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Memory Interventions for Children with Memory Deficits

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Memory is a key component of cognition and plays an integral role in cognitive development. Memory can be broken down into a number of domains including explicit/declarative (consciously recalled memory), implicit/procedural (such as riding a bike), semantic (concept-based knowledge), episodic, and working memory. Working memory is a cognitive system used for short-term storage and manipulation of information required for diverse cognitive tasks (Baddeley 1992). The most recognized model of working memory is that of Baddeley and Hitch (1994), which involves a central executive (an attention control system responsible for manipulating information), a phonological loop (for maintaining and rehearsing verbal information), and a visual-spatial sketchpad (for storing visual–spatial information). This model was later revised to include an episodic buffer, which is thought to be a multi-modal system that integrates memory across domains (visual, spatial, verbal, etc) into scenes or episodes (Baddeley 2000).

Memory impairments in childhood can have negative consequences for the development of language, literacy, social skills, personal relationships, and a sense of personal history (Rankin and Hood 2005). Additionally, childhood memory impairments often impede academic performance, particularly arithmetic (Hitch and McAuley 1991), and can result in secondary deficits such as low self-esteem (Alloway et al. 2009). However, interventions during development have the potential to improve memory performance, and can have positive impacts on related cognitive skills. In this paper, research on memory interventions among children with developmental disorders will be reviewed. The research reviewed, covers a wide range of developmental disorders including Down's syndrome, Fetal Alcohol Spectrum Disorders (FASD), learning disabilities, Attention-Deficit Hyperactivity Disorder (ADHD), and acquired brain injury.

Down's syndrome

Individuals with Down's syndrome are known to have significant deficits in short term memory. Memory span tasks are a commonly used measure of short term or working memory. In these tasks a list of items (usually random numbers, letters, or words) are presented to the individual for him/her to repeat back in the same order. Memory span is the longest list of items one can recall in the correct order. By adolescence, individuals with Down's syndrome have a memory span of 3 or 4 digits, compared to 7 or 8 in typically developing adolescents (Hulme and MacKenzie 1992). One of the early attempts to improve short term memory in children with Down's syndrome was to reduce auditory and visual distractions (e.g., using padded headphones, opaque goggles); however, reducing distractions did not improve performance on memory tasks

(Marcell et al. 1988). Thus the authors concluded that the short term memory deficits in children with Down's syndrome are not likely due to distractions and attention problems.

Further research studies were designed in order to teach children with Down's syndrome how to perform better on memory tasks. Broadley (1993) assigned children with Down's syndrome (aged 4-18 years) to an experimental group (n=25) or a control group (n=26). The experimental group received 6 weeks of memory training focused on teaching rehearsal and organization (categorizing and grouping information). A cross-over design was used: half of the children received the rehearsal training followed by organization training, and half received the training the opposite order. There was no significant difference between the experimental and control group on pre-tests of memory, but after the intervention the experimental group significantly improved on measures of visual recognition, picture memory, verbal memory, word span, and organization memory. The authors also compared the two different experimental groups after the first intervention program on a subset of the memory battery. The rehearsal intervention had the largest improvements on rehearsal tasks and the organization program tended to improve organizational memory tasks. Broadley et al. (1994) conducted a follow up study on these same children, two months and 8 months after the intervention ended and found that the experimental group maintained their memory improvements. Interestingly, those trained by a keyworker (e.g., teacher, parent) performed better than those trained by an experimenter, perhaps because the keyworker spent more time with the child and had more opportunity to prompt and remind the child of the training. However, these results are confounded by the fact that the experimenter-trained group were attending special schools whereas many of the children trained by a keyworker attended mainstream schools.

In a related study, Comblain (1994) compared memory among two groups of individuals with Down's syndrome (children, adolescents, and adults). The experimental group (n=12) participated in an intensive rehearsal training program for 8 weeks, and the control group (n=12) had no training. Both groups were tested on digit, letter, and word span tasks pre- and post-intervention, and then again 6 weeks and 6 months later. At the post-test the experimental group showed significant gains in mean memory span and showed signs of rehearsal, in contrast to the control group who did not improve. At 6 weeks and 6 months post intervention, the memory span of experimental group was lower than at the post-test but still significantly higher than before the intervention.

Other types of interventions have also been found to improve memory among children with Down's syndrome. For instance, Laws (1995) found that reading instruction had positive effects on memory and language of children with Down's syndrome. The study was longitudinal and conducted with 14 children (aged 8-14 years) with Down's syndrome over period of almost 4 years. The children who were able to read or became readers over the course of the study had significantly higher memory and language skills than non-readers, even though there was no difference between readers and non-readers at the beginning of the study. Thus, the authors concluded that the process of reading (sounding out letters, etc.) promotes memory development. In another study, Laws et al. (1996) found that a 6 week memory training program (focussed on rehearsal and categorization) that was designed to be more flexible and could be taught by parents and teachers, resulted in small but significant improvements in word span among children with Down's syndrome. Similarly, Conners et al. (2008) found that a home-based memory intervention instructed by parents (focussing on verbal rehearsal) lead to small but significant improvements in digit span among children with Down's syndrome.

Conners et al. (2001) discussed some common issues with memory training research among children with Down's syndrome. First, the author suggests that early research did not always differentiate between visual and auditory modalities. Second, more research is needed on how to attain meaningful effects and long-term maintenance of memory improvements. Finally, previous studies did not always use adequate control comparison groups with the same number of sessions and equal amount of interaction, reinforcement, and practice focussing attention (Conners et al. 2001). Buckley (2008) discusses some important future directions for memory training research among children with Down's syndrome. She suggests that more research is needed on: the efficacy of different approaches and types of memory interventions, follow-up studies to determine long-term results, and home-based and classroom interventions.

Fetal Alcohol Spectrum Disorders

Children with FASD have significant impairments on many components of memory (see Manji et al. (2009) for a review). However, there is very little research on memory interventions among children with FASD. Loomes et al. (2008) examined whether teaching children (aged 4–11) with FASD verbal rehearsal would increase their memory span. Children with FASD were divided into an experimental group who received rehearsal training (n=17) and a control group (n=16) who did not receive training. Both groups were tested on digit span tasks at baseline (pre-test) and then post-test 1 (immediately after the intervention) and post-test 2 (approximately 2 weeks later). The experimental group showed a significant increase in performance across the three sessions, but the control group did not. There was no significant difference in performance between the two groups on the pre-test and post-test 1, however, by post-test 2 children in the experimental group performed significantly higher than the control group. Furthermore, more children in the experimental group than the control group showed behavioural evidence and self-report of rehearsal after training. Therefore, rehearsal training was an effective strategy in improving memory for numbers among children with FASD.

Learning Disabilities

Children with learning disabilities often have impairments in working memory, which may contribute to deficiencies in other cognitive areas (Hulme and MacKenzie 1992). For example, numerous studies have suggested that reading disabilities stem from a deficit in working memory (Siegel and Ryan 1989). Learning to read requires specific components of working memory to allow for the coding, storage, and retrieval of associations between spoken and written words (Wimmer and Mayringer 2002); thus impairments in these working memory functions can impede reading ability. Additionally, mathematical difficulties are frequently associated with working memory impairments, such as difficulties with executive processing (Bull et al. 1999). However, even simple interventions (e.g. rehearsal training) have been shown to improve working memory performance (Bowler 1991; Bowler 1991; Hulme and MacKenzie 1992) and may have implications for higher level cognitive skills such as reading and mathematics.

One of the early reading intervention studies proposed that working memory deficits in children with reading disabilities stem from an inefficient use of information processing strategies (Torgesen et al. 1979). Researchers tested children with and without reading disabilities (n=19 in each reading group) on a free-recall memory task, following either a free study period, or an “orienting task” which required participants to engage in a complex conceptual analysis of the stimuli to be remembered. Children who completed the orienting task performed equally on the free-recall memory test, regardless of whether they had a reading disability or not. This supports the hypothesis that working memory deficits in children with reading disabilities stem from inefficient information processing, which can be eliminated with strategy training.

Subsequent research has indicated that impaired reading ability is also related to phonological memory codes, and that children with reading difficulties tend to rely more on visual memory (Hulme 1981). To test this hypothesis, Hulme (1981) trained children with and without reading disabilities (n=20 in each reading category) using multi-sensory teaching which included having participants manually trace letters with their finger during reading. An interaction was observed between the effect of letter tracing on memory for letters and group: the impaired readers showed a greater improvement on memory tasks from the multi-modal teaching than the non-impaired readers. The researcher took this as evidence that children with reading disabilities rely more heavily on visual codes, presumably as a result of a deficit in phonological working memory. Letter tracing has also been shown to improve reading ability in pure alexia (characterized by a loss of reading ability in literate individuals following a brain damage) (Friedman et al. 1993; Seki et al. 1995). Although the efficacy of tracing in normal readers has been questioned (Beech et al. 1994), it is a technique that still is widely used in classrooms today.

Not all research supports a model of reading disability that assigns deficit to just one domain of working memory, such as purely phonological. To explore a more ‘domain-general’ model of reading disability, Swanson (2000) examined the working memory performance of readers with learning disabilities (n=22) versus age-matched controls (n=32) for working memory tasks with phonological, visual-spatial, and semantic information. Working memory performance was tested under 3 conditions: initial (no probes or cues), gain (with cues to bring performance to asymptote), and maintenance (asymptotic levels but with no cues). Children with reading disabilities exhibited less change on both visual-spatial and verbal (phonological and semantic) working memory tasks across gain and maintenance conditions than their age-matched peers. Swanson suggested that these data support a ‘domain-general’ system for training of working memory, and that only training one aspect of working memory in isolation would be insufficient to improve reading skill.

Kipp and Mohr (2008) explored an intervention for an 8-year-old boy who was initially almost completely unable to develop letter-sound associations due to a severe phonological memory deficit. The intervention, which involved verbal repetition and identification of spoken letters, produced a limited but significant improvement in letter-reading skills; however, no improvement was seen for more complex reading experiences. Although improvement in complex reading skills was not observed, letter reading improvement was still significant at 5 months, suggesting that the intervention was successful in training letter-sound associations (Kipp and Mohr 2008).

In addition to difficulties with phonological processing, children with reading disabilities are also thought to have deficits in attention processing (Swanson 1993; Swanson 1993), which can make it difficult to determine which information is relevant to keep in mind. Swanson et al. (2010)

suggested that children with reading disabilities have trouble preventing extraneous information from entering working memory, and are therefore more likely to consider alternative interpretations or strategy choices that are not central to the task at hand. These researchers designed a study to examine the effect of rehearsal strategy training on working memory performance in children with and without reading disabilities (n=29 in each reading group). They found that rehearsal training significantly improved working memory performance of children with reading disabilities, but did not account for the variance between children with and without reading disabilities. Only measures relating to demands on processing capacity contributed significantly to the variance in reading skill, providing evidence for the role of attention processing in reading ability. The authors concluded that strategy training may have provided improved working memory by encouraging focus on the relevant aspects of the task; thus training attention processing (Swanson et al. 2010). However, it remains unclear if improvements in working memory directly influence higher order skills such as reading comprehension.

Keeler and Swanson (2001) conducted a study to determine whether declarative knowledge for strategies is related to mathematics ability and working memory performance. Children with and without math disabilities (n=54) were required to perform two working memory tasks: the Digit Sentence Span Task (which tests one's ability to remember numerical information embedded in a short sentence), and the Mapping and Directions Task (which requires remembering a sequence of directions on a map that is devoid of labels). The researchers examined the relationship between these measures of verbal and visual-spatial working memory span, and strategy knowledge, in initial (without cues), gain (with cues to optimize performance), and maintenance conditions (without cues, and at the highest level achieved in the gain condition). They found that strategy stability (rather than strategy choice) was related to working memory span. Additionally, they found that both visual-spatial and verbal working memory contributed significantly to the variance in math ability, and that this relationship was not task specific (Keeler and Swanson 2001).

The reviewed interventions for children with learning disabilities have targeted distinct domains of working memory with varying success. Given that the source and extent of working memory impairments in children with learning disabilities can vary widely, designing an appropriate intervention comes with many challenges. Review of the interventions above indicates that one-on-one training, numerous training sessions, and a focus on keeping memory demands low are all elements of successful interventions for reading and mathematical disabilities. However, none of these interventions have examined the relationship between the working memory tasks that were targeted in each study, and more global measures of reading and mathematical success, such as school performance. Additionally, these interventions were relatively short-term, and do not provide adequate follow up to determine the long term clinical applicability of each approach. Rankin and Hood (2005) suggest that successful long-term interventions require flexibility to adapt to the context of the child, careful monitoring, and adjustment by rehabilitation professionals.

Attention Deficit Hyperactivity Disorder (ADHD)

Working memory deficits are common among children with ADHD (e.g. Karatekin (2004)). As such, some remediation efforts in addressing ADHD have been directed towards improvement of working memory. Klingberg et al. (2002) investigated the impact of computerized cognitive training on working memory capacity and motor activity in children with ADHD (aged 7 to 15 years). Training with a psychologist took place for at least twenty minutes per day, 4-6 days a week, for at least five weeks, and was matched to individual capacity of the individual adjusting difficulty on a trial-by-trial basis. Training entailed four computerized tasks: a visuo-spatial working memory task (remembering circles placed on a grid), a backwards digit-span task, a letter-span task, and a choice reaction time task (in which a choice is required before responding as quickly as possible). A double-blind design was utilized, with seven children in the treatment group and control group. Pre and post cognitive testing was used to measure changes in working memory capacity and prefrontal functioning, whereas a continuous performance test requiring sustained attention combined with video camera monitoring head movements, was used to evaluate level of hyperactivity. Training had a gradual, positive impact on working memory retention, which appeared to generalize to other settings, as evidenced by improvement in both trained and non-trained visuospatial working memory tasks.

Building on their preliminary research, Klingberg et al. (2005) completed a larger study with four clinical sites, in which they evaluated the same computerized treatment program geared towards enhancement of working memory function in youth affected by ADHD. Fifty-three children with ADHD (aged 7-12 years) were randomly assigned to either control or treatment conditions. Pre and post program evaluation and three month follow-up was conducted using neuropsychological assessment and questionnaires. The treatment group improved significantly on a non practiced measure of visuospatial working memory, (still significant by the 3 month follow-up) and on verbal working memory (measured using the digit span task). Secondary effects were also reported for measured improvement in reasoning abilities. As such, the researchers suggest that the effect of working memory training also transfer to additional executive tasks that were not trained. The researchers note that the small number of subjects in this study limits generalizability, and add that a longer follow up would be valuable to determine sustainability of these effects. Nonetheless, they assert that the study provides evidence that working memory can be improved by training, and that this approach may be useful in other conditions affecting working memory deficits, such as after a traumatic brain injury.

Acquired Brain Injury

Attention and memory deficits are the most likely cognitive impairments in both children and adults following head injury, and lead to significant dysfunction in daily activity. Rehabilitation efforts after pediatric brain injury tend to fit into one of three broad categories of intervention: 1) external approaches focused on altering the environment implemented by those supporting the individual (e.g. parent); 2) procedures designed to actually improve or restore cognitive abilities, and 3) training of strategies that can be used by the affected individual to compensate for existing deficits in cognitive functioning. Programs designed to improve memory function often combine all three approaches: environmental agents (e.g. parents and teachers) may be provided with ways to modify environments, efforts to impact brain function may be undertaken (e.g. computerized programs), and children may also be provided with strategies that support their performance. The following studies investigated the use of different cognitive and memory training programs aiming to improve function of children with brain injury.

In their pilot study, Yerys et al. (2003) investigated whether children with sickle cell disease-related cerebral infarcts, in which the frontal or related areas of the brain were impacted, could be trained to use strategies that would improve memory and learning. Six children, ages 11 to 15 were tested on pre and post intervention assessments using a digit span test (from the Children's Memory Scale) and a word list task (California Verbal Learning Test). Six intervention sessions were completed with half of the children receiving academic tutoring for a full hour, while the other half received tutoring for 40 minutes and training in learning and memory strategies (rehearsal and semantic organization) for the remaining 20 minutes. Two of the three children in the treatment condition showed improvement in the short term memory task (digit span) and all three children in the treatment condition improved on the long term memory task (word list). No significant change was identified for the control group in either condition. Consequently, they concluded that providing cognitive remediation strategies to children with cerebral infarcts has the potential to improve learning and memory and is also feasible for families. The authors acknowledge the preliminary nature of these findings, noting that further research with a larger group of children is necessary to confirm these results, and also that a longer study could reveal the sustainability of these benefits as well as the transferability to a classroom setting.

The Amsterdam Memory and Attention Training for Children (AMAT-c) is a cognitive training method designed specifically for children. Training areas include sustained, focused and divided attention; strategies for verbal, visual episodic, and semantic memory; and mental tracking. The program is 18-20 weeks long, 45 minutes per day, five days a week. Supervision and coaching for program delivery is provided by a specialist in cognitive deficits, through which specific strategies for learning and completing school tasks are taught. The program itself entails daily practice and games, as well as exercises in specific memory and attention techniques. In an effort to refine and develop the AMAT-c program, van't Hooft and colleagues have conducted a series of studies, gradually evolving the program. Van't Hooft et al. (2003) conducted a pilot study to determine the feasibility of the newly translated Swedish version of the AMAT-c. Three children with acquired brain injuries completed the training for 30 minutes per day for 20 weeks. Results indicated improvement on psychometric measures conducted at pre and post intervention, and most consistently on those assessing sustained attention. Some improvement on memory tests was also noted. Behaviour scales also revealed that both parents and teachers agreed there were improvements on different aspects of learning, such as increased use of strategies to support daily memory and verbal working memory. The researchers note that drawbacks to the program include the long duration and the lack of individualization within the program. They addressed these concerns in their next study, which they implemented in their next study. Van't Hooft et al. (2005) assigned forty children (ages 9-17) with acquired brain injuries of various aetiologies into treatment and control groups. Results revealed a significant improvement for the treatment group as compared to the control group on several neuropsychological tasks including memory. Specific to memory, they found that performance on both complex memory tasks, as well as daily memory functioning, improved significantly. At six months follow up van't Hooft et al. (2007) found that the treatment group maintained a significant improvement, particularly on complex attention and memory tasks. Additionally, they noted that selective attention and verbal working memory had continued to improve in the treatment group after completion of the training indicating that the program does not only train performance but also equips the children with strategies to best approach tasks. They suggested that the results provide evidence for the value of cognitive and memory training programs, but continue to encourage further research with more specific diagnostic groups as well as to explore transferability to other environments such as schools.

Responding to this call, Sjo et al. (2010) conducted a pilot study to determine feasibility of this program within a school environment. Seven children with acquired brain injuries completed this study, in which teachers were in the coach role, supervised on a weekly basis by staff from a rehabilitation facility. Results based on pre and post neuropsychological assessment using the Wechsler Intelligence Scale for Children, 3rd Edition, Neuropsychological Assessment of the school-aged child, and Test of Everyday Attention for children revealed statistically significant improvements in attention, tempo, visuo-constructive abilities, learning and memory, and executive functions. Questionnaires administered at pre and post intervention provided mixed results: with parents reported a slight negative change in children's executive function (i.e. greater problems), while trainers reported a positive change. Overall, the researchers concluded that the AMAT-c can be integrated into school environments, that supervision within schools could have positive impacts on motivation of the children involved, and that within the school setting positive impact of the intervention as indicated in neuropsychological testing are evident. Study limitations include lack of information regarding transfer of learning to functional applications of the training in the school, limited numbers which preclude generalization, and lack of understanding regarding actual component of the intervention that is contributing to the changes observed.

Van't Hooft and Norberg (2010) conducted a pilot study with a condensed version of the AMAT-c, and added a parent coaching component to facilitate transfer to daily functioning. Three children (ages 9, 12, and 14) being treated for medulloblastoma were involved in this study. Parent coaching entailed five sessions of sixty minutes, with the parents and a specialist in cognitive rehabilitation. The researchers reported that the program successfully produced the expected results of improved psychometric performance, with two of the three children improving in verbal and visuo-spatial memory testing, concluding that larger study of the condensed model with addition of the parent coaching should be undertaken to confirm results.

Overall, studies evaluating the value of training programs indicate the potential for improved memory functioning after participation. However, many questions remain. Because of the multifaceted nature of many of these programs, it is impossible to ascertain whether improvement is best attributed to improvements in memory per se, or whether it reflects improved strategy use (which would suggest better metacognitive skills, and therefore better use of existing memory systems), or simply improved support systems and more appropriate expectations thereby reducing stress. The lack of specificity often reflects the clinical impetus with which treatment programs are designed. Thus the rigorous controls of experimental research are not employed. Consequently, it remains unclear which is the most impactful component of the intervention. Another factor that complicates understanding, particularly in the case of acquired brain injury, is whether the improvement would have occurred regardless. Even in the case of control studies, this may reflect accelerated improvement rather than overall improvement after full recovery. Additional inquiry is needed to determine how individuals with different types of brain injury may respond to intervention approaches, as well as how different ages or developmental levels impact effectiveness of cognitive or memory training approaches.

Conclusions

The research reviewed indicates that memory interventions can improve memory among children with a variety of different disorders including Down's Syndrome, FASD, learning disabilities, ADHD, and acquired brain injury. These memory interventions vary from targeted strategies aimed at improving specific areas of memory function (e.g. rehearsal and organization), to broader computerized or programmed cognitive interventions geared towards improvement in several areas of function (e.g. improved attention leads to improved memory function), to training of strategy use and external memory supports to be employed by individuals or supporters to improve function. Clearly frameworks of intervention are continuing to develop as our knowledge base grows and understanding of memory intervention evolves.

There are still many questions and issues to be addressed. Although gains were noted across many disability groups, it is unclear whether there are more optimal approaches for different groups and specific patterns of acquired brain injuries. It is also unclear whether there is an optimal time for memory intervention post brain injury, and whether the reported improvements truly reflect improvement or simply an acceleration of healing that would have otherwise occurred. In general, evaluating whether developmental age and stage have an impact on effectiveness of interventions needs to be determined.

Furthermore, most of the studies reviewed were relatively short term and thus we do not know whether memory improvements are maintained long-term. Even less is known about whether these increases in memory transfer to other cognitive abilities. Research on whether memory improvements lead to gains other areas cognitive areas such as mathematics and literacy is critical, as well as how these gains affect the overall daily functioning and quality of life of affected individuals. In addition, it is important to determine the amount of intervention training (length of intervention, number and duration of sessions, intensity) required to obtain meaningful increases in memory. Finally, more research is needed on how other program characteristics impact outcomes including who the trainer is (e.g., parent, teacher, researcher), whether the training is done individually or in a group, and whether the intervention is conducted at home or in a classroom setting.

The mechanisms underlying memory improvement following an intervention are not always clear in the research reviewed. Improvements in memory could stem from many factors, including increases memory span, better strategy use, increased attention on task, motivation, improved information processing, or feedback provided. Regardless of the underlying mechanism, Kipp and Mohr (2008) suggest that simply intensifying regular schooling is not sufficient to yield improvements in working memory.

Computerized programs appear to be a promising new approach to memory interventions; they can be done in various settings (e.g. home versus school) and by different facilitators (teacher, researcher, parent etc.). However, more research is needed to determine which factors in computerized memory interventions lead to optimal outcomes (type of media and program, number and length of sessions etc). Additionally, information regarding the type and quantity of coaching needed to support use of computer programs is necessary to determine the optimal way to implement these programs.

Memory deficits in childhood can be idiopathic, or a symptom of a larger disorder such Down syndrome, ADHD, or Dyslexia. As such, interventions designed to improve memory must also take into consideration underlying causes or co-morbid conditions, and their interaction with training and overall cognitive skill. There is also a discrepancy in the literature between the more experimentally driven memory intervention research (Down's syndrome) and more clinically driven research (acquired brain injury). Both lines of carry many strengths, and thus incorporating characteristics of both experimentally and clinically-driven research is important for future research. Finally in all cases large, randomized, and controlled study designs are needed with replication across different sites and samples.

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