A Pilot Visual-Spatial Working Memory Training Protocol in Children with Attention Deficit Hyperactivity Disorder

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Received date: June 21, 2020; **Accepted date:** July 10, 2020; **Published date:** August 29, 2020
Citation: Sleimana Lena Abou, Kechichianb Anna Khanji, A Pilot Visual-Spatial Working Memory Training Protocol in Children with Attention Deficit Hyperactivity Disorder. J Cogn Neuropsychol Vol.4 No.2:1.

Abstract

Executive function deficits give rise to Attention Deficit Hyperactivity Disorder (ADHD) symptoms. Visual-Spatial Working Memory (VSWM) is one of the main executive functions, which is the ability to retain and manipulate visual information (shapes and colors as well as their locations and movements) for a limited time in the brain. This function plays a key role in learning at school as well as during everyday life. Rehabilitation of VSWM is needed for ADHD children, as several studies have shown the importance of mnemonic training in improving this feature. This pilot study provides and evaluates a treatment protocol targeting VSWM in ADHD children. We examined the impact of the protocol on 9 ADHD patients aged 8-9 years by using two tests: memory for faces and the Corsi block-tapping task during the initial evaluation and after treatment. The protocol is based on six training sessions related to the different types of VSWM (simultaneous and sequential, in forwarding, and backward orders). Results included greater mean pretest to posttest change scores on all variables with statistically significant differences in each type of VSWM. The studied performances improved from the pathological range to the normal range according to age. This protocol was shown to be effective in VSWM rehabilitation in ADHD children, potentially improving executive functioning.

Keywords: A D H D, rehabilitation, Visual-spatial working memory, children.

Abbreviations: PERSONA Study: Pediatric Coronavirus in Saudi Arabia Study; DSFH: Dr. Soliman Fakeeh Hospital; IRB: Institutional Review Board; WBC: White Blood Cell; ANC: Absolute Neutrophil Count; CRP: C-Reactive Protein; PCR: Polymerase Chain Reaction; No.: Number; CT: Computerized Tomography; MOH: Ministry of Health; ICU: Intensive Care Unit; ACE2: Angiotensin-Converting Enzyme 2

Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is characterized by asymptomatic triad: motor agitation, attentional disorder, and impulsivity . Children with ADHD represent one group of subjects with Working Memory (WM) deficit, attributed to an impairment of the frontal lobe (prefrontal regions of the brain) (18). In addition, the right hemisphere is involved in tasks requiring VSWM (19). This explains the fact that these subjects show more difficulties in spatial tasks than verbal tasks. The brain volume of subjects with ADHD was 5 to 8% less than the healthy subjects, especially in the right hemisphere (16) work highlighted "the presence of a primary behavioral defect disorder, which has implications for different executive functions: verbal and non-verbal WM, self-regulation of motivations and the awakening, reconstitution or ability to organize elements in an original way". In fact, VSWM (non-verbal WM) is the ability to retain and manipulate visual information (shapes and colors as well as their locations and movements) for a limited time in the brain. This memory constitutes the base of school learning and is one of the constitutive elements of attentional and executive functions (10) view WM as a core, causal cognitive process responsible for ADHD (**Figure 1**). Behavioral inhibition deficits are viewed by these authors as a byproduct of WM deficits because inhibition is dependent on the registration of environmental stimuli. Deficits in WM are presumed to account for several associated and secondary features of ADHD, including disorganization, inattentiveness, poor social skills, delay aversion, and hyperactivity/impulsivity. According to Baddeley and Wilson's model, the WM is 1 a visual-sequential memory, which directly reflects the amount of information that the subject can recall in order and (2) a VSWM, which requires a simultaneous recall of the information arranged in the form of patterns. Another model (Gathercole, Pickering, Ambridge, and Wearing) showed that the processes involved in both types of VSWM tasks are static and dynamic processes. Thus, a part of the VS short-term WM is specialized for storing images, and another part is specialized in the storage of moving images (animated scenes or films). Then, we can extract that VSWM is divided into 2 components: (1) the simultaneous VS span, involving the static process, and (2) the sequential VS span, involving the dynamic process. The dynamic process by itself is also composed of 2 parts: forward dynamic and backward dynamic.

ADHD patients have slower age-related performance progression with age compared with their peers (12). They often forget the tasks to be accomplished and they fail to keep in mind relevant information during the activity. This results in disorganization in their reasoning, as well as the level to be achieved in the various activities. Westerberg, Hirvikoski, Forssberg and Klingberg showed that children with ADHD have a weak visuospatial span compared to a control group of the same age: they have a deficit characterized by capturing new information that will distract them from their task and maintain irrelevant information in the WM. This deficit was directly related to the lack of inhibition of automatic responses (13) confirmed that the VS span is inferior to the verbal memory span in this population.

Other studies focused on VSWM training and improvements among ADHD patients. VSWM training appears promising as an intervention in improving executive functioning and ADHD symptoms. The systematic meta-analytic review undertaken by Peijnenborgh, Hurks, Aldenkamp, Vles and Hendriksen focused specifically on learning disabilities. The authors indicated reliable short-term improvements in verbal WM, VSWM, and word decoding in children with learning disabilities after training (effect sizes ranged between 0.36 and 0.63), when compared to the untrained control group. Moore et al. also performed cognitive training in children with attention-deficit. Compared to the control group, all the scores improved significantly from pretest to post. Subjective patient-reported outcomes such as confidence, cooperation, and self-discipline also enhanced in children with attention-deficit after 60 hours of clinician cognitive training, resulting in both cognitive and behavioral improvement. Moreover, Klingberg et al. proved that WM can be improved by training in children with ADHD. Their computerized training also improved response inhibition and reasoning and resulted in a reduction of the parent-rated inattentive symptoms of ADHD. Another study (Beck, Hanson, Puffenberger, Benninger, and Benninger) assessed the efficacy of a 5-week intensive WM training program for 52 children and adolescents (ages 7-17) who had ADHD and other comorbid diagnoses. Parent ratings indicated that participants improved on inattention, the overall number of ADHD symptoms, initiation, planning/organization, and WM. Teacher ratings approached significance at posttreatment and at 4-month follow-up. Holmes, Gathercole, Place, Dunning, Hilton and Elliott evaluated in their study the impact of two interventions (a training program and stimulant medication) on WM function in 25 children with ADHD aged between 8 and 11 years. While medication significantly improved VSWM performance, training led to substantial gains in all components of WM across untrained tasks. Training gains associated with the central executive persisted over 6 months. These findings indicate that the WM impairments in children with ADHD can be differentially ameliorated by training and by stimulant medication.

Given that WM is considered to be a core deficit in ADHD that way underlie symptom presentation, finding interventions that target this skill is important. To the best of our knowledge, evidence still lack concerning the psychomotor rehabilitation of VSWM in ADHD patients as well as a clear management protocol. In this study, we will attempt to propose a management protocol for VSWM in ADHD subjects in order to reinforce these deficit functions and improve both the executive functioning and academic performance.

Methods

According to the declaration of Helsinki, and after obtaining written consent from the patient's parents or legal guardian, this prospective open-label pilot study was conducted in a private rehabilitation clinic. The population consisted of a total of 9 Lebanese ADHD children aged between 8 and 9 years (standard deviation=0.7). All participants were boys, as the disorder is more common among boys than girls, with a ratio of 3:1 (5). The patients were recruited from French-speaking private Lebanese schools, according to the following inclusion criteria: (1) diagnosis of ADHD confirmed by a research team's board-certified psychiatrist according to the DSM-V, aged seven or older since the VS span is developed at the age of 6 years, (3) having intact ideomotor praxis as evaluated by the EMG Test (Vaivre-Douret), (4) having an average IQ score obtained though Wechsler Intelligence Scale for Children WISC-V (Kaufman, Raiford, and Coalson). Excluded were patients with (1) intellectual deficit, (2) patients undergoing medical treatment, (3) patients receiving memory rehabilitation during their psychomotor and/or speech therapy sessions and (4) patients with auditory and visual deficits (all patients were examined by the research team's ophthalmologist and ear, nose and throat specialists).

Experimental Design and Procedure

The study consists of 3 parts: (1) pre-rehabilitation evaluation phase, (2) the rehabilitation phase, and (3) post-rehabilitation evaluation phase.
The pre-rehabilitation evaluation phase (T1) consisted of evaluating the memory functions of the included patients by the research team's neuropsychologist by using (1) the Corsi block-tapping test that evaluated the sequential VSWM and (2) the Nepsy Memory for Faces Test that evaluated the static simultaneous VSWM. The Corsi block-tapping test consisted of a board on which 9 blocks were randomly distributed and numbered only on one side, visible to the examiner. The patient was asked to observe the sequence of blocks "tapped" by the evaluator and then repeat the sequence in order. Then, the patient was asked to repeat the sequence tapped in backward order. In the memory test faces, the examiner showed the patient multiple faces that, he must have memorized in 5 seconds. Following the presentation of the last face, the child was prompted immediately to identify the face memorized among a set of three faces. Thirty minutes later, the examiner asked the child to recognize the same faces in the set of three faces.
The rehabilitation phase conducted by a psychomotor therapist (one trainer to maintain fidelity to the rehabilitation program) consisted of a protocol applied over six sessions to all participants, with increasing difficulty. It was shown that intensive WM training produces functional changes in large-scale front parietal networks (20). Rehabilitation was performed twice a week for each patient individually and similarly in a quiet room. The progression of the exercises was based on increasing the difficulty of the activities by increasing the number of stimuli to treat, in order to achieve the retention of 5 elements. According to Miller, the WM capacity was composed of 4 to 5 units of information in an exercise involving the maintenance of information and the processing of other information (14). As the exercises progressed, the presentation's duration of the stimuli decreased and the latency time increased. The duration of each session was 30 minutes, including two exercises, 15 minutes each. The path of rehabilitation of VSWM is shown in **Table 1**. We used these types of tasks for each session to motivate and to attract the patients constantly. We chose to do different tasks at each session to eliminate the learning effect while keeping the same goals. To improve the results, we used in parallel many techniques to accelerate and facilitate the memorization during the sessions. In fact, Kerns and colleagues showed that the manipulation of information is more complex in ADHD subjects (8). For example, the application of the "soliloquy technique" where the patient

is encouraged to relate verbally to his inner thoughts and feelings (1) significantly improved the patient's attentional abilities. In addition, in visuospatial exercises where objects cannot be named, the application of the "mnemotechnic" (Lieury) was necessary, more specifically, that of the mental image: subjects were invited to associate with the model, a familiar image for them (a letter or a geometrical form) to facilitate the memorization process.
The post-rehabilitation phase (T2) consisted of evaluating (by the same research team's neuropsychologist) the included patients after the rehabilitation protocol by using the same tests of the pre-rehabilitation evaluation phase: the Corsi Blocks Test and the Memory of Faces Test. The normality of the distribution of the outcome was tested using the Shapiro-Wilk test. The average values were compared using the Paired-Samples t-test. All tests were 2-sided, with $P<0.05$ considered statistically significant. SPSS v24 was used for statistical analysis.

Results

The different types of VSWM (Forward Working Memory (FWM) and Backward Working Memory BWM tested by Corsi Block-tapping test, and Static Working Memory SWM tested by Nepsy Memory for Faces Test) from **T1** to **T2** are summarized in **tables 2** and **3**.

The average result of the subjects' tests evolved from the pathological range to the normal range according to age. This increase in average has been demonstrated for different types of VSWM. Rehabilitation has improved the memory capacity of all the subjects significantly ($p<0.001$).

At first, in T1, concerning the Corsi Block-tapping test results, the subjects were able to memorize only 3.4 (σ=-2.3) elements in FWM and 2.56 (σ =-2.05) elements in BWM. After the application of the protocol, and during the T2 assessment, they managed to memorize 6.04 (σ=0.89) elements in FWM and 5.61 (σ=0.77) elements in BWM. So, for the FWM, the increase in the standard deviation means was statistically significant ($p<0.001$). In fact, the average results increased significantly (from-2.30 to 0.89, $p<0.001$) as well as the BWM type (from-2.05 to 0.77, $p<0.001$). We note that when the standard deviation is $\leq$ -2, this indicates that the results are pathological. On the other hand, if it is $\geq$ -1, then the results would be normal.

Second, the results of the SWM related to the Nepsy Memory for Faces Test showed also a significant change in the standard score averages (from 4.44 to 9.33, $p<0.001$). We note that the standard score between 2 and 7 indicates that the results are within the borderline. However, the results above 7 are considered normal for this Test.

Session	Axis	Objectives	Activities	Difficulty parameters
1	Axis 1: static process	The child will be able to memorize the location of 3 elements, based on a 10-second static process.	<u>Status:</u> The psychomotor therapist does a posture. The child has to repeat the same posture. In the end, the child will choose the status already done.	-Increase the parts mobilized (2-3). -latency time : zero

	Axis 2: dynamic process	The child will be able to memorize a sequence of 3 elements, based on a sequential process.	<u>Reproduction of Postures:</u> The psychomotor therapist performs a sequence of movements. The child will do the same sequence in order.	-increase the number of movements (2-3) - latency time : zero
2	Axis 1: static process	The child will be able to memorize the location of 3-4 elements, based on a 10-second static process.	<u>Hide and seek :</u> The psychomotor therapist puts elements inside a hoop and covers it. The child will have to put again the same elements inside the hoop.	- increase the number of elements (3-4). - latency time : 5 seconds
	Axis 2: dynamic process	The child will be able to memorize a sequence of 4 elements, based on a sequential process.	<u>The frog :</u> The psychomotor therapist and the child will pretend that they are frogs and they must jump on water lilies. The psychomotor therapist jumps from one hoop (water lily) to another in a sequence. The child must jump following the same sequence.	- increase the number of elements (3-4). - latency time : 5 seconds
3	Axis 1: static process	The child will be able to memorize the location of 4-5 elements, based on a 10-second static process.	<u>Game of differences:</u> The psychomotor therapist shows the child a card containing many shapes, and then hides it. Later, the same card is shown, but a shape is missing, the child has to recognize the missing element.	-increase the number of the elements (4-5). - latency time : 10 seconds
	Axis 2: dynamic process	The child will be able to memorize a sequence of 5 elements, based on a sequential process.	<u>Chessboard :</u> The psychomotor therapist moves the pawn on the chessboard. Then the child has to repeat the same sequence in order.	-increase the number of the elements (4-5). - latency time : 10 seconds
4	Axis 1: static process	The child will be able to memorize the location of 4-5 elements, based on a 5-second static process.	<u>Grid :</u> The psychomotor therapist shows a grid with circles and then hides it. The child will indicate in which box there were circles.	-increase the number of circles (4-5). - latency time : 20 seconds
	Axis 2: dynamic process	The child will be able to memorize a sequence of 4 elements, based on a sequential process, in backward order.	<u>Coming back home :</u> The psychomotor therapist moves inside the hoops. The child has to do the same moves but in backward order.	-increase the number of movements (4-5) - latency time : 20 secondes
5	Axis 1: static process	The child will be able to memorize the location of 4-5 elements, based on a 5-second static process.	<u>The shapes :</u> The psychomotor therapist shows a grid containing geometrical shapes, and then hides it. The child has to indicate on the grid, the place and the type of the shapes showed.	-increase the number of squares (3x3, 4x4). - latency time : 60 secondes.
	Axis 2: dynamic process	The child will be able to memorize a sequence of 4	<u>Car :</u> The psychomotor therapist moves a car from a parking to another. The child has to repeat the	-increase the number of moves (3-4) - latency time : 60 secondes

		elements, based on a sequential process, in backward order.	action in backward order.	
6	Axis 1: static process	The child will be able to memorize the location of elements, based on a 5-second static process.	<u>Cards game :</u> The psychomotor therapist will present cards laid face down on a surface and flip two cards face up over each turn. The object of the game is to turn over pairs of matching cards.	-increase the number of card (3x3, 4x4) - latency time : 60 seconds
	Axis 2: dynamic process	The child will be able to memorize a sequence of 5 elements, based on a sequential process, in backward order.	<u>Color palette :</u> The psychomotor therapist taps on different colors of the palette. The child will repeat the sequence in a backward order.	-increase the number of moves (4-5) - latency time : 60 seconds

Table 1: The path of rehabilitation of VSWM

Types of VSWM	n	Mean at T1	Mean at T2
FWM	9	3.18	6.04
BWM	9	2.56	5.61

Table 2: Comparison of the means of FWM and BWM of the Corsi test results between T1 and T2

Types of VSWM	n	Mean of Standard of deviation (T1)	σ	Standard Error Mean	Mean of Standard of deviation (T2)	σ	Standard Error Mean	T of Paired Samples Test	P-value
SWM (Nepsy Memory for Faces Test)	9	4.44	0.52	0.17	9.33	1.41	0.47	-9.07	<0.001*
FWM (Corsi block-tapping test)	9	-2.30	0.84	0.28	0.89	0.69	0.23	-9.76	<0.001*
BWM (Corsi block-	9	-2.05	0.60	0.20	0.77	0.56	0.18	-10.57	<0.001

tapping test									

Table 3: Comparison of the standard deviation raw scores means of the test results between T1 and T2

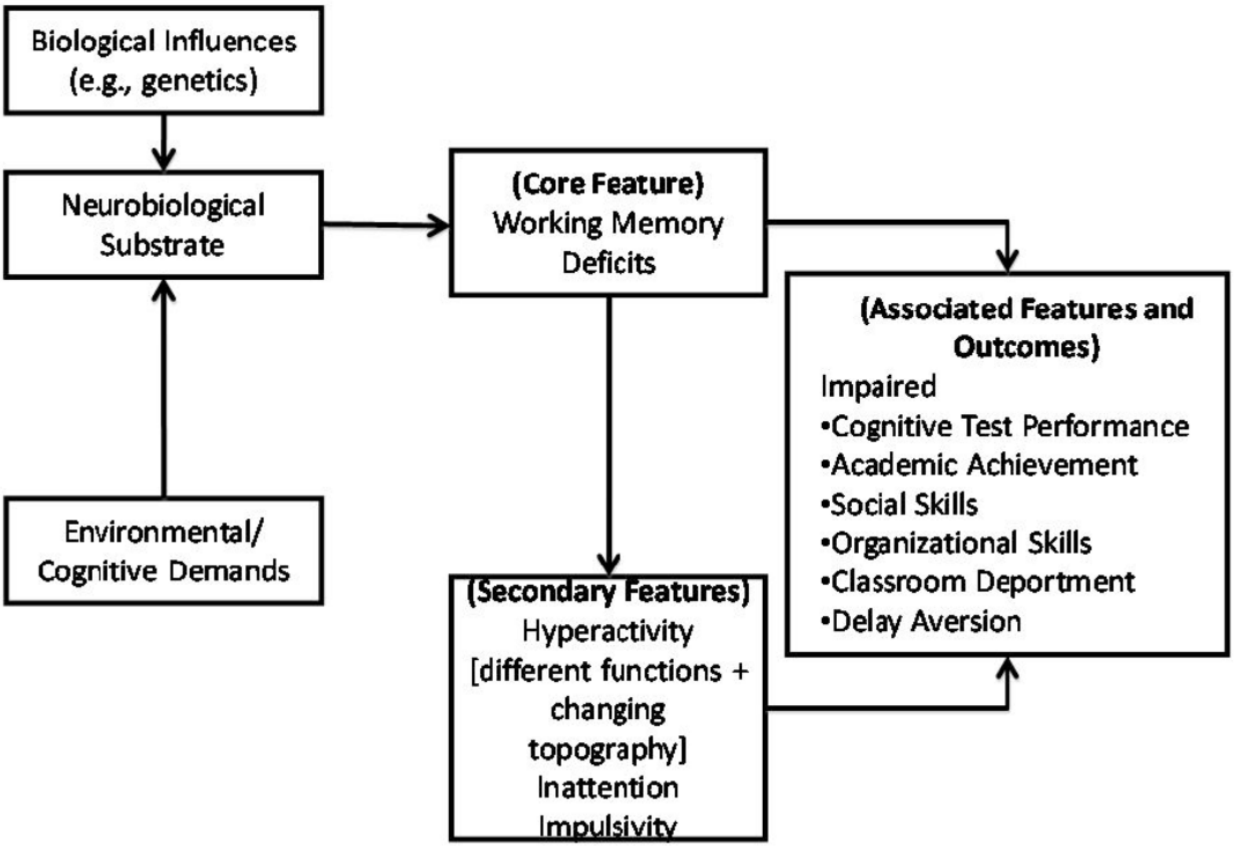

Figure 1: Working Memory Model of ADHD

Discussion

Applying our 6-session VSWM training protocol to school-aged ADHD patients showed statistically significant improvement in all types of VSWM capacities. The "soliloquy technique" and the "mnemotechnic" were generalized since most of the children used them during the post-rehabilitation phase (T2) by (1) verbalizing the characteristics of the stimuli to be treated and (2) associating the sequences made to a mental image.

Our results concord with those of Beck's et al. and Moore et al. studies where children showed significant improvement in attention after intensive cognitive and WM training. Likewise, Klingberg and collaborators evaluated the training of WM through computer games (Klingberg et al.). The sessions were divided into three activities that increased in complexity from one session to another by increasing the number of stimuli to be treated. During the training, the subjects' performances progressively improved in all the proposed activities by increasing the number of stimuli memorized and reducing the presentation time. In line with our results, subjects showed greater and higher memory skills after the training of the WM by using the computer. So, these types of fun game-based activities have an impact on learning and executive functions, including WM. As for Aubin, Coyette, Pradat-itehl and Vallat-Azouvi, they developed as well as an experimental program for the rehabilitation of WM. The various tasks proposed involved storage and processing operations and requested either the phonological loop or the visuospatial sketchpad; along with the central executive. To increase the mental load required to perform the tasks, increasing difficulties have been proposed during the training of the WM. The grading of the activities was defined according to the length of the items, the level of treatment (sequential), and the ability to access into mental images in order to facilitate the memorization of the stimuli, the recall time, and presentation speed. In concordance with our results, the test scores of the included subjects were within normal range after the end of treatment.

Our study has many limitations. The small sample size and the lack of a control group make it a prospective open-label pilot study, and that limits your ability to draw conclusions regarding the efficacy generalization of this treatment. It would also be interesting to expand the sample taking into consideration the female gender. The use of an additional test to evaluate SWM could also have brought new contributions to spatial criteria because the Nepsy Memory for Faces task 30-minute delay condition may not be a real measure of working memory but rather of consolidation to long term memory and this needs to be considered. As well, we may need to do further investigations to check if practice effects were driving the improvement from T1 to T2. Moreover, the rehabilitation program varied week by week, making it difficult to ascertain which aspects of the treatment are responsible for the improvement in VSWM. Finally, it would be interesting to have more measures of how the training translated to improved executive functioning in everyday life (i.e., far-transfer). Having parents complete a questionnaire before and after training would have assisted in further evaluating the impact of this training program on child executive functioning and to determine the extent of observable improvement.

Conclusion

In this study, we proposed an elaborated scientific protocol that can be used by psychomotor therapists, educators, speech-language pathologists, psychologists, or any other contributor to subjects with ADHD. This protocol improved the deficit in VSWM of ADHD children. Future larger trials are warranted to test the effects of this memory training on other executive functions such as attention, inhibition, mental flexibility, and planning as well as on academic performances. This specific training program may translate to improvement in these other domains who view WM as a core that affects automatically behavioral inhibition, organization, attentiveness, social skills, and hyperactivity/impulsivity.

Funding

None

Authors' Contributions

Elio Kechichian, MD for the assistance and the support throughout the study.

Conflict of Interest Disclosures (Includes Financial Disclosures)

The authors report no conflict of interest

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