ORIGINAL ARTICLE

The Impact of Cardiac Coherence on Executive Functioning in Children With Emotional Disturbances

心力凝聚性对受情感干扰儿童的执行功能的影响

El impacto de la coherencia cardiaca sobre el funcionamiento ejecutivo en niños con trastornos emocionales

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ABSTRACT

Objective: We used archival data originally collected using a quasi-experimental design to analyze inhibition, emotional regulation, working memory, and cognitive flexibility before and after an intervention of a coherence training program incorporating heart rate variability biofeedback.
Method: Sixty-three participants, ages 7 to 14 years, were involved in the study: 30 in the treatment group and 33 in the control group. Split-plot analysis of variance (SPANOVA) was used to assess the impact of the intervention for the 4 dependent variables.
Results: SPANOVA yielded no significant differences among inhibition, emotional regulation, working memory, and cognitive flexibility in response to the coherence training intervention.
Conclusions: Future research in this area would benefit from the use of more objective measures of executive functioning. Qualitative assessment of child-reported symptomatology and treatment acceptability on the part of students and staff would also be an area for future research.

摘要

目的：我们使用了原来收集的库存数据，采取了类实验设计并引进了凝聚性训练干预措施，结合心率变化生物反馈在内，对引入干预措施之前和之后的压抑情绪、情感调节、工作记忆和认知灵活性进行分析。
方法：研究包括 63 名参与者，年龄为 7 至 14 岁：其中 30 名在治疗组，33 名在对照组。采用分裂区集变异数分析（SPANOVA）来评估干预措施对四个因变量的影响。
结果：SPANOVA 结果显示，凝聚性训练干预措施对压抑情绪、情感调节、工作记忆和认知灵活性并没有任何大的变化。结论：使用更为客观的执行功能办法对此领域未来的研究会有利。未来研究的另一个方面是就儿童汇报的总症状以及学生和员工对治疗的可接受性进行定性评估。

SINOPSIS

Objetivo: utilizamos datos de archivo recopilados originalmente usando un diseño cuasiexperimental para analizar la inhibición, la regulación emocional, la memoria funcional y la flexibilidad cognitiva antes y después de la intervención mediante un programa de adiestramiento de coherencia que incorpora bioretroalimentación de la variabilidad de la frecuencia cardiaca.
Método: se incorporaron al estudio sesenta y tres participantes con edades comprendidas entre 7 y 14 años de edad: 30 en el grupo del tratamiento y 33 en el grupo de control. Se utilizó un análisis de varianza de parcela dividida (Split-Plot Analysis of Variance, SPANOVA) para evaluar el impacto de la intervención para las cuatro variables dependientes.
Resultados: el SPANOVA no sacó a relucir diferencias significativas entre la inhibición, la regulación emocional, la memoria funcional y la flexibilidad cognitiva en respuesta a la intervención de adiestramiento de coherencia. Conclusiones: las investigaciones futuras en esta área se beneficiarían del uso de mediciones más objetivas de funcionamiento ejecutivo. La evaluación cualitativa de la sintomatología notificada por el niño y la aceptabilidad del tratamiento por parte de los estudiantes y el personal podrían ser también un área para futuras investigaciones.

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INTRODUCTION

Emotions are believed to have a direct influence on physiological and cognitive processes.[1] According to cardiac coherence theory, heart rate variability (HRV) is both a marker and a remediation source for the cognitive processes collectively called executive functioning. Executive functioning is responsible for emotional regulation, inhibition, attention, concentration, and other functions associated with the planning and execution of goal-directed behaviors.[1]

Coherence training involves teaching specific skills to induce positive emotions, breathing patterns, and HRV biofeedback to improve an individual's self-control.[2-3] Cardiac coherence theory suggests that when individuals engage in coherence techniques, parasympathetic influences via the vagal nerve can balance the influence of the autonomic nervous system (ANS) on the heart and the frontal cortex. HRV, which is the naturally occurring beat-to-beat changes in heart rate, can be used as an index of heart-brain interactions and as a measure of the regulation of emotional and cognitive functioning.[1-4] The flow of neurotransmitters moderates communication between the heart and the prefrontal cortex of the brain by means of efferent (descending) and afferent (ascending) pathways. These pathways are referred to as the sympathetic and parasympathetic branches of the ANS. These parasympathetic and sympathetic pathways are involved in cognitive and emotional processing and regulation.[5]

Measures of HRV can detect negative emotions, such as frustration and anxiety, through a recording of incoherent heart-rhythm patterns. Negative emotions have played a vital role in the evolution of humans by inducing heightened sympathetic arousal, leading to "fight-or-flight" responses.[6] Although heightened arousal can serve a protective purpose, prolonged sympathetic arousal has been associated with higher mortality rates and decreased cognitive performance.[1] An irregular heart-rhythm pattern indicates that the 2 branches (parasympathetic and sympathetic) of the ANS are not adequately balanced or coherent. Conversely, positive emotions such as appreciation or compassion create a smooth heart-rhythm pattern, indicating that the 2 branches of the ANS are in a state of optimal order or coherence.[7]

This research study sought to extend the understanding of coherence theory by elucidating whether self-induced coherence with HRV biofeedback does indeed improve specific areas of executive functions including inhibition, emotional control, cognitive flexibility and working memory in a sample of students classified with an emotional disturbance (ED). Students classified with an ED represented more than 7% of all US public school students classified with a disability. Recent data indicate that there are more than 374 000 US students classified with an ED.[8] Students with an ED have problems with social behavior, aggression, inappropriate social skills, acting-out behaviors in class, and difficulty responding to discipline from teachers and administrators. Students are classified as having an ED when they show one or more of the following characteristics over a long period of time and to a marked extent, adversely affecting educational performance: (1) an inability to learn that cannot be explained by intellectual, sensory, or health factors; (2) an inability to build or maintain satisfactory interpersonal relationships with peers and teachers; (3) inappropriate types of behavior or feelings under normal circumstances; (4) a general pervasive mood of unhappiness or depression; or (5) a tendency to develop physical symptoms or fears associated with personal or school problems.[9] ED encompasses all mental health issues under an umbrella category including, but not limited to, mood disorders such as depression or bipolar disorder and thought disorders such as schizophrenia.

According to cardiac coherence theory, HRV is a marker for and remediation source for executive functioning. By providing specificity to the understanding of which executive functions are amenable to change through coherence training, psychological and medical practitioners may be able to make more targeted and cost-effective decisions regarding treatment methods. Furthermore, educators who work with students with ED may be able to utilize a cost-effective method for teaching students self-regulation strategies rather than using the many external-based interventions often used in schools to manage behaviors.

METHODS

Overview of Study Design

This study analyzed archival data collected using nonequivalent control groups. The archival data consisted of pretest-posttest data regarding inhibition, emotional regulation, working memory, and cognitive flexibility after an intervention of a cardiac coherence training program incorporating HRV biofeedback among children ages 7 to 14 years. The archival data were initially obtained through a joint research study conducted in south-central Pennsylvania by Lincoln Intermediate Unit 12, an educational agency serving public and private schools, and Millersville University. Investigators studied a nonrandom sample of children ages 7 to 14 years to evaluate the success of a 12-week cardiac coherence training intervention. The original research study design was a quasi-experimental, nonequivalent control group design with pre- and post-tests. The HeartMath emWave desktop HRV biofeedback program (Institute of HeartMath, Boulder Creek, California) was chosen to assess the efficacy of a coherence training program on the self-regulation of emotionally disturbed children in emotional support classrooms run by one of the educational agencies. A measure of HRV biofeedback produced data on participants' ability to achieve cardiac coherence representing increased synchronization in the ANS.

Participants

This study used archival data from a selected sample of 63 central Pennsylvania public school students classified with an educational diagnosis of an ED who were receiving emotional supports during the 2011-2012 and 2012-2013 school years. This population was selected by the original researchers for study due to an increased level of behavioral and emotional dysregulation diagnosed in each participant relative to typical public school students. The population of interest ranged in grade from first grade through eighth grade attending public elementary and middle schools. A total of 6 classrooms located in 4 different school districts and 2 partial hospital settings were included in the study: 2 emotional support classes in different public schools, 2 therapeutic emotional support classes in different public schools, and 2 partial hospitalization program classes outside of a public school. One partial hospital setting, 1 therapeutic emotional support class, and 1 emotional support class comprised the treatment group and the other 3 classrooms made up the control group. Choice of classrooms for the treatment groups were based on teacher willingness to have the coherence training program occur. The age range of the archival sample was between 7 and 14 years. Of the 63 students in the sample, 55 (87%) were male and 8 (13%) were female.

Intervention

The intervention began in December 2012 for the treatment group. Participants in the treatment group received twelve 20-minute sessions over 12 weeks. During the sessions, participants were trained to generate a positive emotion, such as love, compassion, or appreciation, in order to initiate a distinct shift to coherence in the heart's pattern of rhythmic activity. The strategies involved shifting the focus of attention to the area around the heart and breathing easily and slowly as if breathing through the chest area for 5 to 10 minutes. In addition, the participants learned to evoke a positive emotion while participating in the focused heart breathing activity. The emWave desktop computer program was introduced to help participants achieve coherence. During the emWave sessions, students received real-time visual feedback of their coherence levels via a noninvasive pulse sensor that was attached to the earlobe. The control group was not exposed to the coherence training including HRV biofeedback. They were provided with their typical daily academic instruction and social skills groups, including group counseling sessions with the emotional support teachers and role-plays of various social scenarios such as turn-taking, sharing, and empathic responding.

Data Collection

Executive function was assessed by the Behavior Rating Inventory of Executive Function (BRIEF). The BRIEF forms were completed by the teachers in both the treatment and control classrooms approximately 1 week prior to the commencement of the intervention phase and 1 week post-intervention. We analyzed 4 subscales of the BRIEF: (1) the Inhibit subscale; (2) the Working Memory subscale; (3) the Emotional Control subscale; and (4) the Shift subscale. The BRIEF was initially derived from a need to gather teacher and parent observations of children's executive functioning within the home and school setting in a systematic and efficient method.[10] It is an 86-item Teacher Form that uses a 3-point Likert scale (never, sometimes, often) to quantify a full range of executive functions observed in children aged 5 to 18 years. The BRIEF yields an overall Global Executive Composite (GEC) score, which consists of the Behavior Regulation Index (BRI) and the Metacognitive Index (MI). Four subscales, including Inhibit, Emotional Control, Shift, and Self-Monitor comprise the BRI. The MI consists of 5 subscales, including the Initiate, Working Memory, Plan/Organize, Organization of Materials, and the Self-Monitor. Subscale scores 65 or higher indicate executive functioning deficits.

The BRIEF has been found to be reliable and valid.[10] The Inhibit subscale is made up of 10 questions, and assesses a student's ability to control behavior and avoid acting upon impulse. The Emotional Control subscale, made up of 9 items, measures the student's emotional regulation in a variety of situations. The Shift subscale consists of 10 items and assesses cognitive flexibility. The Working Memory subscale, made up of 10 items, measures a student's ability to hold information such as numbers or words in mind for a short period of time prior to and while in the process of manipulating them.[11]

Data Analysis

A split-plot analysis of variance (SPANOVA) was used to analyze the archival data. The SPANOVA was conducted using the general linear model (GLM) procedure in SPSS (version 21; IBM, Armonk, New York) to analyze between-factor (treatment group vs control group) and within factor (pretest vs posttest) effects on the 4 dependent variables including inhibition, emotional control, working memory, and cognitive flexibility. The assumptions of SPANOVA, including normal distribution, linearity, and equal variances, were analyzed utilizing inferential statistical software to determine if they were met. All 4 dependent variables were normally distributed. All tests were 2-tailed, with an alpha significance level of .05.

In order to achieve an adequate level of power for this study, an a priori power analysis was conducted using G*Power 3.1.[11] Using the F-test for repeated-measures, within- and between-group ANOVA, with two measurements, a medium effect size of .30, an alpha of .05, and a power of .80, the minimum sample size for each group was 24. Based on this power analysis, a total of 48 participants were needed for this study.

Results

The Table shows the mean BRIEF subscale scores for the treatment and control groups. There were no statistically significant changes between pretest and posttest within the intervention or control group on all subscales: Inhibition (P=.63), Emotional Regulation (P=.72), Working Memory (P=.59), and Cognitive Flexibility (P=.32). Furthermore, SPANOVA analyses showed no statistically significant differences between the participants who did and did not receive cardiac coherence training over the 12-week intervention period: Inhibition (P=.97), Emotional Regulation (P=.84), Working Memory (P=.79), and Cognitive Flexibility (P= .42).

DISCUSSION

The acceptance of the null hypothesis for all 4 research questions is consistent with the cardiac coherence literature. Previous research reported efficacy in improving inhibition and cognitive flexibility in typically developing children but not in children and adolescents with severe executive dysfunction.[12] Although efficacy has been reported in the literature regarding coherence training improving test anxiety, studies have not provided evidence of general self-reg-

Table BRIEF Subscale Scores Pre- and Post-Intervention

Measure	Group	No.	Pre-test		Post-test		Change	
			Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Inhibition	Treatment	30	71.2 (14.2)	[45, 101]	70.3 (15.4)	[44, 124]	–1.0 (15.2)	[–34, 46]
	Control	33	67.6 (13.7)	[42, 99]	66.8 (15.3)	[43, 96]	–0.8 (14.1)	[–42, 36]
Emotional regulation	Treatment	30	76.1 (17.2)	[48, 114]	75.1 (18.6)	[45, 113]	–0.8 (16.1)	[–32, 33]
	Control	33	70.7 (14.5)	[45, 101]	70.4 (16.2)	[45, 103]	–0.3 (11.5)	[–27, 25]
Working memory	Treatment	30	69.5 (12.4)	[45. 90]	69.0 (14.4)	[43, 97]	–0.5 (13.0)	[–17, 29]
	Control	33	66.7 (14.8)	[38, 101]	65.1 (16.4)	[38, 101]	–1.6 (17.0)	[–56, 44]
Cognitive flexibility	Treatment	30	76.5 (14.9)	[57, 126]	73.1 (16.4)	[47, 114]	–3.4 (13.7)	[–35, 24]
	Control	33	73.7 (14.2)	[45, 101]	73.4 (18.1)	[49, 126]	–0.3 (16.1)	[–30, 36]

Abbreviation: BRIEF, Behavior Rating Inventory of Executive Function.

ulation or mood and behavior as assessed on the BRIEF.[13-14] Evidence of improving working memory in children and adults in response to cardiac coherence training was not evaluated in the research.[15-16]

The effects of cardiac coherence training augmented with HRV biofeedback on aspects of executive functioning are not fully understood. Theoretically, cardiac coherence training can indirectly influence the ANS to induce optimal HRV necessary to fully regulate the self.[7,17] However this does not explain the effect of cardiac coherence training on specific aspects of executive functioning. New research in this area has been exemplified by inconsistencies in cardiac coherence training's effect on the executive functions. Coherence training studies have shown efficacy in reducing anxiety and in improving immediate emotional self-regulation.[14,18,19] However, despite the literature showing a clear association between HRV and executive functioning, the evidence thus far and the results of our study do not support the hypothesis that cardiac coherence training augmented with HRV biofeedback has a positive impact on specific aspects of executive functions in children with severe emotional disorders.[1,13,15]

Our study has several important limitations. This was a secondary data analysis of a quasi-experimental study design. Participants were not carefully selected based on specific inclusion and exclusion criteria. There was a wide age-range in the archival sample (7-14 y of age) and consequent range of cognitive and emotional development. The treatment and control groups were not selected by randomization. Data are not available to compare the 2 groups on many sociodemographic and educational characteristics. While the data did include gender, the small minority of females (13%) precluded assessing gender as a predictor variable.

Data collection with a school setting can be challenging, considering that the researcher must contend with rigid school schedules, including lunch, recess, test-tasking, assemblies, inclement weather, vacations and sick days. The end of a school year adds even more confounders including high-stakes testing, increased frustrations on the part of students, and a general decline in motivation and concentration levels as the seasons of spring and summer approach. The months of April and May are typically noted as months when school students experience more pronounced emotional and behavioral problematic behaviors.[20] There were increased distractions in the school schedule during the time of the study, including administration of Pennsylvania State School Assessments, which occurred during at least part of each school day for a 2-week period in March 2013. A more desirable time in the school year to conduct research would have been during the fall prior to the distractions that come with the Christmas and New Year holidays.[21]

Parent and teacher rating measures of executive function such as the BRIEF occur in the natural environment and are rated under the context of a lengthier duration of time.[22] Using more sensitive performance-based measures of executive functioning in the areas of inhibition, working memory, and cognitive flexibility and administering them immediately before and after cardiac coherence training with HRV biofeedback may have yielded different results. The executive functioning literature is at odds as to what are the most sensitive measures to assess and detect changes in aspects of executive function.[23,24] The original study utilized the BRIEF teacher rating scale to assess the ecological manifestations of executive dysfunction in the areas of inhibition, working memory, emotional regulation, and cognitive flexibility. The results of the BRIEF were subjectively compiled by teacher observation of student behavior over time. Performance-based measures of executive function which require a trained certified examiner and structured optimal testing conditions may have resulted in a more direct assessment of what each student was directly capable of. Specific performance-based executive-functioning tests to measure inhibition, working memory, and cognitive flexibility include the Halstead Category Test and the Wisconsin Card Sorting Test.[25,26] Performance-based measures directly assessing emotional regulation are not well established.

Lastly, the "dose" of the intervention (ie, duration, frequency) may not have been strong enough for this population with highly severe and chronic emotional and behavioral regulation problems. Teacher data also did not sufficiently assess child perceptions of anxiety, which can also potentially affect response to treatment.

The efficacy of cardiac coherence training augmented with HRV biofeedback is an area of research that is still in new and is in need of further examination. Further study is recommended to address the limitations of this exploratory archival study. Future studies would benefit from a more rigorous design such a cluster randomized controlled trial with multiple sites and a more defined sample. Research would benefit from examining the efficacy of the intervention over a much shorter period of time with different instruments that possess greater sensitivity in assessing executive functioning. Collecting posttest data immediately after exposure to treatment may yield meaningful results given that cardiac coherence augmented with the HRV biofeedback may have a more short-term effect on executive functioning performance. More objective performance-based measures of executive functioning would add greater reliability and potential sensitivity to the data. Assessment of treatment acceptability would also be useful using qualitative approaches such as questionnaires and interviews. Qualitative methodology may also assess children's perceptions of anxiety and emotional regulation, which are not easily accounted for through teacher rating scales.

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