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The efficacy of cognitive-motor rehabilitation on cognitive functions and behavioral symptoms of attention deficit/hyperactivity disorder (ADHD) children: Specification of near-transfer and far-transfer effects in comparison to medication

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Abstract:

BACKGROUND AND AIM: This study aimed to investigate and compare the efficacy of cognitive-motor rehabilitation (CMR) with methylphenidate on cognitive functions and behavioral symptoms of children with attention deficit/hyperactivity disorder (ADHD) and specified the near-transfer and far-transfer effects.

MATERIALS AND METHODS: The research was semiexperimental with posttest and follow-up assessments, in a single-blind design. Forty-eight boys with ADHD, aged 9–12, were selected conveniently regarding the inclusion/exclusion criteria, matched base on severity and Intelligence quotient (IQ) and were randomly assigned to CMR ($n = 16$), methylphenidate medication (MED, $n = 16$), and placebo CMR groups (PCMR, $n = 16$). CMR and PCMR received 20 3-h training sessions, and the MED group received 20 or 30 mg/day methylphenidate. Tower of London (TOL), Swanson, Nolan, and Pelham, Version IV Scale (SNAP-IV), Wechsler's digit span and mathematic subscales, dictation test, and restricted academic situation scale (RASS) were completed at posttest and follow-up. The data were analyzed by repeated measures multivariate analysis of variance.

RESULTS: CMR outperformed PCMR on forward digit span, backward digit span, ToL score at both posttest, and follow-up ($P < 0.05$). CMR scored lower than MED on ADHD-PI and ADHD-C at both posttest and follow-up ($P < 0.05$). Moreover, CMR outperformed MED on dictation at both assessment phases ($P < 0.01$) and RASS at the follow-up phase ($P < 0.05$). CMR outperformed PCMR on mathematics at post-test ($P = 0.038$) and also, in dictation and RASS, at both post-test ($P < 0.001$) and follow-up ($P < 0.05$).

CONCLUSION: CMR Improves near-transfer cognitive functions and behavior symptoms of ADHD as much as MED, but only CMR has more generalizable and endurable improvement on complex Efs and academic performance (far-transfer effects).

Keywords:

ADHD, cognitive functions, pharmacotherapy, rehabilitation

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Introduction

Attention deficit hyperactivity disorder (ADHD) as a neurobiological problem,[1] accompany not only some special behavioral symptoms, but also deficits in cognitive functioning especially executive functions (Efs).[2] Neuroimaging studies demonstrate deficiencies in the prefrontal cortex and executive cortical regions mediating cognitive processes such as motor and attention planning.[3] Taken together, there appears to be a robust link between the aforementioned neuro-anatomical abnormalities and the cognitive impairments and clinical symptoms observed in children with ADHD. In fact, targeting Efs and the underlying neuro-anatomical regions involved in ADHD is a promising trajectory in the treatment of ADHD.[4]

While there have been umpteen efforts taken place historically, the contemporary validated treatments of ADHD are disheartening and there are some critical limitations to these interventions, ranging from medication side effects to feasibility and costs of behavioral interventions.[5] Also, stimulants and behavioral interventions do not encompass far-transfer effects and sustained improvements which are critical factors in academic performance and graduation rates,[6] in addition ADHD children usually face significant problems specially in academic function[7] and researches demonstrate the role of different physical activities to be associated with higher grades. So, it is prudent to design motor activities that would affect academic grades which could be considered as far transfer effect. Near transfer and far transfer effects refers to an increase in performance on tasks that are highly similar and dissimilar to those used during training, respectively.[4]

Although still a matter of debate, an approach called cognitive rehabilitation therapy (CRT), especially as Computer-assisted cognitive rehabilitation (CACR), has been effective in improving cognitive functions and clinical symptoms of ADHD.[8] Favorably, Klingberg *et al*.[9] reported improvement of the working memory by performing working memory tasks implemented in a computer program (RoboMemo). However, according to Sonuga-Barke's dual pathway theory,[10] CACR interventions solely impact the top-down pathway and do not affect the bottom-up pathway and hence, it would not represent an endurable and far-transfer therapeutic effects for ADHD.

Promising intervention which targets both top-down and bottom-up pathways through combination of cognitive and motor exercises is cognitive-motor rehabilitation (CMR).[11,12] CMR not only impacts the cool Efs, but it also targets hot Efs[10] and could comprise better therapeutic results than CACR interventions.[13] Collectively, CMR could directly impacts the central executive processing deficits through therapeutic effects on underlying brain structures involved in ADHD, such as the frontal and prefrontal cortex, basal ganglia, cerebellum and the frontal cingulate.[14,15] Also, results from meta-analytical studies indicate that motor interventions are particularly effective in improvement of cognitive functions[16,17] and behavioral symptoms of ADHD.[18]

However, few studies have examined the effectiveness of CMR in clinical symptoms and Efs in children with ADHD. In fact, in a review article, Grassmann *et al*.[19] demonstrated that during 1980–2013, only three studies had examined the effectiveness of one single bout of exercise in improvement of cognitive functions in ADHD and only two of them comprised 30 minutes of exercise. Taken together, although some studies suggest the effectiveness of CMR in improvement of cognitive functions[20] and particularly Efs in children with ADHD,[21] these studies are limited in number and have methodological problems such as lack of control group, inadequate sample size and insufficient motor intervention time (less than 20 min). Rapport *et al*.[4] emphasized the role of central Efs in the treatment of ADHD, which inherently demand applying associative tasks, although, the majority of studies have recruited only simple task interventions. According to Baddeley,[22] As central Efs has the visuo-spatial sketchpad, for visual information, and the phonological loop, for verbal information, in association tasks, design of this study intervention involved both systems simultaneously. In addition, other studies have missed far-transfer effects and solely examined near-transfer effects. Hence, the present study aimed to investigate and compare the efficacy of CMR with psychostimulant medication in improvement of cognitive functions and behavioral symptoms of children with ADHD through implementing associative tasks and also specified the near-transfer and far-transfer effects of interventions.

Materials and Methods

Study design and setting

The present study was a single-blind, semiexperimental design with three parallel groups, assessed at posttest and 3-month follow-up phases.

Study participants and sampling

The statistical population of the study consisted of the 9-12-year-old male, elementary schoolchildren in Tehran's ninth district who met the criteria for ADHD diagnosis. Forty-eight participants were selected conveniently regarding the inclusion–exclusion criteria and matched based on ADHD severity (parent form of CSI-IV) and IQ scores (short form of WISC-R-III), then randomly (according to a computer-generated randomization list) assigned to cognitive-motor rehabilitation (CMR), psychostimulant medication (MED), and an active control group which received placebo cognitive-motor rehabilitation (PCMR). Each group consisted of 16 participants (1- β = 0.90, effect size = 0.5, α = 0.05)[23] and the inclusion criteria were as follows: (1) ADHD diagnosis based on psychiatrist clinical interview, rating scales, parental clinical interview, (2) ranging between 9 and 12 years old, (and 3) IQ scores above 90. The exclusion criteria were as follows: (1) comorbid psychiatric disorders, (2) epileptic seizures in the last 2 years, (3) motor disability, and (4) other medical conditions. The discontinue criteria included the following: (1) Any change of received medications, (2) Taking less than 80% of the received pills in MED group, and (3) reluctance to continue cooperation.

Data collection tool and technique

In this study, near-transfer effects were assessed by forward/backward digit span and Tower of London (TOL), behavioral symptoms by Fourth Edition of the Swanson, Nolan and Pellham Scale (SNAP-IV), and far-transfer effects were assessed by Wechsler's mathematic sub-scales, dictation test and restricted academic situation scale (RASS).

Forward/Backward Digit Span: To assess the verbal working memory, the digit span subtest of the Wechsler intelligence test (WISC-IV) was used. The coefficients reliability of the subtests of the fourth edition of the Wechsler intelligence test for children have been reported by Cronbach's alpha ranging from 0.65 to 0.94.[24] Also, the concordant validity of this test, through Wechsler and Raven test, has been reported as optimal.

TOL: The test measures the executive planning. This test has appropriate construct validity in assessing the planning and organization ability of individuals. The validity of this test was also reported as 0.79.[25]

Swanson, Nolan, and Pelham, Version IV Scale-Parent Form (SNAP-IV) – 18 item form: The first nine items are related to the subtype "prominently inattentive (ADHD-PI)," and the second nine items are pertinent to the subtype "prominently hyperactive-impulsive (ADHD-PHI)." All the 18 items are calculated for the "combined subtype (ADHD-C)." Sadr *et al*.[26] have reported the coefficient reliability of this scale by the retest method as 0.85, and Cronbach's alpha coefficient as 0.90, and the coefficient of two-half as 0.76.

Dictation Test: To assess the writing ability of participants, a dictation test, designed by the author, was used. To design the test, the last version of the "Let's read" book for each grade (third, fourth, and fifth grade) was used. This test comprises of traditional dictation, based on the "Let's read" book; a text with 110 words was prepared for each grade. The traditional dictation includes a number of corrects. For each correctly written word, the participant gains one score. To assess the face validity of the test, ten well-experienced, elementary school teachers and two psychologists evaluated the test. Also, in a pilot trial, the test was performed on a group of elementary schoolchildren and, according to their performance, the necessary changes were exerted in the final version of the test.

Wechsler Mathematic Subscale: This test is used to measure students' mathematics information. The coefficient of reliability was reported by a retest method 0.8 and comparison method 0.74.[24]

RASS: The scale was developed by Barkley[27] to provide information on the frequency and severity of ADHD symptoms, independently during performing an academic assignment. The coefficient of validity has been reported optimal among evaluators.[28] In a preliminary study, before the implementation of this study, the retest validity coefficient of this test in a 2-week interval on 20 students aged 9–12 years was examined. The results of the coefficient validity of this test were, respectively, engaging category (0.68) and negative scores as (0.64).

In addition, to assess the inclusion and exclusion criteria, the following instrument was used:

Wechsler Short Form Scale of Intelligence: This test was used to assess the subjects' IQ scores. The coefficient validity of the best four-component form of this test (vocabulary, information, cubes, and image completion) has been reported 0.91.[29] The sum of standardized scores obtained from these four subtests, using this formula (IQ = 40+ (x) 1.5), can be converted to IQ. Participants with an intelligence score lower than 90 were excluded.

Procedure

Initially, 112 schoolchildren were introduced by Tehran's ninth district elementary schools. Subsequently, after parents' interview and children observation, and based on the inclusion–exclusion criteria, 48 participants were selected through multistage sampling. Afterward, the parents were informed about the research procedure and signed the consent form. Participants were matched and randomly assigned to CMR, MED, and PCMR groups [Figure 1]. Based on the determined timetable, blinded evaluators conducted the posttest and 3-month follow-up assessments (single-blind). In order to increase generalizability and external validity of results, the pretest assessment phase was not performed. It is worth noting that the MED Group

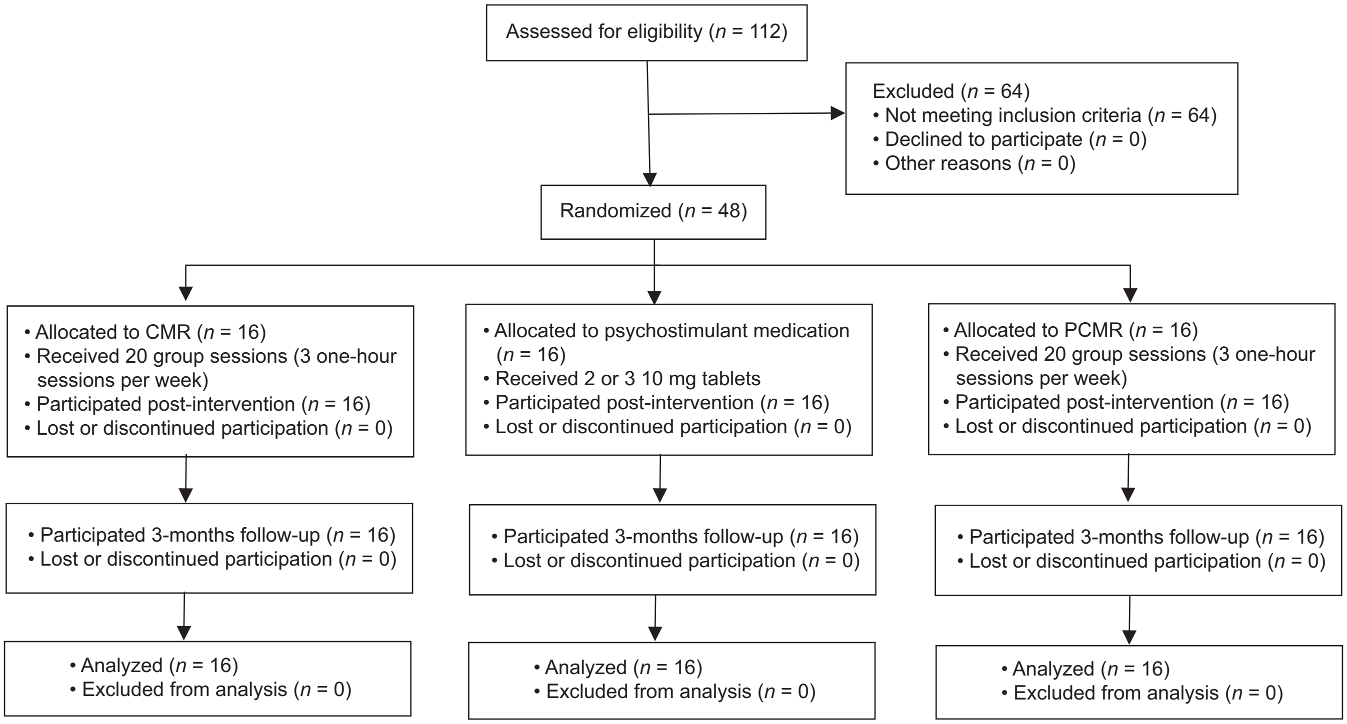

Figure 1: Flow of the participants through the trial

had taken medication about 20 min prior to the posttest assessment.

Before the initiation of the research procedure, evaluators and trainers were trained in three 4- h sessions. Additionally, all the evaluators, trainers, and the participants, except the participants in the medication group, were blinded to the research procedure. The research procedure took place from October 14, 2020 to February 20, 2021 at Tehran's ninth district consulting center, the ministry of training and education. Worsening of the clinical symptoms, parental unwillingness, and medication adversities, which were assessed every session, were criteria to stop intervention.

The CMR group received 20 group sessions (three sessions per week, with two groups of five and a group of six participants) as the sole treatment. Each 1-h session consisted of 5 min of warm-up, 5 min of cool-down, and 50 min of performing progressive associative tasks, including sequential movements, starting with a single sequence in hand and then doing the sequence in the legs, and at the end doing the combined movements of the hands and feet. All the tasks were progressive in speed and complexity which were designed with a metronome.

The PCMR group completed 20 group sessions in an exactly similar way to the CMR group. In each session, simple activities without therapeutic effect were performed. The medication group received 2–3 tablets of methylphenidate 10 mg (immediate release) per day, prescribed by a psychiatrist. Medication adverse effects, dosage, and compliance were regularly assessed every 2 weeks. Also, participants received the medication 20 min prior to the posttest assessment. Furthermore, parents of the children in the medication group were requested to stop medication 24 h before the follow-up assessment. The repeated measure MANOVA test was applied for the determination and comparison of the trend of changes between three groups (CMR, PCMR, and MED) in two assessment phases (posttest and follow-up).

Ethical considerations

The study was approved by the ethical committee of Semnan University and registered in ClinicalTrials.gov (Identifier: NCT02780102). The participants were informed about the research procedure and a written consent form was obtained from all parents of participants. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and, if desired, the research results would be available to them.

Results

As shown in Table 1, results of ANOVA test showed that there was no significant difference between the mean age ($F = 0.317$, $P = 0.73$) and IQ of CMR, MED, and PCMR groups ($F = 0.689$, $P = 0.50$). Also, in terms of education grade, result of Chi-square test showed no significant difference between the three groups ($X^2 = 5.83$, $P = 0.12$).

Table 1: Demographic characteristics for all participants

	CMR (*n*=16)	MED (*n*=16)	PCMR (*n*=16)
Age (Mean±SD)	10.37±0.885	10.12±1.024	10.37±1.147
IQ (Mean±SD)	98.43±5.124	100.12±8.845	97.50±4.335
Education grade (percent)			
Third	12.5	25	31.3
Fourth	37.5	56.3	25
Fifth	37.5	0	25
Sixth	12.5	18.7	18.7

SD=Standard deviation, CMR=Cognitive-motor rehabilitation, MED=Medication, PCMR=Placebo cognitive-motor rehabilitation

According to two times of assessment phases and multiple dependent variables, repeated measure MANOVA test was utilized. First, its assumption such as homogeneity of variances by Levene's test ($P = 0.052$) and Bartlett's test ($X^2 = 799.96$, $P < 0.001$) was checked.

According to results of time*group interaction effects (Pillai's trace = 0.284, $F_{(20, 74)} = 0.613$, $P > 0.05$, Eta squared = 0.142), there was no significant interaction between experimental groups (CMR, MED, and PCMR) and assessment phases (posttest and follow-up). In the next step, the results of univariate analysis based on assessment phases are presented.

Near-transfer effects

As shown in Table 2, at the post-test phase, there was a significant difference between experimental groups on forward digit span (F = 5.033, $P = 0.01$), backward digit span (F = 6.26, $P = 0.004$) and TOL score (F = 5.402, $P = 0.008$).

According to the post-hoc test [Table 3], CMR outperformed PCMR on forward digit span (95% CI = 0.262–3.613, $P = 0.018$), backward digit span (95% CI = 0.426–2.949, $P < 0.005$), and the Tol score (95% CI = 1.047–8.953, $P = 0.009$).

In addition, there was a significant difference between MED and PCMR on forward digit span (95% CI = 0.75–3.425, $P = 0.038$) and backward digit span (95% CI = 0.113–2.637, $P = 0.028$), which indicates the effectiveness of medication in improvement of these components.

At the follow-up phase, there was a significant difference between experimental groups on forward digit span ($F = 7.41$, $P = 0.002$) and backward digit span ($F = 4.80$, $P = 0.01$).

As shown in Table 3, CMR outperformed PCMR in forward digit span (95% CI = 0.606–3.644, $P = 0.003$) and backward digit span (95% CI = 0.301–2.824, $P = 0.011$). On forward digit span, the changes in the MED group were more sustained in comparison to the PCMR group (95% CI = 0.418–3.457, $P = 0.008$). There was no significant difference in other between-group comparisons.

Far-transfer effects

According to Table 2, at the posttest phase, there was a significant difference between experimental groups on ADHD-PI ($F = 4.89$, $P = 0.012$), ADHD-PHI ($F = 3.73$, $P = 0.032$), ADHD-C ($F = 4.709$, $P = 0.014$), dictation scores ($F = 1.80$, $P = 0.0001$), mathematics ($F = 3.37$, $P = 0.043$), the RASS task engagement ($F = 4.37$, $P = 0.01$), and the RASS negative scores ($F = 3.69$, $P = 0.03$).

The result of posthoc tests indicated that CMR improved significantly more than PCMR on ADHD-C (95% CI = -16.520 to -0.230, $P = 0.042$). Furthermore, on behavioral symptoms such as ADHD-PI (95% CI = -9.253 to -0.872, $P = 0.013$) and ADHD-C (95% CI = -17.145 to -0.855, $P = 0.026$), CMR improved significantly more than MED.

CMR outperformed PCMR on dictation scores (95% CI = 11.278–36.222, $P = 0.0001$), mathematics (95% CI = 0.140–6.735, $P = 0.038$), the RASS task engagement (95% CI = 0.528–8.597, $P = 0.022$), and the RASS negative scores (95% CI = -27.390 to -1.110, $P = 0.026$). Moreover, CMR outperformed MED on dictation scores (95% CI = 7.153–36.097, $P = 0.001$).

At the follow-up phase, there was a significant difference between experimental groups on ADHD-PI ($F = 4.94$, $P = 0.01$), ADHD-PHI ($F = 3.52$, $P = 0.03$), ADHD-C ($F = 5.04$, $P = 0.011$), dictation scores ($F = 1.804$, $P = 0.0001$), the RASS task engagement ($F = 10.25$, $P = 0.0001$), and the RASS negative scores ($F = 6.01$, $P = 0.005$).

According to posthoc tests, CMR significantly more sustained than PCMR on ADHD-PI (95% CI = -8.608 to -0.267, $P = 0.034$) and ADHD-C (95% CI = -17.330 to -1.045, $P = 0.022$). Moreover, CMR more sustained than MED on ADHD-PI (95% CI = -8.858 to -0.517, $P = 0.023$) and ADHD-C (95% CI = -16.955 to -0.670, $P = 0.030$).

Also, in comparison to the PCMR groups, changes in the CMR group were significantly more sustained in dictation scores (95% CI = 12.97–40.025, $P = 0.0001$), the RASS task engagement (95% CI = 2.887–10.113, $P = 0.0001$), and the RASS negative scores (95% CI = -28.951 to -2.924, $P = 0.012$). Also, CMR outperformed MED on dictation scores (95% CI = -28.614 to -5.511, $P = 0.002$), the RASS task engagement (95% CI = 6.162 to 33.213, $P = 0.02$), and the RASS negative scores (95% CI = -28.513 to -2.487, $P = 0.015$).

Discussion

This study aimed to investigate near-transfer and far-transfer effects of CMR on cognitive functions and

Table 2: Results of univariate analysis of cognitive functions and behavioral symptoms based on assessment phases

Scales	Group	Posttest					Follow-up				
		Mean	SD	*F*	*P*	η^2	Mean	SD	*F*	*P*	η^2
Forward digit span	CMR	6.75	1.570	5.033	0.015	0.183	7.43	1.364	7.41	0.002	0.248
	MED	6.56	1.896				7.25	1.693			
	PCMR	4.81	2.197				5.31	2.056			
Backward digit span	CMR	4.43	1.78	6.26	0.004	0.218	4.62	1.987	4.80	0.011	0.176
	MED	4.12	1.258				4.01	1.897			
	PCMR	2.75	1.183				3.06	1.181			
TOL Score	CMR	29.93	3.586	5.402	0.008	0.194	29.01	4.320	1.29	0.28	0.054
	MED	26.12	5.439				26.87	4.318			
	PCMR	24.93	4.265				26.87	4.303			
SNAP-IV: ADHD-PI	CMR	11.68	4.527	4.89	0.012	0.179	11.93	4.265	4.94	0.012	0.180
	MED	16.75	4.878				16.62	3.964			
	PCMR	15.5	4.885				16.37	5.795			
SNAP-IV: ADHD-PHI	CMR	10.31	5.069	3.73	0.032	0.142	10.31	4.935	3.52	0.038	0.135
	MED	14.56	5.525				14.43	4.830			
	PCMR	15.12	5.725				15.31	7.030			
SNAP-IV: ADHD-C	CMR	22.25	8.559	4.709	0.014	0.173	22.25	7.289	5.04	0.011	0.183
	MED	21.25	9.088				31.06	7.903			
	PCMR	30.62	10.07				31.43	11.90			
Dictation scores	CMR	101.75	5.790	1.80	<0.001	0.363	102.27	4.773	1.804	<0.001	0.363
	MED	82.12	14.202				82.68	16.965			
	PCMR	78	19.193				75.87	19.982			
Mathematics	CMR	20.18	3.350	3.37	0.043	0.131	20.56	4.396	1.74	0.18	0.072
	MED	18.68	5.160				19.62	3.913			
	PCMR	16.75	2.081				18.06	3.021			
RASS: engagement	CMR	27.12	3.792	4.37	0.018	0.163	28.75	1.483	10.25	<0.001	0.313
	MED	26.12	5.572				24.62	5.863			
	PCMR	22.56	4.210				22.25	3.750			
RASS: negative scores	CMR	13.25	8.152	3.69	0.033	0.141	11.12	9.308	6.01	0.005	0.211
	MED	21.87	20.369				26.62	19.966			
	PCMR	27.51	13.735				27.06	13.112			

ADHD-PI=Prominently inattentive, ADHD-PHI=Prominently hyperactive impulsive, ADHD-C=Combined subtypes, CMR=Cognitive-motor rehabilitation, MED=Medication, PCMR=Placebo cognitive-motor rehabilitation

behavioral symptoms of children with ADHD and sought to compare these findings with psycho-stimulant medication.

Results indicated that CMR was effective in improvement of short-term memory (STM), working memory, and executive planning. Although the CMR performed better than MED (at the posttest phase, the MED group assessed after taking medication) on STM, these differences were not statistically significant. At the follow-up phase, CMR had sustained improvement in STM and working memory and also outperformed MED on STM. These findings indicate the effectiveness of cognitive-motor rehabilitation on improvement of the Efs. This is consistent with some studies.[30] Favorably, Ziereis and Jansen[12] reported the sustainability of the outcomes of motor activities in improvement of Efs in children with ADHD. Similarly, Verret *et al*.[31] reported the sustainability of the outcomes after 10 weeks of motor activities, in processing speed, visual probing, and sustained attention in children with ADHD. However, these studies did not assess academic results of intervention.

Higher serum levels of brain-derived neurotrophic factor (BDNF) after physical exercise are associated with better working memory training task; similarly, cognitive-motor exercise could be accompanied by chemical and structural changes such as increment of BDNF which plays a critical role in synaptic plasticity and neuro-development[32] and consequently leads to sustained changes; more effectiveness of the CMR approach in comparison to medication is reasonable.

Based on fMRI studies, it seems that CMR has provocative effects in neuroanatomical substrate deficits that implicated in the pathophysiology of ADHD (analogous to the mechanism of psychostimulants) such as prefrontal cortex, cerebellum, and the posterior cortex,[33] which are related to various neurologic processes such as response inhibition, working memory, and sustained attention.[34]

Table 3: Results of posthoc tests by pairwise comparisons

Scale	Groups	Posttest			Follow-up		
		Mean difference	P^a	Cohen's d	Mean difference	P^a	Cohen's d
Forward digit span	CMR Vs. PCMR	1.93	0.018	1.0160	2.12	0.003	1.2151
	CMR Vs. MED	0.18	1.000	0.1091	0.18	1.000	0.1170
	MED Vs. PCMR	1.75	0.038*	0.8528	1.93	0.008	1.0301
Backward digit span	CMR Vs. PCMR	1.68	0.005	1.1086	1.56	0.011	0.6742
	CMR Vs. MED	0.31	1.000	0.2006	0.62	0.67	0.3140
	MED Vs. PCMR	1.37	0.028*	1.1219	0.93	0.21	0.6012
TOL Score	CMR Vs. PCMR	5.001	0.009	1.2689	2.12	0.51	0.4963
	CMR Vs. MED	3.81	0.062	0.8270	2.12	0.51	0.4954
	MED Vs. PCMR	1.18	1.000	0.2434	-3.33	1.000	0.00
SNAP-IV: ADHD-PI	CMR Vs. PCMR	-3.81	0.086	0.8111	-4.43	0.034	0.9434
	CMR Vs. MED	-5.06	0.013	1.0774	-4.68	0.023	1.1391
	MED Vs. PCMR	1.25	1.000	0.2560	0.25	1.000	0.0503
SNAP-IV: ADHD-PHI	CMR Vs. PCMR	-4.81	0.049*	0.8895	-5.01	0.050	0.8232
	CMR Vs. MED	-4.25	0.097	0.8015	-4.12	0.138	0.8437
	MED Vs. PCMR	-0.563	1.000	0.0995	-0.87	1.000	0.1459
SNAP-IV: ADHD-C	CMR Vs. PCMR	-8.37	0.042	0.8956	-9.18	0.022	0.9303
	CMR Vs. MED	-9.00	0.022	0.1132	-8.81	0.031	1.1588
	MED Vs. PCMR	0.62	1.000	0.9768	-0.37	1.000	0.0366
Dictation scores	CMR Vs. PCMR	23.75	<0.001	1.6754	26.51	<0.001	1.8173
	CMR Vs. MED	19.62	0.001	1.8100	19.68	0.002	1.5720
	MED Vs. PCMR	4.12	1.000	0.2440	6.81	0.65	0.3674
Mathematics	CMR Vs. PCMR	3.43	0.038	1.2299	2.50	0.21	0.6628
	CMR Vs. MED	1.50	0.79	0.3448	0.93	1.000	0.2258
	MED Vs. PCMR	1.93	0.45	0.4905	1.56	0.76	0.4462
RASS: engagement	CMR Vs. PCMR	4.56	0.022	1.1381	6.50	<0.001	2.2795
	CMR Vs. MED	1.01	1.000	0.2098	4.12	0.021	0.9657
	MED Vs. PCMR	3.56	0.10	0.7209	2.37	0.327	0.4815
RASS: negative scores	CMR Vs. PCMR	-14.25	0.026	1.2617	-15.93	0.012	1.4019
	CMR Vs. MED	-8.62	0.32	0.5556	-15.50	0.015	0.9950
	MED Vs. PCMR	-5.62	0.87	0.3240	-0.438	1.000	0.0260

[a]Adjustment for multiple comparisons with Bonferroni, *$P < .05$. ADHD-PI=prominently inattentive., ADHD-PHI=prominently hyperactive impulsive, ADHD-C=combined subtypes, CMR=cognitive-motor rehabilitation, MED=Medication, PCMR=placebo cognitive-motor rehabilitation

Furthermore, frequent cognitive-motor practice, which relies mainly on associative tasks, would enhance function of the aforementioned structures and consequently improve more efficiently cognitive functions in children with ADHD.

Academic performance and behavior rating measures demonstrated that CMR outperformed PCMR on academic functions. Also, at the follow-up phase, CMR outperformed MED on behavior and also on dictation. Likewise, Pontifex, *et al*.[35] reported improvement of the reading skill and the mathematics scores following motor activity with moderate intensity. Although these studies did not compare it with medical treatment to convince researchers or clinicians if it is still prudent to consider it while medication is prescribed. It is while, according to brain plasticity principles, frequent practice propels other tasks and activities by cognitive improvement.[36] It could be attributable entirely to neuronal-level improvements in the trained cognitive functions. Overlapping between demanded cognitive functions, in performing dictation and mathematics tasks (such as working memory, attention/concentration, and planning), with cognitive abilities targeted during training and involve similar brain regions could explain this finding.

Results of behavioral rating by blinded parents showed that CMR scored lower than MED on ADHD-C. Moreover, CMR scored lower than PCMR on ADHD-PHI and ADHD-C. Also, at the follow-up phase, CMR was more sustained, as it scored lower than MED and PCMR on ADHD-PI and ADHD-C. These findings were congruent with Lufi and Parish-Plass[37] findings. In addition, Verret *et al*.[31] reported the effectiveness of performing motor activity with moderate to high intensity in the decrement of behavioral symptoms of children with ADHD.

Limitation and recommendation

The key limitation of the present study was utilizing only parental rating behavior scales. Therefore, using of the teacher rating scale is also recommended. In addition, applying objective measures such as QEEG and fMRI as neuro-physiological procedures would help to understand underlying mechanisms of CMR in treatment of ADHD.

Conclusion

Altogether, CMR improves cognitive functions related to near-transfer effects and behavioral symptoms of ADHD as much as MED (although MED had taken psychostimulant medication about 20 minutes before the posttest assessment phase), but only CMR has more generalizable and endurable improvement on complex Efs and academic performance (far-transfer effects). As CMR includes associative tasks, it could be considered as a supplementary therapeutic technique in the treatment of ADHD to achieve more sustainable improvement.

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Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.

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