilities and reading skills among third graders. Child Neuropsychology, (ahead-of-print)	This study investigated the influence of reading acceleration and WM training programs on improving reading skills and WM abilities on third grade students.	Between participants	The study enrolled 97 children (50 boys and 47 girls, mean age 8y 6m) from four third grade classes.	-All training programs significantly improved reading skills and WM abilities -Compared with the control group, the group trained with only the reading acceleration program improved word	-Working Memory Program (WMP; Breznitz & Shany, 2011) -Reading Acceleration Program (RAP; Breznitz & Bloch, 2010; Breznitz & Nevat,

				accuracy, whereas the groups trained with a combination of reading and WM programs improved word and pseudo-word fluency. - Training program that combines a long reading acceleration program and a short WM program is the most effective for improving the abilities most related to scholastic achievement.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
10) Smith, G. E., Housen, P., Yaffe, K., Ruff, R., Kennison, R. F., Mahncke, H. W., & Zelinski, E. M. (2009). A cognitive training program based on principles of brain plasticity: Results from the Improvement in Memory with Plasticity-based Adaptive Cognitive Training (IMPACT) Study. Journal of the American Geriatrics	The efficacy of a novel brain plasticity–based computerized cognitive training program in older adults and to evaluate the effect on untrained measures of memory and attention and participant-reported outcomes.	Between participants	Two treatment groups. 487 Community-dwelling adults aged 65 and older without a diagnosis of clinically significant cognitive impairment	- Comparing with children in the control group, the intervention group gained improvements in visual spatial short-term memory and verbal working memory. -No improvements to any other academic outcomes.	brain plasticity–based computerized cognitive training program

Society, 57(4), 594-603.					
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
11) Grunewaldt, K. H., Løhaugen, G. C. C., Austeng, D., Brubakk, A. M., & Skranes, J. (2013). Working memory training improves cognitive function in VLBW preschoolers. Pediatrics, 131(3), e747-e754.	To determine whether a group of preterm born VLBW preschoolers would benefit from a computerized working memory training program (Cogmed JM) designed for children aged 4 to 6 years, and if the training would have a generalizing effect on memory, learning, attention, behavior, and anxiety.	Stepped wedge randomized trial design	The sample consisted of 20 VLBW preschoolers aged 5 to 6 years.	The main findings were that the VLBW preschoolers improved significantly on trained and Non-trained working memory tasks, and transfer effects were observed as improvement on auditory attention, visual as well as verbal memory, phonological processing which plays a central role in the pre-reading linguistic ability and sentence repetition.	Cogmed JM
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
12) Sánchez-Pérez, N., Castillo, A., López-López, J. A., Pina, V., Puga, J. L., Campoy, G., ... & Fuentes, L. J. (2017). Computer-based Training in Math and Working Memory Improves	Test the effects a computer-based training program designed by the research group for training WM and math.	Between participants	The final sample consist of 104 children (56 boys) aged from 7 to 12 years old.	The results revealed a significant improvement in cognitive skills, such as non-verbal IQ and inhibition, and better school performance in math and reading among	Working Memory and Mathematics Tasks program designed by the authors.

Cognitive Skills and Academic Achievement in Primary School Children: Behavioral Results. Frontiers in Psychology, 8, 2327				the children who participated in the training compared to children in the control group.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
13) Gray, S. A., Chaban, P., Martinussen, R., Goldberg, R., Gotlieb, H., Kronitz, R., ... & Tannock, R. (2012). Effects of a computerized working memory training program on working memory, attention, and academics in adolescents with severe LD and comorbid ADHD: a randomized controlled trial. Journal of Child Psychology and Psychiatry, 53(12), 1277-1284.	To determine whether computerized WM training improves WM in a hard-to-treat group of students with combined LD/ADHD and to evaluate transfer effects into academic achievement.	Between participants	A total of 60 adolescents (aged 12–17; 13% females) were then randomized to either the WM training group or the math-training group.	The major finding was that WM training had a robust beneficial effect on the students' performance on a measure of auditory-verbal WM that resembled the training activities, as well as an effect on visual-spatial WM for those with a confirmed co-occurring ADHD diagnosis. However, there was no evidence for the transfer of training to other cognitive abilities, behavior, or academic function. Students showed some gains over the study period in the area of cognitive	(Cogmed RoboMemo) a computerized program designed to train WM.

				attention, reading and math as well as behavior as observed by parents.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
14) Phillips, N. L., Mandalis, A., Benson, S., Parry, L., Epps, A., Morrow, A., & Lah, S. (2016). Computerized working memory training for children with moderate to severe traumatic brain injury: a double-blind, randomized, placebo-controlled trial. Journal of neurotrauma, 33(23), 2097-2104.	To examine whether different components of WM can be improved following adaptive WM training (Cogmed) and whether improvements in WM generalize to other cognitive (attention) and academic skills (reading and mathematics) in children with TBI.	Between participants	Twenty-seven children with moderate to severe traumatic brain injury (TBI) were randomized to adaptive (Cogmed; n = 13) or non-adaptive training (active placebo; n = 14)	- Children in the adaptive group demonstrated significantly greater gains on select WM tasks (VSSP, but not PL or CE) from pre- to post-training (pre-post) and pre-training to follow-up (pre-follow-up; CC and ITT analyses). - Adaptive training resulted in significantly gains on select academic skills (reading, but not mathematics): reading comprehension pre-post-training and reading accuracy pre-follow-up	Cogmed Working Memory Training (CWMT)
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
15) Bigorra, A., Garolera, M., Guijarro, S., & Hervás, A. (2016). Long-term far-	To analyse the effect of CWMT on EFs scales in a sample of children with	Between participants	The final sample size included 66 subjects, all were diagnosed of	- Significant improvements were noted in EF scales-parent	Cogmed Working Memory Training (CWMT)

transfer effects of working memory training in children with ADHD: a randomized controlled trial. European child & adolescent psychiatry, 25(8), 853-867.	ADHD with or without comorbid disruptive behavior, and to study other far-transfer effects on clinical symptoms, functional impairment, PBMEFs, and academic achievement.		combined-type ADHD according to the DSM-IV-TR criteria.	version, also in EF scales-teacher version. - There were significant improvements in PBMEF, ADHD symptoms, and functional impairment. - CWMT had a significant impact on ADHD deficits by achieving long-term far-transfer effects. - No improvements on learning when assessing with a measure of reading comprehension (Canals).	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
16) Van der Molen, M., Van Luit, J. E. H., Van der Molen, M. W., Klugkist, I., & Jongmans, M. J. (2010). Effectiveness of a computerised working memory training in adolescents with mild to borderline intellectual disabilities. Journal of Intellectual Disability Research, 54(5), 433-447	To evaluate the effectiveness of a computerized working memory (WM) training on memory, response inhibition, fluid intelligence, scholastic abilities and the recall of stories in adolescents with mild to borderline intellectual disabilities	Between participants	A total of 95 adolescents with mild to borderline intellectual disabilities were randomly assigned to either a training adaptive to each child's progress in WM, a non-adaptive WM training, or to a control group. Seven special schools for children with M-BID participated in the study. A criterion for entrance in this type of	- Verbal short-term memory (STM) improved significantly from pre- to post-testing in the group who received the adaptive training compared with the control group. - The beneficial effect on verbal STM was maintained at follow-up and other effects became	'OddYellow' The computerized training program developed by the authors.

			school is an IQ score in the range 55–85.	clear at that time as well. -Both the adaptive and non-adaptive WM training led to higher scores at follow-up than at post-intervention on visual STM, arithmetic and story recall compared with the control condition. -The non-adaptive training group showed a significant increase in visuo-spatial WM capacity. - The current study provides the first demonstration that WM can be effectively trained in adolescents with mild to borderline intellectual disabilities.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
17) Söderqvist, S., Bergman Nutley, S., Ottersen, J., Grill, K. M., & Klingberg, T. (2012). Computerized training of non-verbal	Can Computerized training of non-verbal reasoning and working memory work in children with intellectual	Between participants	6–12 years with mild or moderate ID ,(IQ < 70, retrieved from clinical records) and were registered with the mental	- The major finding of this study is that it is feasible for children with intellectual disability to undergo intensive	Cogmed Working Memory Training (CWMT)

reasoning and working memory in children with intellectual disability. Frontiers in human neuroscience, 6, 271.	disability?		habilitation center in the area of Buskerud in Norway	computerized cognitive training, with more than 85% of participants completing approximately 20 min of training per session for an average of 24 (and minimum of 20) sessions. -There was large variability in training performance with some participants showing little progress during training. The amount of progress during training was significantly related to improvements on transfer tasks measuring visuo-spatial and verbal WM and language comprehension. -Training progress predicted improvements on both WM and language comprehension directly following training, but not at a 1-year follow-up. Training on purely visuo-spatial tasks resulted in improvements tasks	

				assessing verbal WM and language function, thus showing transfer between cognitive constructs and modalities	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
18) Roberts, G., Quach, J., Spencer-Smith, M., Anderson, P. J., Gathercole, S., Gold, L., ... & Wake, M. (2016). Academic outcomes 2 years after working memory training for children with low working memory: a randomized clinical trial. JAMA pediatrics, 170(5), e154568-e154568.	Compared with usual classroom teaching, does a computerized adaptive working memory intervention program (Cogmed) improve long-term academic outcomes in children 6 to 7 years of age who were determined to have low working memory after a population screening?	Between participants	First graders students 6 to 7 years of age who were classified as having low working memory from 44 primary schools.	The intervention group gained improvements in visual spatial short-term memory and verbal working memory. However, benefits on WM remained at 12 months, but not at 24 months. - There were no improvements to any other academic outcomes; in fact, scores of the children in the intervention group were worse in math and reading at 12 months and at 24 months than children in the control group. - results from this study indicate that adaptive working memory training	Cogmed RM program,

				program may temporarily improve visuospatial short-term memory.	
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
19) Grunewaldt, K. H., Skranes, J., Brubakk, A. M., & Lähaugen, G. C. (2016). Computerized working memory training has a positive long-term effect in very low birthweight preschool children. Developmental Medicine & Child Neurology, 58(2), 195-201.	To evaluate if a computerized working memory training program has long-term positive effects on memory, learning, and behavior in very-low-birthweight (VLBW) children at age 5 to 6 years	Between participants	20 VLBW preschool children in the intervention group and 17 age-matched, non-training VLBW children in the comparison group.	- This study proves that computerized working memory training in very low birthweight preschool children has long-term positive effects on visual and verbal working memory, and speculate that such training is beneficial by improving the ability to learn from the teaching at school and for further cognitive development.	(Cogmed JM)
Reference	**Research Question/Purpose**	**Design**	**Subjects**	**Findings**	**Computerized- training program**
20) Chacko, A., Bedard, A. C., Marks, D. J., Feirsen, N., Uderman, J. Z., Chimiklis, A., ... & Ramon, M. (2014). A randomized clinical trial of Cogmed working memory training in school-age children with ADHD: A	To study the benefits of Cogmed Working Memory Training (CWMT) utility of WM training to alleviate key symptoms of ADHD.	Between participants	Eighty-five 7- to 11-year old school-age children with ADHD were randomized to either standard CWMT (CWMT Active) or a well-controlled CWMT placebo condition (CWMT Placebo).	CWMT shows effects on certain aspects of working memory in children with ADHD. particulary in verbal and nonverbal working memory storage. -In addition, no treatment	Cogmed Working Memory Training (CWMT)

replication in a diverse sample using a control condition. Journal of Child Psychology and Psychiatry, 55(3), 247-255.				group differences were observed for any other outcome measures; however, CWMT does not appear to foster treatment generalization to other domains of functioning.	

5. Conclusion

The research reviewed indicated that working memory training can improve WM capacity among children with different types of disabilities including learning disabilities, ADHD, intellectual disabilities, Down's Syndrome, and typically developing students with poor WM. However, the underlying mechanism of memory improvement following training is not always clear in the research reviewed. Although gains were noted across some groups in reading skills after WM training, it is also unclear whether the improvements in WM capacity can increase the children's performance in overall reading academic achievement, daily functioning and quality of life. Clearly, computerized and programmed cognitive interventions appear to be an effective approach to memory interventions. However, further research is needed to determine the required amount of the computerized training (length of intervention, number and duration of sessions, intensity) needed to gain meaningful improvements in memory.

Among previous studies, there were inconsistent findings about transfer of working memory training effect on other executive functions. It has been suggested that the strength of transfer effects relies heavily on the level of similarity between the training itself and transfer tasks (Karbach & Kray, 2009). "The underlying principles governing the type of cognitive training that would better facilitate transfer were still unclear; the transfer of training effects between inhibition and working memory required further investigation" (Wong & He, 2014, p. 327). Thus, examining the impact of working memory training on a broad set of transfer tasks, different functional categories of working memory, and executive functions is suggested for future research. Also, future research is needed to study the basic standards and principles that determine the various aspects of WM training.

It appears that using computer-based training programs can help a student with disability keeping up with his/her peers in regular classrooms since these programs have a positive influence on academic performance and social interaction. Another advantages, is that computer-based training programs can be used with different ages and disabilities because they are interactive programs which can adapt the task's difficulty level to fit the student's ability. Thus, it is important for people who are involved in policy decisions regarding the placement of students with disabilities, teacher training, and the funding of educational technologies to give more attention to the use of technology for students with disabilities, and work to create classroom environments in which all students have opportunities to learn.

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