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The Effectiveness of Biofeedback Using Heart Rate Variability (HRV) on Working Memory Performance in Children with Attention Deficit/Hyperactivity Disorder (ADHD)

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A B S T R A C T

Objective: The present study aimed to investigate the effectiveness of a biofeedback intervention program using heart rate variability (HRV) on working memory performance in children with Attention Deficit/Hyperactivity Disorder (ADHD).

Methods and Materials: In this quasi-experimental study, a total of 30 children aged 8 to 12 years were selected through convenience sampling from clinics and counseling centers in District 3 of Tehran during 2021-2022 and were included in the study. Participants were randomly assigned to either the experimental group (15 participants) or the control group (15 participants). The experimental group participated in 15 sessions of a biofeedback intervention program using HRV, while the control group was placed on a waiting list without receiving any intervention. The working memory performance of both groups was assessed at the pre-test and post-test stages using the n-back working memory test, introduced by Kirchner in 1958. The data were analyzed using univariate analysis of covariance.

Findings: The results indicated the effectiveness of the biofeedback intervention program using HRV on the working memory performance of children with ADHD.

Conclusion: Overall, this study provides preliminary evidence for the use of HRV biofeedback as a potential intervention to improve working memory performance in children with ADHD, although further research is needed to confirm these findings.

Keywords: *Biofeedback, Heart Rate Variability, Attention Deficit/Hyperactivity Disorder, Working Memory*

1. Introduction

Attention Deficit/Hyperactivity Disorder (ADHD) is a neurodevelopmental disorder characterized by persistent patterns of inattention, hyperactivity, and impulsivity that significantly affect an individual's functioning and daily life (Baniasadi, 2024). This disorder is one of the most common psychiatric conditions in childhood, affecting approximately 5-10% of children worldwide (Ghandomizadeh, 2023). Children with ADHD often struggle with deficits in various executive functions, including memory, attention, inhibition, cognitive flexibility, and planning, which are crucial for academic success and daily functioning (Shojaei, 2024). Based on research conducted on the cognitive abilities of this group of children, one of the primary cognitive deficits associated with ADHD is a deficiency in working memory. In other words, a deficiency in working memory can lead to academic challenges and impair various aspects of a child's daily life (Dobrakowski & Łebecka, 2020).

Working memory refers to the ability to temporarily hold and manipulate information in mind during cognitive activities (Baddeley, 2012; Li, 2024; Long et al., 2024). Given the significant impact of working memory deficits on the daily and academic performance of children with ADHD, the design and evaluation of effective interventions to improve working memory in this population have garnered considerable attention from specialists over the past decade (Pisacco et al., 2018). Traditional treatment approaches for ADHD often include pharmacological and behavioral interventions. However, there is increasing interest in exploring alternative interventions that can complement or enhance existing treatments (Doulou & Drigas, 2022).

One such intervention is biofeedback using heart rate variability (HRV), which has shown promise in improving executive functions in individuals with ADHD and has recently gained attention as a non-pharmacological approach to enhancing cognitive performance in individuals with ADHD. Biofeedback is a method that helps individuals increase their awareness and regulate their physiological functioning by receiving signals from their bodies, thereby improving their health and performance. The goals of biofeedback are threefold: awareness—increasing awareness of physiological, cognitive, and emotional processes to bring about fundamental changes; change—the ability to self-regulate depends on the capacity to make beneficial changes; and generalization—long-term progress is only possible when learned skills in the therapist's office are generalized to the daily living environment (Lehrer et al., 2020; Schoenberg & David, 2014; Tinello et al., 2022).

The goal of biofeedback skills is both to create immediate relaxation and to retrain the nervous system and brain to produce beneficial responses over the long term. One type of biofeedback is heart rate variability (HRV). Heart rate variability (HRV) refers to the variation in the time intervals between heartbeats, as with most body systems, heart rate is never constant. Our heart rate is always changing, meaning the intervals between heartbeats either increase or decrease. In simple terms, HRV reflects the rhythmic increase or decrease in heartbeats, as evidenced by the rise and fall of a sinusoidal wave. Both heart rate and blood pressure continuously play a role in maintaining the body's vital balance and restoring physiological equilibrium after disruption. When this system functions properly, the body can self-regulate and maintain balance whenever disruption occurs. When HRV decreases, the body's self-regulatory capacity is compromised. Supporting the importance of HRV, various studies have shown its significant impact on emotional well-being. Fluctuations in heart rate variability reflect the interaction between the sympathetic and parasympathetic branches of the autonomic nervous system. The sympathetic nervous system increases heart rate (Dormal et al., 2021; Eddie et al., 2015). In this method, individuals learn to regulate their heart rate using proper breathing and achieve psychophysiological coherence, which reflects effective communication between the heart and mind (Lehrer et al., 2020; Lehrer & Gevirtz, 2014; Pop-Jordanova & Chakalaroska, 2008; Prinsloo et al., 2013; Prinsloo et al., 2011).

Changes in heart rate variability are a physiological phenomenon controlled by the autonomic nervous system (sympathetic and parasympathetic) and respiration, and they can be influenced by and influence psychological factors. For example, when a person experiences anxiety and negative emotions, their heart rate variability is lower (Prinsloo et al., 2011). HRV biofeedback training leads to a balanced autonomic system and improved control over it, thereby enabling emotional regulation. Generally, high heart rate variability indicates a flexible autonomic system that responds to internal and external stimuli and is associated with rapid reaction and adaptability (Lehrer et al., 2020; Lehrer & Gevirtz, 2014). Several studies have investigated the effectiveness of HRV biofeedback in improving various executive functions, including attention and inhibition, in individuals with ADHD (Dormal et al., 2021; Eddie et al.,

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2015; Lehrer et al., 2020; Lehrer & Gevirtz, 2014; Pop-Jordanova & Chakalaroska, 2008; Prinsloo et al., 2013; Prinsloo et al., 2011; Reyes, 2014; Schoenberg & David, 2014; Tinello et al., 2022). These studies have shown promising results, suggesting that HRV biofeedback may be a valuable intervention for enhancing cognitive functions in children with ADHD.

The present study aimed to investigate the effectiveness of a biofeedback intervention program using HRV on working memory performance in children with ADHD.

2. Methods and Materials

2.1. Study Design and Participants

The present study employed a quasi-experimental design with a pre-test, post-test, and control group. The statistical population included children with ADHD in District 3 of Tehran during the 2021-2022 academic year. These children had visited psychological and psychiatric clinics and received a diagnosis of ADHD. The sample group consisted of 30 children with ADHD, selected through convenience sampling, who were then randomly divided into two groups of 15: the experimental and control groups. The experimental group received 15 sessions of HRV biofeedback training, while the control group received no intervention. All participants took part in both the pre-test and post-test, where their working memory performance was assessed using the n-back test.

2.2. Measures

2.2.1. N-Back Computerized Test

The n-back test is one of the most well-known and validated assessments of working memory, introduced by Kirchner in 1958. In this test, sequences of stimuli are presented step by step to the participant, who must determine whether the current stimulus matches the one presented one step earlier. As the number of stimuli increases, the difficulty of the task increases. In this test, the participant can compare the most recent stimulus with the previous one or the current stimulus with the stimulus from three steps earlier. The reliability coefficients of this test range from 0.54 to 0.84. Additionally, the validity coefficients range from 0.54 to 0.78, indicating acceptable validity for this test. In Iran, Taghizadeh et al. validated this test in 2014 (Bakhtiary Javan et al., 2020; Najjari Alamooti et al., 2023).

2.2.2. Visual and Auditory Continuous Performance Test

The Continuous Performance Test (CPT) is one type of continuous performance test developed by Rosvold and colleagues in 1956. In children with ADHD, the goal of this test is to assess sustained attention. The variables measured in the continuous performance test include omission errors, commission errors, and response time (reaction time) (Hadian Fard et al., 2000).

2.3. Intervention

2.3.1. HRV Biofeedback Program

HRV biofeedback is a non-pharmacological intervention that uses electronic sensors to measure physiological responses such as heart rate, respiration, and muscle tension. This method is based on the principle of operant conditioning, which involves providing feedback to individuals about their physiological responses and allowing them to learn to control these responses (Schoenberg & David, 2014). In heart rate-based biofeedback, the measure of interest is the variation in time between successive heartbeats. In fact, HRV reflects the activity of the autonomic nervous system (ANS), which regulates the body's physiological responses to stress and relaxation (Lehrer et al., 2020). HRV biofeedback has been used to improve ANS regulation in individuals with various conditions such as anxiety, depression, and chronic pain (Lehrer et al., 2020).

In the biofeedback sessions, participants were first taught how to breathe correctly and understand its importance. They were then fitted with a respiratory sensor placed on their abdomen, which provided feedback on their breathing, allowing them to practice. Next, an EKG sensor was attached to the participants' wrists to measure their heart rate, and work on heart rate variability began. Participants were trained to synchronize their breathing with the breathing graph in the software and align their breathing with their heart rate. This synchronization relaxed the participant's body and activated the parasympathetic system, increasing cardiac power and heart rate variability. Positive feedback, both auditory and visual, was provided to the participant to encourage them. In the present study, the ProComp 2 biofeedback device was used. This device, through the EKG sensor and the respiratory sensor, reflected heart rate variability to the individual via the BioGraph software.

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2.4. Data analysis

To analyze the data, descriptive statistical methods, including the examination of means, standard deviations, minimum, and maximum values, were used. Additionally, to assess the effectiveness of the intervention program, univariate analysis of covariance (ANCOVA) was employed. The collected data were analyzed using SPSS software version 22.

3. Findings and Results

In this section, the descriptive findings of the study, including the mean, standard deviation, minimum, and maximum scores of individuals in the experimental and control groups at the pre-test stage, are presented (Table 1).

Table 1

Descriptive Findings of the n-back Test by Group

Variable	Group	Stage	Mean	Standard Deviation	Minimum	Maximum
Working Memory	Experimental	Pre-test	42.26	22.28	14	85
		Post-test	87.86	12.24	63	100
	Control	Pre-test	38.20	17.54	16	71
		Post-test	39.53	17.32	15	68

As shown in Table 1, in the working memory test, the difference between the pre-test and post-test means in the experimental group is significant. Therefore, a univariate analysis of covariance was conducted to examine the significance of the observed differences and the effectiveness of the biofeedback intervention program using heart rate variability on working memory performance in children with Attention Deficit/Hyperactivity Disorder (ADHD).

Table 2

Findings from the Analysis of Covariance for the Working Memory Variable

Scale	Type III Sum of Squares	Degrees of Freedom	F Ratio	p Value	Partial Eta Squared	Power
Pre-test	2723.84	1	20.55	.001	0.43	0.99
Group	15925.26	1	120.18	.001	0.81	1.00
Error	3577.61					

As shown in Table 2, considering the pre-test scores as a covariate, the biofeedback intervention program using heart rate variability resulted in a significant difference between the experimental and control groups in working memory performance ($p = .001$), with a partial eta squared of 0.81 and a power of 1.00. The biofeedback intervention using heart rate variability had a significant positive effect on the working memory performance of the experimental group in the n-back test ($F(1,1) = 120.18$, $p = .001$, $\eta^2 = 0.81$).

4. Discussion and Conclusion

The present study aimed to investigate the effectiveness of biofeedback using heart rate variability (HRV) on working memory performance in children with Attention Deficit/Hyperactivity Disorder (ADHD). The findings of this study align with previous research, demonstrating that a biofeedback intervention program using heart rate variability can significantly improve the working memory performance of children with ADHD (Anastopoulos et al., 2011; Sjöwall et al., 2013; Spencer et al., 2011).

The results of this study are consistent with previous research (Lehrer et al., 2020; Lehrer & Gevirtz, 2014; Prinsloo et al., 2013; Prinsloo et al., 2011). Lehrer and Gevirtz (2014) stated that HRV biofeedback is a method that, by teaching individuals to control their physiological responses, can lead to improved cognitive performance (Lehrer & Gevirtz, 2014). This is particularly relevant for children with ADHD, who often struggle with working memory deficits (Kasper et al., 2012). Additionally, several studies have examined the effectiveness of HRV biofeedback on working memory performance in children with ADHD. For instance, a study by Prinsloo et al. (2013) found that HRV biofeedback training led to significant

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improvements in working memory performance in children with ADHD. This study suggested that HRV biofeedback may strengthen working memory by improving the regulation of the autonomic nervous system (ANS), thereby enhancing cognitive performance (Prinsloo et al., 2013). Furthermore, Lehrer et al. (2020) found that children with ADHD who underwent HRV biofeedback training showed significant improvements in working memory tasks compared to the control group. These researchers suggested that HRV biofeedback might improve working memory by increasing the balance between sympathetic and parasympathetic activity, resulting in enhanced cognitive performance (Lehrer et al., 2020).

In explaining these findings, it can be noted that the improvement in working memory performance observed in these studies may be attributed to HRV biofeedback's potential to modulate the autonomic nervous system (ANS), which plays a critical role in cognitive functions, including working memory. By learning to control heart rate variability, children with ADHD may be able to better regulate their executive functions, leading to improved working memory performance as one of the components of executive functions. A systematic review and meta-analysis by Dormal et al. (2021) evaluated the effectiveness of HRV biofeedback on the performance of children and adolescents. These researchers assessed the effectiveness of this intervention across various domains and demonstrated its effectiveness in the daily lives of children and adolescents (Dormal et al., 2021). More specifically, Tinello et al. (2022) conducted a systematic review on the effectiveness of HRV biofeedback on executive functions. The findings of this systematic review also demonstrated the positive impact of HRV biofeedback (Tinello et al., 2022).

However, it is important to note that while the results of these studies are promising, given the novelty of this field in treating and improving executive functions, further research is needed to confirm these findings and examine the long-term effects of HRV biofeedback on working memory performance in children with ADHD. Future studies should consider the potential influence of other factors such as age, gender, and the severity of ADHD symptoms on the effectiveness of HRV biofeedback.

Thus, it can be concluded that this study and similar studies provide preliminary evidence that HRV biofeedback can be an effective intervention for improving working memory performance in children with ADHD. In other words, non-pharmacological and non-physiological interventions may be effective in managing cognitive deficits associated with ADHD. However, it is essential to conduct more research to fully understand the underlying mechanisms of this improvement and determine the long-term effects of HRV biofeedback. Additionally, individual differences in response to biofeedback should be considered in future research. Consequently, while this study provides promising evidence for the use of HRV biofeedback in improving working memory in children with ADHD, further research is needed to confirm these findings and explore the potential of this intervention in a broader context.

5. Limitations & Suggestions

There were some limitations in this study that should be acknowledged. The sample size of the study was relatively small, which limits the generalizability of the findings. Larger sample size studies are needed to confirm these results and explore potential differences in response to HRV biofeedback among children with ADHD. Moreover, this study was limited in its duration and lacked the possibility of long-term follow-up due to time constraints and lack of participant cooperation. Therefore, it remains unclear whether the improvements in working memory are sustained over time and whether continued HRV biofeedback is necessary to maintain these improvements in memory. As a result, while this study provides valuable insights into the potential benefits of HRV biofeedback for children with ADHD, these limitations should be addressed in future research to provide a more comprehensive understanding of this intervention.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed in this article.

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