RANDOMIZED CONTROLLED TRIAL

COHERENCE TRAINING IN CHILDREN WITH ATTENTION-DEFICIT HYPERACTIVITY DISORDER: COGNITIVE FUNCTIONS AND BEHAVIORAL CHANGES

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Attention-deficit hyperactivity disorder (ADHD) is the most prevalent behavioral diagnosis in children, with an estimated 500 000 children affected in the United Kingdom alone. The need for an appropriate and effective intervention for children with ADHD is a growing concern for educators and childcare agencies. This randomized controlled clinical trial evaluated the impact of the HeartMath self-regulation skills and coherence training program (Institute of HeartMath, Boulder Creek, California) on a population of 38 children with ADHD in academic year groups 6, 7, and 8. Learning of the skills was supported with heart rhythm coherence monitoring and feedback technology designed to facilitate self-induced shifts in cardiac coherence. The cognitive drug research system was used to assess cognitive functioning as the primary outcome measure. Secondary outcome measures assessed teacher and student reposted changes in behavior. Participants demonstrated significant improvements in various aspects of cognitive functioning such as delayed word recall, immediate word recall, word recognition, and episodic secondary memory. Significant improvements in behavior were also found. The results suggest that the intervention offers a physiologically based program to improve cognitive functioning in children with ADHD and improve behaviors that is appropriate to implement in a school environment.

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It is estimated that approximately 500 000 school children in the United Kingdom suffer from attention-deficit hyperactivity disorder (ADHD) and that the number appears to be growing.[1] Untreated, ADHD can lead to academic underachievement, poor interpersonal relationships, anxiety, depression, and increased risk of involvement in crime.[2-5] Of particular concern is the increased risk of mental health problems for adolescents with ADHD. Moreover, many sufferers continue to experience symptoms throughout their adult lives.[6] Educators know that children with ADHD experience multiple disadvantages, but few seem to be aware of the possible lifelong chronic impact of this condition.[7]

Diagnosis of ADHD often relies on the subjective observations of teachers, parents, and physicians. Inevitably, symptoms overlap with other comorbid conditions such as anxiety, depression, psychological trauma, or dissociation resulting from adverse life events, such as family breakdown, bereavement, bullying, and exam-related stress, which can be mistaken for ADHD. Misdiagnosis inevitably results in the underlying causes of ADHD-type behaviors remaining untreated.[8] The United Kingdom's National Attention Deficit Disorder Information and Support Service (ADDISS) maintains that diagnoses are underestimated for both girls and boys, although the ratio of boys to girls suffering from ADHD is estimated at approximately 4:1.[9]

Over the past 2 decades, there has been an increasing tendency to treat ADHD pharmacologically. According to a report by the National Institute for Clinical Excellence (NICE), prescriptions for psychostimulant medication to treat ADHD in the United Kingdom burgeoned from 2606 cases in 1992 to 456 909 in 2006.

There is a substantial body of research suggesting that stimulant medication alleviates ADHD symptoms and moderates impulsive and inattentive behaviors, resulting in improved school performance.[5] However, there is growing concern among some researchers and clinicians both that there is a tendency to overprescribe such medications and that there may be potential long-term side effects of psychostimulants, which are still unknown; some reports indicate they are not as efficacious as was previously reported.[10]

The British Psychological Society, ADDISS, physicians, and educators all recommend multimodal approaches to diagnosis and treatment so children affected by ADHD can better thrive and enjoy childhood. Multimodal approaches include counselling and advice on nutrition and parenting as well as specific approaches to increasing self-regulation skills for children who experience impulsive behaviors and inattention.

Emotional self-regulation underpins intellectual development and, therefore, academic attainment.[11] Research suggests that adolescents are ideally suited to learn emotional self-regulation due to enhanced neurogenesis and brain plasticity associated with this stage of development.[11-14] A growing body of research on brain development in infancy and adolescence suggests that emotional self-regulation can be learned by all children, including those affected by ADHD, with multiple benefits for well-being and potentially less reliance on psychostimulant medication.[15-17]

Learning and maintaining the capacity to self-regulate are based on one's ability to formulate coherent patterns of information that are coded in neural nets throughout the entire nervous system. Executive functions develop as the brain matures, and young adults acquire greater impulse control as they develop attentional control systems in the prefrontal cortex. However, in children with ADHD, executive functions and working memory are underdeveloped, thus undermining their ability to analyse, plan, and self-regulate behavior.

A substantial amount of the neural physiology literature suggests that the brain and nervous system construct is not linear or hierarchical but rather must be viewed as a dynamic, nonlinear, self-organizing, and self-regulating system that coordinates multiple systems both within and outside the organism, including cultural and social regulation and relationships.[18] Therefore, understanding the biology of learning and self-regulation and how to optimize these processes must become one of the basic tenets of education, including curriculum design and delivery. It follows, therefore, that schools must provide the optimum environment for intellectual, emotional, and social development through the medium of psychophysiological balance, thus acknowledging the centrality of emotional processing systems in learning and development. We must explore how to best enable children to stay adaptable and resilient so that they can respond to changing environmental influences, maintain stability, and thrive.

Following the lead of many educational researchers, the Institute of HeartMath (IHM; Boulder Creek, California) has conducted research on the importance of emotional self-regulation and the physiology of optimal leaning and performance.[19-21] These researchers introduced the term *psychophysiological coherence* to describe how this state reflects a physiologic state characterized by increased synchronization, harmony, and efficiency in the interactions within and among the physiological, cognitive, and emotional systems. Coherence can be activated naturally with intentional shifts to a positive emotional state such as appreciation, compassion, and love.[22, 23] This shift reflects increased synchronization in higher-level brain systems and between the two branches of the autonomic nervous system (ANS), as well as a shift in autonomic balance toward increased parasympathetic activity.[21, 24] These observations between increased physiological coherence and efficiency and positive emotions may provide an understanding of the mechanism that explains the growing number of documented correlations between positive emotions,[25] increased cognitive flexibility, creativity,[26, 27] broadened thought action repertoires, increased personal resources,[28] improved health, and increased longevity.[29-31]

One of the key indicators of the coherent state is changes in the heart rhythm created by the naturally occurring changes in beat-to-beat heart rate, called heart rate variability (HRV). HRV is more than an assessment of heart rate; it is a much deeper assessment of the complex interaction of the heart with multiple body systems, especially the brain. The amount of HRV is related to age, with younger individuals having higher levels than older ones.[32] Abnormally low HRV, relative to one's age, is a strong and independent predictor of future health problems, including all causes of mortality.[33,34] In addition, HRV, a psychophysiological marker of emotion regulation, is considered an important indicator of both physiological resilience and behavioral flexibility, and it reflects individuals' capacity to adapt effectively to stress and environmental demands.[35] For example, low HRV is associated with depression,[36] ADHD,[37] generalized anxiety,[38] and depletion of the autonomic nervous system reserves, as well as numerous medical conditions.[39-42]

In addition to accumulated stress leading to lower levels of HRV, research has shown that stress-related emotions such as anxiety, fear, anger, and frustration produce state-specific heart rhythm patterns that appear incoherent—disordered and erratic.[24,43,44] Studies have shown that prefrontal cortex activity affects patterns of heart activity via modulation of the efferent fibers in the parasympathetic branch of the ANS[45]; therefore, disordered activity in higher-level brain systems can manifest as increased disorder in heart rhythm patterns. This desynchronization in the brain and autonomic nervous system reflected in the HRV patterns can impede the efficient flow of information throughout the psychophysiological systems and decrease cognitive performance.[43]

A range of HRV indices converge to implicate low parasympathetic activity and elevated sympathetic activity as a systemic inflexibility grounded in poor inhibitory control. Low parasympathetic activity has been linked with poor emotion regulation, decreased reactivity to various stimuli, increased stress vulnerability, delinquency risk in preadolescent boys,[46] and antisocial behavior.[47] In contrast, greater parasympathetic activity has been associated with increased physiological and behavioral flexibility, responsiveness to the environment, stress resiliency, and emotion regulation ability.[48,49]

Evidence suggests that high parasympathetic activity also enhances cognitive processes involved in learning, including attentional capacity[50-54] and verbal memory.[55] These findings establish a clear link between HRV measures and key aspects of affect and behavior regulation. The inhibition or self-control of immediate, automatic responses is a key component of adaptive, flexible behavior.

A recent study also found that resting levels of HRV are associated with individual differences in cognitive performance and higher levels of resting HRV were associated with superior performance on tasks requiring executive functions. The research concluded that HRV can be manipulated in order to improve cognitive function. Thus, HRV coherence feedback can play a significant role in helping to increase HRV and both afferent and efferent vagal activity.[20,56]

IHM has developed a system designed to enhance emotional self-regulation. This system includes a set of heart-focused techniques designed to enable individuals to obtain greater self-management; learning of the skills is supported by a PC-based HRV coherence-monitoring device. These techniques and technology offer an approach for facilitating learning states and impulse control that involves a physiological shift. Coherence-building interventions have indicated that HRV coherence is associated with improvements in autonomic nervous system function,[24] immune and hormonal system function,[57] and cognitive functioning.[46,58] An investigation undertaken in Merseyside, England, employed externally validated measures to demonstrate the impact of heart-focused breathing, simultaneous activation of positive emotions, and easy-to-use non-invasive HRV coherence feedback–controlled computer games to improve cognitive functioning. A recent study also employing the use of biofeedback computer games[59] demonstrated improved IQ scores in children with ADHD. The HeartMath (HM) system is now being employed in diverse applications in several schools throughout the United Kingdom, and evidence from pilot studies conducted there indicate that this training could help pupils build resilience to environmental stressors in a school context.

METHODS

This study used a randomized controlled design to assess the potential benefits of providing a non-pharmacological–based self-regulation training developed for children with a clinical diagnosis (*DSM-IV*) of ADHD. The primary hypothesis was that the HM training would diminish the effects of ADHD by improving cognitive function and ability to self-regulate behaviors. Ethical approval (institutional review board) for the study was obtained from the Wirral Children's Services and Liverpool John Moores University Ethics Committee, and parental and participant consent was obtained in writing.

PARTICIPANTS

Participants were recruited from three secondary Schools (Plessington Catholic Technology College, Bebington High School, and Mosslands High) and two primary schools in Wirral Local Authority that agreed to participate in the study. Thirty-nine students aged 9 to 13 years (M=35, F=4) meeting the diagnostic criteria of *DSM-IV* for ADHD were recruited for the study. All participants agreed to keep existing medication regimens constant, to not take part in any other study, and to refrain from starting a new weight-reduction program or new sports program for the duration of study. Participation selection was blind to the assessors and randomized within the schools from which the students were recruited; participants did not know which groups were control or experimental.

Ethical considerations necessitated that all participating students would have the opportunity to benefit from the HM intervention. Therefore, a control group that did not receive an active intervention was not included in the design. Thus, the participants randomly assigned to the control group (active placebo) for the first 6 weeks then participated in the HM intervention during the following 6 weeks. Logistical difficulties and human resourcing limitations were such that 14 children received only the HM intervention and 22 children were provided with both the active placebo (Legos) and the HM intervention. Two children received only the active placebo as a result of changing schools and were therefore dropped from the analysis.

The interventions were delivered by a learning support and research assistant and designated staff members in each of the schools who were rigorously trained in the HM, Lego, and Cognitive Drug Research measurement system (CDR Ltd, Goring-on-Thames, Oxfordshire, United Kingdom) assessment protocols. Both control and experimental interventions were conducted daily during sessions of 20 minutes' duration in the same room and by the same staff member over a period of 6 weeks. Participants in the experimental group were taught three HM emotional self-regulation techniques by an adult learning assistant who supervised their practice over the 6-week period. Two of the techniques, Neutral and Quick coherence, are designed as emotion-refocusing tools, and the third, called the Heart Lock-In, as an emotional restructuring technique.

All of these techniques involve shifting one's focus of attention to the area around the heart and breathing easily and slowly as if one were breathing through the chest area. The Quick coherence and Heart Lock-In tools include activation of a positive emotion. The participants were encouraged to use the techniques regularly in school and at home. Heart Lock-In involves self-generating and sustaining a positive emotional state for 5 to 10 minutes and was the primary technique practiced in the one-on-one sessions with the learning assistant.

Learning of the Heart Lock-In technique was facilitated with an HRV coherence-feedback technology called the emWave Desktop, designed to objectively monitor and relay the students' level of heart rhythm coherence. The technology was used as a training aid to confirm that the students were in fact attaining a state of increased psychophysiological coherence. The system uses a pulse sensor that is clipped to the student's ear lobe. During the emWave sessions, visual feedback on coherence levels was provided to the children as they played one of the games included with the system, which is controlled by the user's level of HRV coherence. Students started with the "Rainbow Game," which lasts for 5 minutes. They were instructed to play the game twice during the 20-minute sessions. Two other games were available; students could play them when they had mastered the rainbow game. While practicing with the emWave, students also listened to musical tracks from the Quiet Joy CD, which is designed to promote emotional balance and physiological coherence. Progress was monitored on the system's tracking function, which records physiological coherence ratios across the various sessions.

An active control group was employed to control for changes due to the increased attention and time spent with the staff member who provided the intervention. The active placebo control used Lego building blocks to construct models of the student's choice. Lego was chosen as an active placebo because there is evidence of its efficacy as a therapeutic medium.[60] Several models and their component parts were available, and the students were allowed to complete as much of a puzzle as possible in the 20-minute sessions. There was no "pass" or "fail" element to the task, and participants were allowed to continue building the model for more than one session if necessary.

MEASURES

Cognitive function was assessed with the CDR. A selection of tasks from this computer-based assessment was presented on each testing session to allow for repeated assessment by presenting different but equivalent stimuli. All tasks are computer-controlled, the information presented on a notebook computer and the responses recorded via a response module containing two buttons, one marked "no" and the other, "yes." The tasks and corresponding measures are specific to different aspects of human cognition in order to determine a profile of cognitive efficiency for the participant. Each task is comprehensively assessed so that strategy changes cannot be misinterpreted as changes in cognitive efficiency, such as improved speed at the expense of accuracy. The test battery takes approximately 25 minutes to perform, and the tasks were administered in the following order: immediate word recall, picture presentation, simple reaction time, digit vigilance, choice reaction time, spatial working memory, numeric working memory, delayed word recall, word recognition, and picture recognition.

A signal-detection theory index of sensitivity is used for the working memory and recognition tasks to provide an overall measure of quality of recognition. This sensitivity index (SI) is calculated from formulae presented by Frey and Colliver[61] and combines the accuracy scores to the original as well as the novel (distracter) information. Thus, the sensitivity index, by combining the ability to identify previously presented items and to correctly reject items which were not previously presented, represents the overall ability of the volunteer to recognize (or be sensitive to) the task information. For all practical purposes, this score ranges from 0 to 1. A score of 1 represents perfect recognition performance—all of the previously presented items are correctly identified, and all distracters are correctly rejected as being novel. At the other extreme, a score of 0 represents chance performance or total insensitivity to the task information. In addition to the analysis of the individual measures, five combined scores based on the outcome of factor analysis are used to further characterize the data[62]: power of attention, which in everyday terms reflects levels of effortful concentration; continuity of attention, which reflects the ability of the volunteer to sustain concentration; quality of working memory, which reflects how well volunteers can maintain a string of digits in working memory by continual rehearsal and how well they can hold information about the spatial location of information in working memory; quality of episodic secondary memory, which reflects how well the volunteer can recall the words in the immediate and delayed word recall tasks, as well as how well they can correctly recognize the same words, and correctly recognize the pictures. This factor thus reflects the ability to store, hold, and retrieve information of an episodic nature (eg, an event, a name, an object, a scene, an appointment), and speed of memory, the fifth score, reflects the time it takes to correctly decide whether or not an item is held in working memory or to correctly decide whether or not an item is held in episodic secondary memory. CDR Ltd designed a version specifically for children for a study investigating the impact of not eating breakfast on learning,[63] which was also used in a large international trial with child participants investigating psychotropic drugs for epilepsy.[64]

The CDR test battery was administered by the adult learning assistants and the data independently analyzed and validated by CDR Ltd on a double-blind basis. Cognitive function was assessed three times in a group of 22 students who first completed a 6-week period interacting with Legos (active placebo) and then participating in the HM intervention (group 1). The assessments were conducted prior to the start of the intervention (time 1, or baseline), again 6 weeks later after completing the Lego sessions (time 2), and again 6 weeks later after completing the HM training (time 3). An additional 14 students (group 2) participated only in the HM training sessions. The CDR assessment was completed twice, pre- and postintervention. To ensure external validity of the testing, four training sessions on the CDR test were completed by each student within 2 weeks before the time 1 assessment.

The Strengths and Difficulties Questionnaire (S11-16 and T 4-16) was the primary secondary measure and is widely used to determine the emotional well-being of children. It collects information on 25 attributes, both positive and negative, which are divided between five scales: emotional symptoms, conduct problems, hyperactivity/inattention, peer relationships, and prosocial behavior.[7] This questionnaire was completed by the students and teacher. The scores from the various scales were combined to establish an overall "Difficulties" score and a prosocial behavior score.

Discussions with educational psychologists and pastoral staff in the schools resulted in a decision not to capture quantitative data from parents. The view was that the researcher was likely to gain more information if this was approached in an informal way. Therefore, parents were not asked to complete a formal rating scale but were provided feedback on observed changes in behavior at home. The secondary outcome data relating to behavior were seen as enriching the investigation and offering suggestions for further research.

TABLE 1 Between-groups Analysis of Covariance (ANCOVA), Baseline Adjusted Before-After Change

	HM (n=14)		Active Control (n=21)		Group Effect	
	Adj Mean Change	SE	Adj Mean Change	SE	F	*P* <
Immediate word recall	5.49	3.85	5.87	3.12	0.01	ns
Delayed word recall	8.80	4.07	9.37	3.31	0.01	ns
Word recognition, speed	-20.30	51.59	-20.23	41.65	0	ns
Word recognition, sensitivity	0.25	0.05	0.03	0.04	11.23	.01
Picture presentation, speed	-31.48	46.93	22.10	38.20	0.77	ns
Picture presentation, sensitivity	0.01	0.06	0.01	0.05	0	ns
Power of attention	-6.84	31.91	43.98	25.82	1.47	ns
Continuity of attention	0.40	2.37	-1.51	1.94	0.39	ns
Quality of episodic secondary memory	45.30	13.84	19.24	11.25	2.09	ns
Quality of verbal episodic secondary memory	43.18	10.15	16.61	8.18	3.91	.057
Quality of working memory	0.03	0.06	0.10	0.05	0.72	ns
Speed of memory	-152.37	118.36	-180.49	95.59	0.03	ns

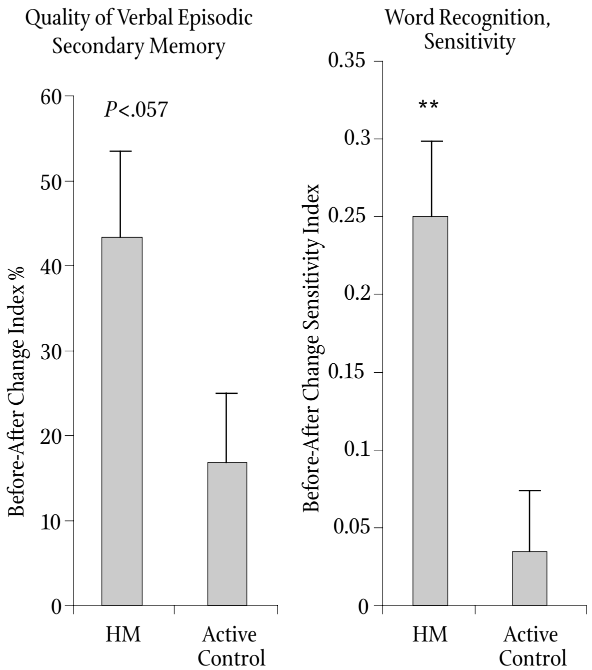

FIGURE 1 Between-groups Analysis of Covariance (ANCOVA) (Post-study Adjusted Means)

RESULTS

The comparison between group 1 (active control) and group 2 (HM intervention) was analyzed by analysis of covariance (ANCOVA) with group as a fixed factor and baseline measurement as the covariate. Each CDR cognitive function measure was assessed individually.

The data for group 1 were subject to a mixed-model repeated measures analysis of variance (ANOVA), with the successive assessment visits fitted as a fixed factor and the subjects as a random factor. Where a main effect of assessment visits was identified, *t*-tests on the differences of least square means between the three assessment visits were conducted to identify where the differences lay.

The data for group 2 were combined with the equivalent sessions for the 21 children in group 1 and were subjected to a split-plot repeated measures mixed-model ANOVA. Assessment visits (pre- and post-), group (active control, HM intervention), and the interaction between were fitted to the ANOVA as fixed factors, and the subjects as a random factor. Depending on the significance of the fixed effects, appropriate comparisons between the groups and assessment visits were made to identify the nature of any effects. For all assessments, the 5% level of significance was adopted, and 2-tailed testing was applied.

Between-groups comparisons (ANCOVA) are shown in Table 1 and Figure 1. There were two notable findings. There was a significant difference in word recognition sensitivity (P<.01) and a marginally significant difference in quality of verbal episodic secondary memory (P<.057), where the HM group performed better on both assessments.

Table 2 and Figure 2 show the results for the repeated measures ANOVA for group 1. There were no significant differences between before and after the 6 weeks of Lego sessions. There were significant differences after the 6 weeks of HM intervention sessions. Delayed word recall (long-term memory) (P<.01), immediate word recall (short-term memory) (P<.01), and quality of verbal episodic memory (P<.01) all improved.

TABLE 2 Active Waiting Control Group Mixed Model Repeated Measures ANOVA (n=21)

	Least Squares Means						Differences of Least Squares Means							
	Before Lego		After Lego/Before HM		After HM		Before-After Lego				Before-After HM			
	Mean	SE	Mean	SE	Mean	SE	Mean Diff	SE	t	*P* <	Mean Diff	SE	t	*P* <
Delayed word recall	22.54	4.02	30.79	4.02	42.54	4.02	8.25	4.25	1.94	ns	11.75	4.25	2.77	.01
Immediate word recall	38.10	3.43	42.54	3.43	52.70	3.43	4.44	3.65	1.22	ns	10.16	3.65	2.79	.01
Word recognition, sensitivity	0.63	0.05	0.64	0.05	0.72	0.05	0.01	0.05	0.15	ns	0.08	0.05	1.50	ns
Word recognition, speed	877.34	39.95	882.35	39.95	877.58	39.95	5.01	44.23	0.11	ns	-4.77	44.23	-0.11	ns
Picture presentation, sensitivity	0.71	0.06	0.73	0.06	0.67	0.06	0.02	0.06	0.31	ns	-0.06	0.06	-0.98	ns
Picture presentation, speed	940.03	39.95	976.42	39.95	954.16	39.95	36.39	42.53	0.86	ns	-22.26	42.53	-0.52	ns
Quality of episodic secondary memory	189.36	13.76	206.35	13.76	229.53	13.76	16.98	12.82	1.32	ns	23.18	12.82	1.81	ns
Quality of verbal episodic secondary memory	120.31	10.31	133.97	10.31	163.81	10.31	13.65	9.53	1.43	ns	29.85	9.53	3.13	.01
Power of attention	1296.61	34.11	1348.27	34.11	1321.10	34.11	51.66	32.95	1.57	ns	-27.17	32.95	-0.82	ns
Continuity of attention	75.27	2.66	73.65	2.66	74.52	2.66	-1.62	1.95	-0.83	ns	0.87	1.95	0.45	ns
Quality of working memory	1.53	0.09	1.63	0.09	1.57	0.09	0.09	0.11	0.85	ns	-0.06	0.11	-0.52	ns
Speed of memory	3358.92	107.22	3264.33	107.22	3288.32	107.22	-94.60	84.20	-1.12	ns	23.99	84.20	0.28	ns

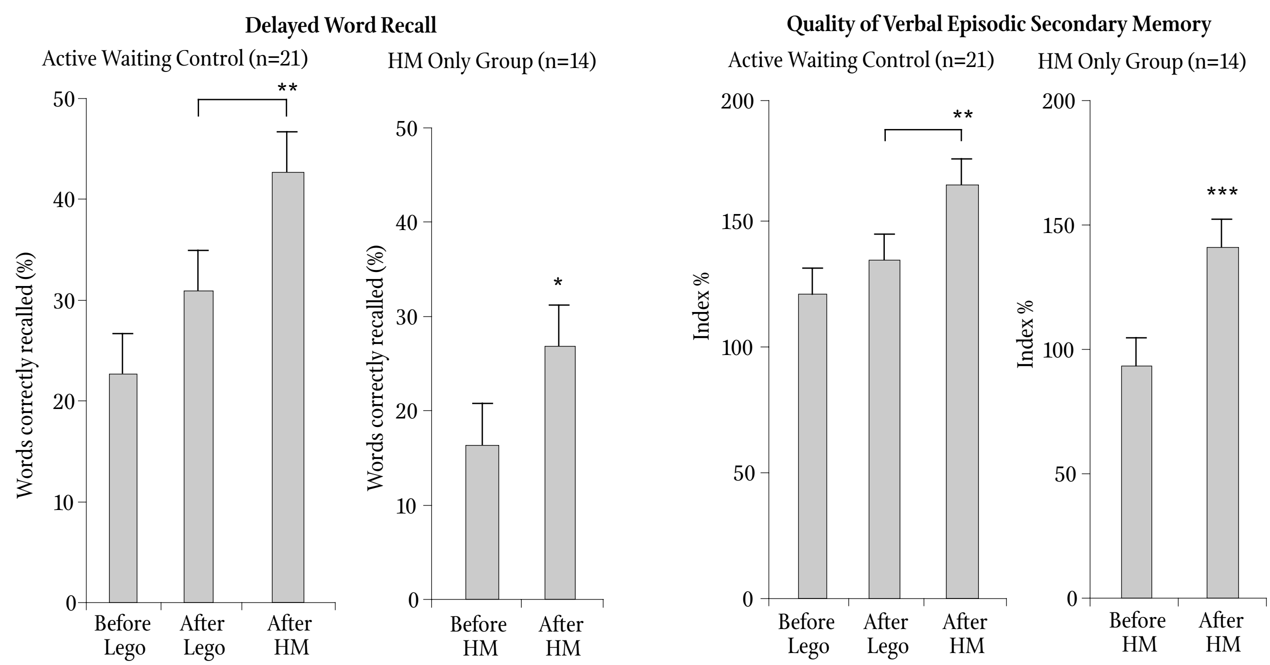

FIGURE 2 Active Waiting Control Group vs HM Only Group Mixed Model Repeated Measures Analysis of Variance

In the mixed-model ANOVA for group 2, there were also significant differences after the HM intervention sessions. Delayed word recall ($P<.05$), word recognition sensitivity (speed and accuracy) ($P<.001$), quality of episodic secondary memory ($P<.001$) and quality of verbal episodic secondary memory ($P<.001$) all improved (Table 3 and Figure 2).

Table 4 shows the mixed-model ANOVA results for the combination of students from groups 1 and 2 who participated in the HM intervention. There were significant differences after the HM intervention. Delayed word recall ($P<.01$), immediate word recall ($P<.01$), word recognition sensitivity ($P<.001$), quality of episodic secondary memory ($P<.001$) and quality of verbal episodic secondary memory ($P<.001$) all improved.

An analysis of the of the Strengths and Difficulties Questionnaire for differences between groups 1 and 2 (Mann-Whitney U test) found significant differences in difficulties scores in both student- ($P=.044$) and teacher- ($P=.001$) reported data sets (data not show). There was a positive trend that did not reach significance in pro-social scores.

Qualitative data from participants, teachers, and parents were collected to inform the researchers of potential effects not captured in the formal measures and to help identify unexpected outcomes or trends.

Interviews were conduced with 32 parents. Without excep-

TABLE 3 HM Intervention Group Mixed Model ANOVA (n=14)

	Before HM		After HM		Paired Difference			
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**t**	***P*<**
Delayed word recall	16.19	4.43	26.67	4.43	10.48	5.05	2.07	.05
Immediate word recall	32.38	3.85	40.00	3.85	7.62	4.79	1.59	ns
Word recognition, sensitivity	0.49	0.06	0.77	0.06	0.29	0.06	4.46	.001
Word recognition, speed	1001.39	53.30	943.24	53.30	-58.16	54.22	-1.07	ns
Picture presentation, sensitivity	0.77	0.07	0.77	0.07	0.00	0.05	-0.05	ns
Picture presentation, speed	1009.90	53.08	956.97	53.08	-52.92	65.74	-0.81	ns
Quality of episodic secondary memory	167.85	15.36	216.55	15.36	48.70	12.30	3.96	.001
Quality of verbal episodic secondary memory	92.85	11.19	140.48	11.19	47.62	11.26	4.23	.001
Power of attention	1393.44	45.51	1375.08	45.51	-18.37	41.08	-0.45	ns
Continuity of attention	74.45	3.04	75.02	3.04	0.57	2.60	0.22	ns
Quality of working memory	1.51	0.11	1.55	0.11	0.04	0.12	0.34	ns
Speed of memory	3797.03	167.73	3515.82	167.73	-281.21	145.91	-1.93	ns

TABLE 4 All HM Intervention Participants Mixed Model ANOVA (n=35)

	Before HM		After HM		Paired Difference			
	Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**t**	***P*<**
Delayed word recall	23.49	2.86	34.60	2.86	11.11	3.26	3.41	.01
Immediate word recall	37.46	2.49	46.35	2.49	8.89	3.10	2.87	.01
Word recognition, sensitivity	0.56	0.04	0.75	0.04	0.18	0.04	4.4	.001
Word recognition, speed	941.87	34.41	910.41	34.41	-31.46	35.00	-0.9	ns
Picture presentation, sensitivity	0.75	0.04	0.72	0.04	-0.03	0.03	-1.07	ns
Picture presentation, speed	993.16	34.26	955.57	34.26	-37.59	42.43	-0.89	ns
Quality of episodic secondary memory	187.10	9.91	223.04	9.91	35.94	7.94	4.53	.001
Quality of verbal episodic secondary memory	113.41	7.23	152.14	7.23	38.73	7.27	5.33	.001
Power of attention	1370.86	29.37	1348.09	29.37	-22.77	26.52	-0.86	ns
Continuity of attention	74.05	1.96	74.77	1.96	0.72	1.68	0.43	ns
Quality of working memory	1.57	0.07	1.56	0.07	-0.01	0.08	-0.09	ns
Speed of memory	3530.68	108.27	3402.07	108.27	-128.61	94.19	-1.37	ns

tion, all stated they had seen improvements in their children's behavior at home. Surprisingly, all of the parents commented that there had been improvements in their children's sleep patterns. The feedback from both teachers and parents indicated that improvements in behavior were more evident after the HM intervention. Some of the parents noted that their child continued to practice the Lock-In technique after they had finished the program.

Of the children who participated, 37 stated they enjoyed the sessions, and 32 children said they continued to practice the HM Lock-In technique when asked 3 months after the training was completed. Of the nine primary school students who participated in the study, two were able to discontinue all medication use within 12 months. No data on changes in medication was available for the secondary school participants.

Limitations

The self-reported questionnaire assessments of student behaviors completed by teachers and by pupils are subject to demand characteristics and multiple uncontrollable variables such as the culture of the school or adverse life events for the children participating in the study. Also the extent to which teachers in a secondary school context can truly know a child when they have limited contact inevitably undermines the validity of the questionnaires. However, the reduction in behavioral difficulties scores of 12% employing Strengths and Difficulties Questionnaires after a period of only 6 weeks was beyond the expectations of this study.

Unfortunately, there was inconsistency across the school sites relating to the capture of data on HRV coherence, and it was not possible to assess whether a correlation existed between the changes in individual coherence scores and cognitive function scores. Thus, the correlation between improved cognitive function and HRV can only be inferred but was not proven. However, a study involving 18 adult subjects conducted by CDR Ltd/Bradford et al prior to this study identified a correlation between HRV coherence and improved cognitive functioning.[58] However, the results that were properly captured did indicate a large increase in coherence after HM training.

DISCUSSION

There is a growing consensus among health and education practitioners that emotional regulation underpins intellectual development and academic attainment, ensuring an upward developmental trajectory extending beyond school. Cooper supports this view by emphasizing that without diversity and flexibility in the provisions for special-educational students' needs, children will increasingly be pathologized with educational pedagogy.[65] The HM intervention is intended to help reset physiological and behavioral set points, potentially offering a more efficient behavioral change agent than other methods typically employed in the classroom.

The results of the investigation were significantly beyond what was expected. We did not expect to find such large gains in cognitive functions. The data also show that these improvements were not gained at the expense of speed. Moreover, questionnaire data from teachers indicated a significant reduction in difficult behaviors. Further solidifying students' self-regulation was their use of the Lock-In technique at home. In addition, parents who learned and practiced the techniques along with their children reported personal benefits themselves.

The findings of this study suggest that the HM system offers a unique intervention for building psychophysiological resilience leading to improved cognitive function and self-regulation of behaviors and offers a compelling case for future research to investigate the potential efficacy of these techniques and technology for improving cognitive functioning and behaviors for children who do not experience learning difficulties such as ADHD. The findings also suggest that a larger study to evaluate the efficacy of this system in students with ADHD would be of value. We suggest future studies include ADHD subtypes and include controls to assess if certain aspects of the HM system (heart-focused breathing, self-activation of positive emotions, HRV coherence feedback—or the synergy between them) provide the primary benefits.

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