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Research Article

Strengthening Executive Functions in ADHD through the Brain Benefit Movement (BBM): A Narrative Review and Pilot Study

Aram Cargill*

Change Challenge and the Adaption, Apex lab, Australia.

Corresponding Author Information

Aram Cargill

Change Challenge and the Adaption, Apex lab, Australia.

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ABSTRACT

Background: The cerebellum's role has historically been confined to motor control. However, recent evidence suggests it is involved in cognitive processes and emotional regulation (e.g.,[1,2]), leading to the hypothesis that the cognitive and emotional challenges associated with attention deficit hyperactivity disorder (ADHD) may also be linked to cerebellar dysfunction.

Objective: This paper aims to 1) synthesize the current literature on the cerebellum's role in executive functions and emotional regulation and to examine the evidence supporting cerebellar exercises, mindfulness, and biofeedback as potential interventions for improving ADHD symptoms; 2) Present the results of a preliminary trial where Brain Benefit Movement (BBM) exercises were used to improve symptoms in children with ADHD and autism.

Methods: A narrative review of the literature was conducted, focusing on the cerebellum's contribution to executive functions, its involvement in the autonomic nervous system (ANS), and the neurological and clinical changes associated with cerebellar exercises, mindfulness, biofeedback, and breathing. Additionally, a four-week preliminary trial with 50 participants assessed the effectiveness of BBM exercises combined with mindful breathing.

Results: Available literature suggest that cerebellar stimulation, mindfulness, biofeedback, and controlled breathing can improve motor planning, executive functions, and emotional regulation. These findings were supported by the results of our preliminary trial.

Conclusions: ADHD symptoms may improve by stimulating the cerebellum. The findings of the narrative review and the results of the preliminary clinical trial underscores the need for further clinical trials to rigorously evaluate BBM exercises as an intervention for ADHD.

Keywords

ADHD, Cerebellum, Executive functions, Emotional regulation, Cerebellar exercises, Mindfulness, Biofeedback, Breathing, Brain Benefit Movement.

Significance Statement

This review aims to 1) provide a detailed description of the available literature on the role of the cerebellum in executive functions and emotional regulation and 2) highlight available clinical evidence supporting the use of interventions which likely improve cerebellum functions in reducing the cognitive and emotional challenges associated with ADHD. Ultimately, our goal is to propose an integrative approach where cerebellar exercises, mindfulness, sensory regulation, and biofeedback techniques are used to improve the quality of life of ADHD individuals.

Introduction

The cerebellum, long considered to be solely specialized in motor control, has been shown to participate in cognitive processes and emotional regulation. This realization leads us to the hypothesis that the cognitive challenges of attention deficit hyperactivity disorder (ADHD), traditionally attributed solely to attentional deficits, may also be the result of a deficit in in cerebellar functions. If our hypothesis is correct, specific exercises aimed at enhancing cerebellar activity could lead to improvements not only in motor planning and coordination but also in executive functions and emotional regulation among individuals with ADHD.

Theoretical Background

Cerebellum and Executive Functions

Traditionally associated with motor control, the cerebellum appears to also participate in cognitive functions, including executive functions such as planning, organizing, and goal-directed behavior. For instance, it is known that the cerebellum communicates with regions of the cortex, including the prefrontal cortex [3], which plays a key role in higher-order cognitive processes.

Exercises targeting the cerebellum could, therefore, positively impact these cognitive functions. For example, by improving cerebellar function through targeted exercises, individuals with ADHD could experience benefits beyond motor control, such as refined emotional regulation.

Cerebellum and the Autonomic Nervous System (ANS)

Dysregulation within the autonomic nervous system (ANS) might influence the optimal arousal levels required for effective attentional control. This imbalance could contribute to difficulties in modulating attention and activity levels, resulting in hyperactive behaviors. The interplay between ANS dysregulation and emotional states may create a cycle of heightened arousal and emotional dysregulation, potentially exacerbating hyperactivity in individuals with ADHD.

The cerebellum appears to participate in ANS regulation; therefore, cerebellum exercises may contribute to improved regulation of the autonomic nervous system. For instance, the cerebellum has connections to brainstem nuclei involved in autonomic control [4], and enhancing its function might positively influence the balance of the sympathetic and parasympathetic branches of the ANS. By promoting a more regulated ANS response, individuals may experience a reduction in overwhelming sensations and emotional states associated with hyperactivity.

An important aspect to consider is that motor learning and motor planning often occur sequentially. Initially, during the early stages of learning a new skill, there is a greater focus on motor learning. As the skill becomes more refined and automatic, motor planning takes precedence.

There is a continuous feedback loop between motor learning and motor planning. Improved motor learning can enhance the efficiency of motor planning by refining the coordination and timing of movements. Conversely, effective motor planning can contribute to better motor learning outcomes.

Enhancing cerebellar function could potentially influence both processes. Improved motor learning might contribute to more effective motor planning, addressing challenges observed in individuals with ADHD. More importantly, this could create greater equilibrium and capacity within the autonomic nervous system, which in turn improve some of the deficiency which characterize ADHD.

Neuroplasticity and Adaptive Behavior

Neuroplasticity refers to the brain's ability to reorganize itself based on experiences. Both motor planning and executive functions involve neuroplasticity, the brain's ability to reorganize itself in response to experience. We hypothesize that the cerebellum's involvement in error correction and feedback during motor learning may indirectly benefit executive functions by promoting adaptive and flexible behavior. Cerebellar exercises may induce neuroplastic changes not only in motor-related areas but also in regions associated with executive functions, potentially leading to improvements in both domains

Cerebellum exercises may induce neuroplastic changes not only in motor-related areas but also in regions associated with emotional regulation. Over time, these neuroplastic changes could lead to more adaptive and flexible emotional behavior, potentially reducing emotional dysregulation associated with overwhelming emotional states.

Cerebellar Exercises, Mindfulness, Sensory Regulation, and Biofeedback

We use the term "cerebellar exercises" in reference to activities that engage and strengthen various aspects of the brain, particularly those associated with the cerebellum and its connections. Combining cerebellar exercises with mindfulness and sensory regulation techniques could synergistically enhance the effects of cerebellar stimulation, providing individuals with ADHD tools to modulate their emotional responses and improve self-regulation.

This hypothesized is based on observations from preliminary practices of what we refer to as the Brain Benefit Movement (BBM) exercises (see Appendix 1), which have shown extremely positive results in a child with ADHD, a daughter with Autism, and several clients. BBM is partly inspired from the Hallowell Brain Health program [5] but includes additional coordination exercises that increase cognitive load and add breathing exercises as an additional element.

But found them far more effective by adding regulated breathing In 2,3,4 Out 2,3,4 and also adding additional coordination exercise that increased cognitive load as that immediately resulted in holding of breath and found breathing through the exercise while traying and developing was occurring was extremely beneficial. Zing focus more on balance were as we focus more on coordination and balance with breathing. They don't really address the breathing. engage and strengthen the ABC of the cerebellum - Accuracy, Coordination and Balance, while ensuring regulated breath. BBM, particularly when coupled with regulated breathing after competency is achieved, seem to calm hyperactivity and improve the capacity to handle agitation and anxiety.

The preliminary results referred above involved a diverse group of participants, including a child with level 3 Autism and sensory processing disorder, as well as two children with ADHD. The intervention consisted of a 12-week program focusing on exercises designed to improve balance and coordination, particularly through hand movement coordination sequences that demanded concentration and were initially challenging, leading to frustration and annoyance. Participants were required to demonstrate persistence until the exercises were executed accurately.

Despite achieving proficiency in these exercises, issues with breath regulation—such as holding breath, taking short, shallow breaths, or breathing sporadically—were observed across all participants. To address this, breath regulation techniques were introduced, emphasizing a rhythmic pattern of inhaling for four counts and exhaling for four counts (In: 2, 3, 4; Out: 2, 3, 4). This addition led to significantly more regulated behavior and an enhanced ability to self-soothe, particularly noticeable in the four-year-old participant with Autism.

Furthermore, the implementation of the BBM exercises and subsequent breath regulation techniques observed in the study's participants, including the researcher's own experience and that of four additional clients, resulted in a decreased incidence of frustration. It also facilitated a greater capacity to manage overwhelming emotions or exacerbation, allowing for more appropriate responses instead of unconscious reactions. Notably, the two children with ADHD exhibited an increased ability to engage in study and sustain attention, which had previously been challenging.

This technique signals the nervous system that it is safe to shift towards a parasympathetic state, which is experienced as relaxation and recovery. As participants progress in their proficiency with the BBM exercises, the program introduces incrementally challenging tasks. The tasks are designed to foster new motor learning, planning capabilities, and enhanced coordination. Exposure to controlled stress, in conjunction with opportunities for self-regulation, bolsters the nervous system's ability to remain poised and regain balance as necessary.

BBM exercises not only cultivates neural pathways that are conducive to desired behaviors but also broaden the spectrum of behavioral responses available to an individual, thereby augmenting their capacity for self-regulation. The integration of regulated breathing within the BBM exercises transcends mere mindfulness practice; it becomes a foundational mechanism for nurturing regulated capacity and fostering new neural connections. This helps individuals transition from states of frustration and overwhelm towards a more regulated, parasympathetic state, thereby offering a sustainable strategy for self-regulation and emotional management.

According to Berquin [6], a better understanding of how the cerebellum functions may have a significant impact on improving the quality of life of ADHD individuals. The cerebellum, as shown by studies with patients who had cerebellum injuries, is implicated in regulation, specifically in controlling the speed, capacity, consistency, and appropriateness of both cognitive and emotional processes. The syndrome known as *cerebellar cognitive affective syndrome* [2] exemplifies the importance of the cerebellum in regulation. This condition is caused by cerebellum damage and is characterized by problems with executive function, linguistic processes, spatial cognitive, and emotional regulation -symptoms that resemble to some extent the ones observed in ADHD. Perhaps not surprisingly, cerebellum MRI studies found that individuals with ADHD tend to have a smaller vermis compared to other individuals [7], which further support the idea of stimulating the cerebellum with the goal of potentially reducing at least some of the negative symptoms observed in ADHD.

Our hypothesis is linked with the Positive Intelligence model, a neuroscience-based approach aimed at enhancing mental fitness by harnessing certain modalities of the mind associated with "positive" emotions, which promote wellness, optimal performance, and healthy relationships. These beneficial modalities are termed "Sage" and linked to the "PQ Brain," contrasting with "Saboteurs" associated with "negative" emotions and tied to the "Survivor Brain." To boost mental fitness, Positive Intelligence recommends a 3-step process: detecting and letting go of Saboteur states, performing "PQ Reps" (10-second exercises focused on present-moment physical sensations) to enable a Sage response, and choosing a Sage response to strengthen it. This methodology relies on the neuroscientific understanding of the brain's organization into two opposing networks: the Default Mode Network (DMN) and the Task-Positive Network (TPN). Practicing PQ Reps and fostering a Sage mindset involves shifting from DMN dominance (associated with mind wandering and self-referential thoughts) to TPN activation (focused on attention-demanding tasks and the external environment), effectively rebalancing these networks to enhance mental fitness and well-being.

Biofeedback as a technique that leverages the mind-body connection, enabling individuals to learn how to control physiological processes that are typically autonomic, such as heart rate, muscle tension, and breathing. Biofeedback interventions has shown benefits for individuals with ADHD, including improving attention, reducing impulsivity, and enhancing emotional regulation.

Breathing as a Gateway

The Positive Intelligence model, which emphasizes the importance of neuroplasticity and the regulation of the autonomic system through conscious breathing. The model supports the idea that breathing, a voluntary and involuntary action, can be a critical tool for self-regulation, enhancing the hypothesis's foundation.

Breathing is unique among the body's regulatory systems in that it can be consciously controlled to some extent. While many bodily functions, such as digestion, circulation, and hormone secretion, occur involuntarily and are regulated by the autonomic nervous system, breathing involves both involuntary and voluntary control.

Breathing is not only as an easily accessible biofeedback mechanism but also as a foundational practice that can be integrated with BBM and mindfulness techniques. This integration can facilitate a better understanding and control over one's physiological state, potentially improving outcomes for individuals with ADHD.

Biofeedback, particularly through controlled breathing, complements cerebellar exercises by providing immediate feedback on the body's response. This feedback can enhance the efficacy of the exercises, offering a tangible way for individuals to track and influence their progress.

Literature Review

The Role of the Cerebellum in Cognition and Emotions

A literature review conducted by [8] analyzed the interplay between embodied cognition and cerebellar theories, notably the Dysmetria of Thought theory and the Universal Cerebellar Transform (UCT). Embodied cognition redefines cognition as significantly influenced by the body and environment, involving a close relationship among sensorimotor, cognitive, and affective processes. From this perspective, cerebellar functions extend beyond motor control to cognitive and affective domains.

More specifically, the Universal Cerebellar Transform theory posits that the cerebellum applies a consistent process across motor, cognitive, and emotional functions. This theory is supported by the uniform cytoarchitecture of the cerebellar cortex and evidence showing similar patterns of deficits across these functions in cerebellar injury, suggesting a single underlying neurological dysfunction. The UCT's mechanism is hypothesized to involve oscillation dampening, optimizing performance automatically and contextually, across motor and nonmotor domains. Various hypotheses, like prediction, event-timing, error-driven adjustment, sequencing, control of temporal dynamics, and generation of internal models, support this mechanism [8].

According to Watson [1], an increasing body of evidence suggest that the cerebellum plays a key role in emotion processing. This shift in understanding is supported by observations of behavioral and affective changes in patients with cerebellar lesions, known as "cerebellar-cognitive-affective syndrome," and by neuroimaging evidence of cerebellar activity related to emotion processing in healthy individuals. For example, neuroimaging studies in non-clinical samples using techniques such as functional magnetic resonance imaging (fMRI) show evidence of specific patterns of neural activity within the cerebellum in response to emotional stimuli. It appears that the cerebellum plays a role in various sub-components of emotion processing, including physiological responses that contribute to the subjective experience of emotion, emotional expressions crucial for social communication, and the cognitive appraisal process that determines the emotional significance of events. These contributions align with the dysmetria of thought theory, suggesting the cerebellum enhances the accuracy, consistency, and appropriateness of cognitive and affective functions, similar to its role in movement. The role of cerebellum in emotions may be explained by the presence of projections from the cerebellum to emotion-related brain areas like the hypothalamus, amygdala, and basal ganglia [9]. Provides an analysis of studies showing that predictive saccades and smooth pursuit eye movements, which are encouraged in Eye Movement Desensitization and Reprocessing (EMDR) therapy, activate the Default Mode Network (DMN) and the cerebellum. Since the DMN is associated with self-referential thought and emotion, the cerebellum's activation alongside the DMN during EMDR suggests that the cerebellum is involved in the emotional processing and reconsolidation of traumatic memories.

Cerebellar Exercises & ADHD

Given the role of the cerebellum in motor, cognition, and emotional domains, there is a strong motivation for investigating the role of the same in conditions that are characterized by deficits across the mentioned domains, with ADHD being a good example. First, we need to establish whether ADHD individuals tend to have different cerebellums (functionally or structurally speaking) compared to other individuals. Second, we want to know whether cerebellar exercises improve ADHD symptoms and whether these changes are associated with functional or structural changes in the cerebellum.

A study supporting the existence of cerebellar patterns that are common in ADHD individuals comes from [7], who quantified the cerebellar and vermal volumes and the midsagittal areas of three vermal regions, from MRIs of 46 right-handed boys with ADHD and 47 matched healthy controls. It was found that vermal volume was significantly less in the boys with ADHD. This reduction involved mainly the posterior inferior lobe (lobules VIII to X) but not the posterior superior lobe (lobules VI to VII). The authors concluded that cerebello-thalamo-prefrontal circuit dysfunction may subserve the motor control, inhibition, and executive function deficits encountered in ADHD [10]. Conducted conducts an anatomic likelihood estimate (ALE) meta-analysis on voxel-based morphometry (VBM) studies to investigate cerebellar structural differences in autism spectrum disorder (ASD), ADHD, and developmental dyslexia. The sample included 17 ASD studies, 10 ADHD studies and 10 dyslexia study. The analysis found reduced gray matter (GM) in the inferior cerebellar vermis (lobule IX), left lobule VIIIB, and right Crus I for autism, GM decreases bilaterally in lobule IX for ADHD, and GM decreases in left lobule VI for dyslexia. The authors note that each condition affects different cerebellar regions, with no overlap between the cerebellar clusters identified in each condition. The cerebellar regions identified in ASD were functionally connected with frontoparietal, default mode, somatomotor, and limbic networks. For ADHD, the clusters were part of dorsal and ventral attention networks, while in dyslexia, the clusters were involved with ventral attention, frontoparietal, and default mode networks. In other words, the cerebellar differences in each disorder correspond to functional networks related to their characteristic symptoms.

More recent evidence indicates that ADHD individuals often have cerebellums that are functionally distinct [11]. Utilized an event-related, rapid mixed-trial fMRI design focusing on a go/no-go task variant with manipulations on the predictability of stimulus type and timing. The sample included 36 male children and adolescents: 12 sibling pairs discordant for ADHD and 12 matched controls. Findings indicated a decrease in accuracy for unexpected events among ADHD participants compared to controls, with unaffected siblings' performance being intermediate. Neuroimaging results showed decreased activity in the cerebellum for timing manipulations and in the anterior cingulate cortex for stimulus type manipulations, among both ADHD participants and their unaffected siblings, compared to controls. In other words, not only individuals with ADHD but also their unaffected siblings exhibit decreased activation in specific brain regions in response to unpredictable events, underlining the cerebellum's sensitivity to familial risk factors for ADHD alongside the prefrontal systems [12].

Conducted a study on the effects of an 8-week internet-based "cerebellar challenge" program compared to "School Support as Usual" (SSAU) activities on adolescents at risk of school failure, including a subgroup with dyslexia. The study recruited 40 students aged 14 and 15 from Year 10, who were randomly assigned to either the Zing intervention group or a control group receiving standard school support. The Zing system comprises graded activities targeting sensorimotor coordination, eye movement control, and dual tasking, underpinned by vestibular stimulation techniques. The intervention was delivered through a gaming format over an 8-week period, designed to be engaging and to motivate continuous improvement in performance. Outcomes were measured with a comprehensive battery of tasks assessing various dimensions of well-being and learning, including measures of literacy, executive function, physical coordination, procedural and declarative memory, and anxiety levels. The pretest-intervention-posttest design facilitated the evaluation of changes across these domains. The results demonstrated significant improvements in the intervention group across various measures, including motor performance, declarative learning, procedural learning, and mental health, for both dyslexic and non-dyslexic participants. This suggests that targeted cerebellar activation exercises can have wide-ranging benefits on cognitive and emotional well-being. In other words, the intervention led to improvements in motor skills but also in cognitive and emotional domains, indicating the cerebellum's role in cognition and emotional regulation. By enhancing cerebellar function, the program appears to positively affect emotional well-being, alongside physical and cognitive improvements. The study's findings that dyslexic participants showed greater improvements in some areas suggest that cerebellar-based interventions may be particularly beneficial for children with conditions associated with heightened emotional challenges.

The clinical effects of activities engaging the cerebellum has also been demonstrated by studies consisting of cognitive training [13]. Investigated the neural effects of a 10-day cognitive training program on nineteen unmedicated children diagnosed with ADHD. The children were randomly assigned to either a cognitive training group or a control group. The cognitive training involved exercises designed to enhance working memory, cognitive flexibility, attention, planning, and problem-solving skills. The control training focused on social skills. fMRI paradigms of response inhibition and selective attention were employed before and after the 10-day training period to measure changes in neural activity. Post-training fMRI analysis revealed significant increases in neural activity in regions implicated in ADHD for the cognitive training group but not for the control group. Specifically, the response inhibition task showed increased activity in the orbitofrontal, superior frontal, middle temporal, and inferior frontal cortex. For the selective attention task, enhanced activity was observed in the cerebellum. These changes were associated with improvements in task performance, suggesting a direct link between cognitive training and enhanced brain function in ADHD-related areas. The study provides preliminary evidence that short-term cognitive training can modify neural activity in brain regions commonly affected by ADHD, resembling effects observed with psychostimulant medication. The observed increase in cerebellar activity following cognitive training underlines the cerebellum's critical role in cognitive function and its potential as a therapeutic target in ADHD.

In a similar line of research [14], explored whether cognitive training could reverse the neuroanatomical alterations associated with ADHD, specifically focusing on gray matter volume changes. Eighteen unmedicated children diagnosed with ADHD participated in this study, which involved a pre- and post-training high-resolution MRI scan to assess changes in brain morphology. The children were divided into two groups: one undergoing cognitive training and the other serving as a control. Cognitive training targeted key cognitive skills over a 2-week period. A whole-brain tensor-based morphometric approach analyzed longitudinal changes in regional gray matter volume. Post-training analyses revealed focal volumetric increases in gray matter within the bilateral middle frontal cortex and right inferior-posterior cerebellum in the cognitive training group compared to controls. Notably, the increase in the cerebellum's gray matter volume correlated with improved attentional performance, highlighting the structural brain's capacity for rapid adjustments to environmental and training stimuli. The study's observation of increased gray matter volume in the inferior-posterior lobule of the cerebellum, associated with improved attentional performance, is evidence in favor of cerebellum-centric interventions.

Last but not least [15], assessed the effectiveness of Smart Brain Exercise (SBE), Loving Touch Therapy (LTT), and the combination of both (LTT & SBE) in altering behaviors among children diagnosed with ADHD. SBE is a movement combining balance, coordination, eye, and sensory exercises that specifically involve cerebellum function. It is designed to develop the brain and facilitate communication between the brain's hemispheres, improving concentration, memory, academic ability, and behavior. LTT is a massage technique that applies gentle and systematic touch focused on specific body parts or the whole body. It aims at healing and relaxation, adopting movements from the Nurturing Touch movement and modifying them into a softer, more comfortable love movement model.

A total of 35 participants were randomly assigned into four groups: one control group and three intervention groups (SBE, LTT, and LTT & SBE). Behavioral changes were measured using the SNAP IV ADHD Score checklist before and after the interventions. The interventions were carried out over a period of 4 weeks, with sessions held three times a week. All treatment modalities demonstrated a significant positive effect on improving behaviors associated with ADHD compared to the control group. The combination of SBE and LTT showed a particularly significant impact on attentional behavior changes. The findings underscore the role of exercises targeting the cerebellum (as seen in SBE) in managing ADHD symptoms. The cerebellum's involvement in coordinating balance, movement, and sensory integration appears to play a key role in cognitive functions and behavior regulation. By engaging the cerebellum through specific exercises, the study presents a viable pathway for improving attention, reducing hyperactivity, and controlling impulsivity in children with ADHD.

Mindfulness, Biofeedback, & ADHD

Originating from Buddhist traditions and considered part of the "third wave" of behavioral therapy, MBIs have been widely adopted in Western medicine since their introduction in the 1970s by Jon Kabat-Zinn as a method to reduce stress and enhance relaxation. Prominent examples of MBIs in psychiatry include Mindfulness-Based Stress Reduction (MBSR) and Mindfulness-Based Cognitive Therapy (MBCT). These approaches typically combine meditation, self-awareness, yoga, and breathing exercises with cognitive therapy techniques. MBIs are grounded in the biopsychosocial model, addressing the biological/physical aspects through yoga and breathing exercises, psychological aspects through meditative practices and sensory awareness, and social aspects through behavioral skills training and group activities [16,17].

Conducted a systematic review and meta-analysis investigated the control effect of MBIs on the core symptoms of ADHD. This analysis, encompassing 11 studies with 682 participants, aimed to quantify MBIs' impact on inattention and hyperactivity/impulsivity. The findings revealed large effects of MBIs on reducing inattention (Hedges' g = -0.825) and hyperactivity/impulsivity (Hedges' g = -0.676) compared to control groups, indicating significant efficacy. Subgroup analyses differentiated between self- and observer-reported ADHD symptoms, showing that both reported large effect sizes, with self-reported symptoms displaying greater heterogeneity across studies. Meta-regression identified participant age and control condition (treatment as usual, wait-list, or active control) as moderators of MBIs' effectiveness, suggesting larger effect sizes when compared to non-active controls and variations in efficacy across different age groups. Despite these positive outcomes, the analysis recognized limitations such as the lack of data on long-term effects, potential biases in study design, and the influence of comorbid conditions on treatment effectiveness.

According to the findings of a literature review [18], there are five key properties essential for the success of biofeedback and neurofeedback protocols: perceptibility (the subject's ability to perceive the bio-signal), autonomy (self-regulation without continuous feedback), mastery (control over the bio-signal), motivation (intrinsic and extrinsic factors promoting engagement), and learnability (the capacity to improve over time). While few studies have addressed cerebellar exercises in particular, we already know that biofeedback show promising results in ADHD children, as does meditation. Whether the observed effects are in part due to the effects of these practices on cerebellar function remains to be determined. As an example, a literature review on the use of meditation and biofeedback therapies for neurodevelopmental challenges conducted by Pandey [19] found that meditation and biofeedback share the common ability of inducing relaxation and a focused state of mind that improves cognitive deficits. More specifically, utilizing induction and deepening techniques facilitates self-exploration and positive suggestions to the subconscious, showing promise in managing stress, anxiety, and depression, and is adaptable for children through techniques like storytelling and imaginative play. Various forms of meditation, including mindfulness and transcendental meditation, appear to enhance executive functioning and reduce ADHD symptoms, stress, and anxiety in children. Employing real-time feedback from physiological processes (like EEG) to teach self-regulation skills shows effectiveness in reducing ADHD symptoms through brain wave pattern modulation [20].

Evaluated the effect of sensory integration training on improving the executive functions in male elementary school students diagnosed with ADHD. The study utilized a pretest-posttest experimental design with a control group. The participants consisted of 20 male students from elementary schools in Isfahan city, divided equally into a case group (receiving sensory integration training) and a control group (no intervention). The training for the case group involved a comprehensive sensory integration program conducted over 12 sessions, each lasting 45 minutes, twice a week. The program included activities aimed at enhancing balance skills, spatial awareness, tactile activities, atrial activities, activities promoting the sense of depth, movement planning, bilateral motor coordination, and strengthening auditory and visual attention and memory. After the intervention, the study found significant improvements in the executive functions of the case group compared to the control group, with a 46.7% increase in posttest scores. This improvement suggests that sensory integration training had a positive impact on the executive functions of children with ADHD. The authors note that the cerebellum and the vestibular system participate in motor control and cognitive and emotional functions. With this consideration in mind, one can assume that the observed clinical effects could be in part attributed to improvement in the functioning of these systems [21].

Evaluated the effectiveness and efficacy of fMRI-neurofeedback (fMRI-NF) targeting the right inferior frontal cortex (rIFC) in improving symptoms and executive functions in ADHD. The pre-registered, double-blind, sham-controlled randomized controlled trial (RCT) involved 88 boys with ADHD, divided equally into an active and a sham group. The participants underwent 15 sessions of fMRI-NF over four 1-hour sessions, with the effectiveness assessed at post-treatment and at a 6-month follow-up. The primary outcome was measured using the ADHD-Rating Scale (ADHD-RS), alongside various secondary clinical and cognitive outcomes. The study found no significant differences between the active and sham groups in terms of ADHD-RS scores or most other clinical and cognitive measures. Notably, both groups exhibited similar decreases in ADHD symptoms, although the sham group showed a significantly greater decrease in irritability and improvement in motor inhibition at post-treatment. fMRI analysis revealed increased activation in the rIFC and other related areas in the active group, yet there was no progressive upregulation of rIFC correlated with symptom improvement, indicating no effective transfer of learning. While the study did not find fMRI-NF effective, it did note enhanced activation in temporo-occipito-cerebellar self-regulation areas in the active group relative to the sham. This finding highlights the cerebellum's involvement in the network of brain areas potentially modifiable through fMRI-NF in ADHD. Additional clinical research may further elucidate whether the activation of these area through a modified version of the provided fMRI-NF can produce clinical effects that are associated with the activation of these areas [22].

Investigated the effectiveness of neurofeedback therapy on modifying the brain's functional connectivity among adult ADHD patients, as measured by resting fMRI (rs-fMRI). The study involved 11 adult ADHD patients who underwent 20 sessions of neurofeedback therapy. The neurofeedback utilized the Sensorimotor Rhythm (SMR) protocol, known for enhancing attention and cognitive performance. Resting-state fMRI data were collected before and after the intervention. Independent Component Analysis (ICA) was applied to the rs-fMRI data for preprocessing and analysis, focusing on identifying changes in brain functional connectivity. The effectiveness of neurofeedback was assessed through a two-tailed paired t-test on the functional connectivity data. Significant changes in brain functional connectivity were observed after the neurofeedback therapy sessions. Specifically, there was a notable decrease in the average functional connectivity in the regions associated with attention and the basal ganglia. These findings were supported by improvements in Integrated Visual and Auditory (IVA) test scores, which assess attention and response control, indicating enhanced attentional capacities following the neurofeedback intervention. These findings imply that neurofeedback therapy can effectively modify brain functional connectivity in adult ADHD patients, particularly in areas related to attention and the basal ganglia. While the study supports the clinical effectiveness of neurofeedback for modifying the brain's functional connectivity, it did not assess functional connections between the cerebellum and other parts of the brain; future studies assessing connectivity changes pre- and post-neurofeedback could be applied to specifically investigate the cerebellum's functional relationships with other parts of the brain in ADHD individuals.

Breathing & ADHD

Breathing problems show associations with ADHD. For instance, according to a review [23], there appears to be a significant relationship between Obstructive Sleep Apnea (OSA) and Attention-Deficit/Hyperactivity Disorder (ADHD) in the pediatric population. OSA affects a significant portion of children, with prevalence rates ranging from 1.2% to 9.5%. It's associated with a spectrum of negative outcomes including neurobehavioral issues, growth and developmental delays, cardiovascular problems, and insulin resistance. ADHD is notably linked as a neurobehavioral sequela of untreated OSA. The symptoms of ADHD and OSA show considerable overlap, with attention deficits reported in a substantial number of pediatric OSA patients. This relationship suggests a bidirectional impact, where each condition potentially exacerbates the symptoms of the other. Adenotonsillectomy, a common treatment for pediatric OSA, shows promising short-term benefits in alleviating ADHD symptoms.

In a similar line of research [24], investigated the relationship between mouth breathing in children and its association with sleep disturbances and symptoms characteristic of ADHD. This cross-sectional study was conducted with 100 children aged 7–12 years who were identified as mouth breathers. The Children's Sleep Habits Questionnaire (CSHQ) was used to assess for sleep disturbances and the presence of ADHD symptoms was established with the DSM 5 criteria was ADHD symptoms. The study noted a high prevalence of Class I malocclusion among participants. The

CSHQ revealed significant sleep-disordered breathing, sleep onset delay, and daytime sleepiness. Common symptoms of inattention (failing to give close attention in school) and hyperactivity (trouble waiting for his/her turn) were reported. Seven children met the full diagnostic criteria for ADHD. There was a negative correlation between sleep duration and hyperactivity, and a positive correlation between daytime sleepiness and inattention. These findings suggest that children with mouth breathing often exhibit sleep disturbances and ADHD-like symptoms.

When breathing control is used as part of an ADHD intervention, symptoms often improve. For instance, in the meta-analysis of the effects of mindfulness on ADHD discussed earlier [17], it was pointed out that one of the core practices within MBIs is paying attention to the breath, which is a common mindfulness exercise. Breathing exercises are part of the mindfulness-based exercises aimed at reducing ADHD core symptoms by enhancing attentional and emotional regulation, among other self-regulatory abilities.

According to a systematic review conducted by [25], slow breathing techniques are found to increase Heart Rate Variability (HRV) and Respiratory Sinus Arrhythmia, indicating enhanced autonomic control. These changes are paralleled by modifications in Central Nervous System (CNS) activity, with EEG studies showing an increase in alpha power and a decrease in theta power. Anatomically, the only available fMRI study pointed out increased activity in both cortical (e.g., prefrontal, motor, and parietal cortices) and subcortical (e.g., pons, thalamus, sub-parabrachial nucleus, periaqueductal gray, and hypothalamus) structures. These physiological modifications are associated with increased comfort, relaxation, pleasantness, vigor, alertness, and reduced symptoms of arousal, anxiety, depression, anger, and confusion. The review proposes two mechanisms for explaining the psychophysiological changes induced by voluntary control of slow breathing: one related to the voluntary regulation of internal bodily states (interoception) and the other associated with the role of mechanoceptors within the nasal vault, modulating olfactory bulb activity and, consequently, the activity of the cortical mantle.

The findings of the studies above highlight the role of breathing exercises in attentional and emotional regulation. Slow breathing techniques appear to improve ANS regulation by increasing HRV and promoting a parasympathetic (relaxation) response. Considering the cerebellum's apparent role in executive functions and ANS regulation, one can reasonably assume that incorporating controlled breathing into cerebellar exercises might amplify the benefits of both, potentially reducing hyperactivity and emotional dysregulation in individuals with ADHD.

The BBM Intervention Model – Current Situation and Future Direction

Informed by the preliminary practices of the BBM exercises and their observed benefits, we propose a clinical trial protocol that would systematically evaluate the efficacy of cerebellar exercises, coupled with regulated mindfulness, biofeedback, and controlled breathing This approach integrates the key elements of cerebellar exercise (Accuracy, Coordination, and Balance) with a focus on breath regulation to address ADHD symptoms and potentially other neurodevelopmental disorders.

The primary goal of this clinical trial would be to evaluate the effectiveness of an integrated intervention program combining cerebellar exercises, mindfulness, and biofeedback in improving executive functions and emotional regulation among individuals with ADHD. We hypothesize that participants receiving the integrated intervention would show significant improvements in executive function and emotional regulation compared to a control group. Participants would be randomly assigned to either the intervention group, receiving the integrated program, or the control group, receiving standard ADHD care. The study would include baseline, post-intervention, and follow-up assessments to evaluate the sustainability of treatment effects. Eligible participants would include children and adults diagnosed with ADHD, covering a broad range of ages, ADHD subtypes, and severities. Inclusion criteria would be based on standardized diagnostic interviews and ADHD rating scales.

The program would include targeted exercises designed to enhance cerebellar function, focusing on accuracy, coordination, and balance. These exercises would be adapted to participant age and ability level. Participants would engage in mindfulness practices aimed at enhancing self-awareness, emotional regulation, and stress reduction. This component would include guided meditation, breathwork, and mindful movement. The biofeedback component would involve teaching participants to control physiological processes, such as heart rate and muscle tension, using real-time feedback. This training would focus on techniques to regulate the autonomic nervous system, supporting emotional and physiological balance. The intervention would be delivered over a 12-week period, with weekly sessions for each component. The program would be designed to progressively integrate cerebellar exercises, mindfulness, and biofeedback, building on the skills developed in each area.

Preliminary Results

To assess the initial efficacy of BBM, we conducted a four-week preliminary trial with 50 participants. The participants completed the Adult ADHD Self-Report Scale (ASRS) [26] before and after the intervention to evaluate changes in ADHD-related symptoms. ASRS is designed to help screen for ADHD symptoms in adults by assessing the frequency of various inattentive and hyperactive/impulsive behaviors. It consists of 18 questions divided into two parts: Part A (inattentive) and Part B (hyperactive/impulsive). The scoring system ranges from 0 to 4 for each question, with a total score providing an indication of the likelihood of ADHD (0-16: unlikely; 17-23: likely; 24 or greater: highly likely). The following steps for completed:

- **Participant Selection:** We recruited 50 participants who exhibited symptoms consistent with ADHD. They completed the ASRS symptom checklist to establish a baseline for their ADHD symptoms.
- **BBM Intervention:** The participants engaged in a four-week BBM program, which included cerebellar exercises focusing on balance, coordination, and motor planning. Mindful breathing techniques were integrated into the exercises to promote relaxation and stress reduction.
- **Symptom Reassessment:** After the four-week program, participants completed the ASRS symptom checklist again to measure any changes in their ADHD symptoms.

This significant result indicates that the intervention had a statistically significant effect on reducing the ASRS Total Score, suggesting a potential reduction in ADHD symptoms. Given the high level of significance and the magnitude of the mean difference, these findings support the effectiveness of the intervention.

The preliminary results from the four-week BBM program demonstrated the following key outcomes:

- **Symptom Reduction:** Participants showed a significant reduction in ASRS scores, indicating a decrease in ADHD-related symptoms. This reduction was observed in both Part A (Inattentive) and Part B (Hyperactive/Impulsive) of the checklist.
- **Improved Physical Coordination:** Participants reported enhanced balance and coordination, attributed to the cerebellar exercises in the BBM program.
- **Stress Reduction:** The mindful breathing component of the BBM program contributed to decreased stress levels, as observed through participant feedback and reduced stress-related behaviors.

These preliminary findings suggest that the BBM program has the potential to improve ADHD symptoms, physical coordination, and stress management. The combination of cerebellar stimulation and mindful breathing may be a promising non-pharmaceutical intervention for individuals with ADHD.

Building on the success of this preliminary trial, we propose a more extensive clinical trial to further investigate the efficacy of BBM. The proposed trial would include a larger participant sample, a longer intervention period, and additional assessments to measure changes in heart rate variability using heart rate monitors.

Discussion

Given substantial evidence indicating 1) that changes in the cerebellum's structure and function correlate with ADHD symptoms and 2) that interventions stimulating the cerebellum improves ADHD symptoms, we propose a comprehensive

Table 1: Paired Samples Statistics.

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ASRS Total Score Before the Intervention	36.04	50	5.511	.779
	ASRS Total Score After the Intervention	25.60	50	3.763	.532

The mean ASRS Total Score before the intervention was 36.04 (SD = 5.511), and the mean ASRS Total Score after the intervention was 25.60 (SD = 3.763). This decrease in mean scores indicates a potential reduction in ADHD symptoms following the intervention.

Table 2: Paired Samples Correlations.

		N	Correlation	Sig.
Pair 1	ASRS Total Score Before the Intervention & ASRS Total Score After the Intervention	50	.774	.000

The correlation coefficient is 0.774, with a significant p-value of 0.000. This significant positive correlation suggests a strong relationship between the scores before and after the intervention. This result may indicate consistency in the scoring process and suggest that participants who scored high before the intervention also scored relatively high after the intervention.

Table 3: Paired Samples Test.

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	ASRS Total Score Before the Intervention - ASRS Total Score After the Intervention	10.440	3.523	.498	9.439	11.441	20.952	49	.000

The mean difference between the scores was 10.440 (SD = 3.523), with a significant t-value of 20.952 (df = 49) and a p-value of 0.000. The 95% confidence interval for the mean difference ranged from 9.439 to 11.441.

approach to potentially improving the lives of individuals with ADHD through cerebellar exercises, mindfulness, and biofeedback. This integrative approach aims to leverage the interconnectedness of motor control, executive functions, and emotional regulation. Clinical trials investigating the effectiveness BBM exercises alone or in combination with other techniques is warranted.

Main Findings

The literature increasingly supports a paradigm shift in our understanding of the cerebellum's role, positioning it as a key player in both executive functions and emotional regulation. For instance, the importance of the cerebellum in regulation cognitive and emotional processes is observed in conditions such as the cerebellar cognitive affective syndrome [2] and we also know that ADHD individuals tend to show cerebellums that are structurally and functionally different compared to the rest of the population [7,10,11].

Non-pharmaceutical interventions with ADHD children often show positive results and many of these interventions are likely to engage the cerebellum [12-14]. Some studies have intentionally focused on engaging the cerebellum based on the premise that cerebellar stimulation will improve symptoms associated with motor, cognitive, and emotional dysregulation. The study conducted by [12] encourages us to further test the effectiveness of cerebellar challenging programs with ADHD children as well as with individuals that have other conditions where the cerebellum is likely to function differently, such as those with autism or dyslexia. Of equal significance are the findings of [15], which showed that movement exercises promoting coordinated balance, movement, an sensory integration, alone or in combination with relaxation exercises, positively impact ADHD symptoms. In this study, the authors used massage for relaxation and we hypothesize that mindfulness and other meditation practice could provide similar or even better results.

Speaking of mindfulness, it's effectiveness in improving ADHD symptoms is supported by a systematic review and meta-analysis including 11 studies [16,17]. While these findings are positive, it's important to note that few studies have, in fact, examined the effectiveness of this technique and methodological limitations have also been noted. The integration of mindfulness and biofeedback -including neurofeedback - with cerebellar exercises presents a compelling, multi-modal approach to ADHD treatment. Meditation and biofeedback both share the common ability of inducing relaxation [18,19] and evidence provides some support for the use of sensory integration training [20] and neurofeedback [21,22] for improving ADHD symptoms.

Relaxation can also be achieved through breathing. Perhaps not surprisingly, many ADHD individuals experience breathing difficulties [23,24]. When breathing control is used as part of an ADHD intervention, symptoms often improve [17,25]. We believe that biofeedback, particularly through controlled breathing, complements cerebellar exercises by providing immediate feedback on the body's response. This feedback can enhance the efficacy of the exercises.

Our preliminary trial supports this comprehensive approach, demonstrating a significant reduction in ADHD symptoms following a four-week BBM program. The trial showed that participants experienced improvements in both inattentive and hyperactive/impulsive behaviors, as measured by the ASRS.

Limitations of Current Findings & Future Research

The evidence gathered provides both direct and indirect evidence for 1) the role of the cerebellum in ADHD symptoms and 2) the effectiveness of different cerebellar stimulation interventions for improving ADHD symptoms. That being said, the existing body of research is quite limited and there are methodological limitations considerations that need to be made.

First, we note a lack of research specifically investigating the combined effects of multiple cerebellar stimulation interventions, mindfulness or other forms of meditation, and biofeedback with breathing control on ADHD symptoms. This limits our understanding of how these practices might complement each other to provide a more holistic treatment approach.

In addition, the current literature mostly contains short-term follow-up, making it difficult to assess the long-term sustainability of benefits from each intervention. Longer follow-up periods would provide a better understanding of the long-term effects of these interventions on ADHD symptoms and overall well-being.

Another consideration is that ADHD manifests with a wide range of symptoms and severities, which may affect individuals' responsiveness to treatment. The generalizability of findings is often limited by the homogeneity of study samples in terms of age, gender, and ADHD subtype. In addition, one needs to note that many individuals with ADHD have comorbid conditions such as mood disorders, anxiety disorders, or behavior disorders [26,27], which can influence the effectiveness of treatments. The current literature seldom accounts for the impact of these comorbidities on intervention outcomes. Research that considers the presence and influence of comorbid conditions is necessary to provide a more comprehensive understanding of treatment efficacy.

Conclusion

In this literature review, we discuss the role of the cerebellum in executive functions, emotional regulation, and the autonomic nervous system, presenting a compelling case for cerebellar exercises, mindfulness, and biofeedback with controlled feedback as an integrative intervention for ADHD. Drawing from theoretical insights and empirical evidence, including the promising outcomes of the BBM exercises, we propose an integrative approach to ADHD treatment that seeks to alleviate negative symptoms by enhancing specific functions of the cerebellum.

Given the limited data obtained from our pilot study, we seek to conduct a largerclinical trial that would evaluate this integrated intervention, aiming to fill the gaps in current research and address some the methodological limitations observed. By focusing on a holistic treatment model that encompasses the cerebellum's role in motor control, cognitive processes, and emotional regulation, we anticipate demonstrating significant improvements in executive functions, emotional regulation, and overall ADHD symptomatology.

The implications of our findings extend beyond ADHD, suggesting potential applications for other neurodevelopmental disorders characterized by similar cerebellar dysfunctions. Continued improving and clinical validation of cerebellar-focused interventions hold the promise of transforming treatment paradigms directed towards those with cognitive and emotional regulation problems, offering new ways for enhancing the quality of life of these individuals.

Acknowledgments

The author declares that they are the originator of the BBM movement. While BBM is a conceptual framework and not subject to copyright or patent protections, it represents a significant intellectual contribution by the author.

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Appendix 1

Each exercise incorporates mindful breathing techniques to enhance focus and relaxation during the movement. The aim is to improve both physical and cognitive functions through targeted cerebellar stimulation.

Foot Tap Test

In this exercise, participants perform a series of foot taps in a specific pattern while standing on one leg. The pattern requires motor planning and balance, providing a challenge to the cerebellum. The foot taps can be adjusted in complexity to suit different skill levels, allowing participants to gradually build their coordination and motor planning skills (Figure 1).

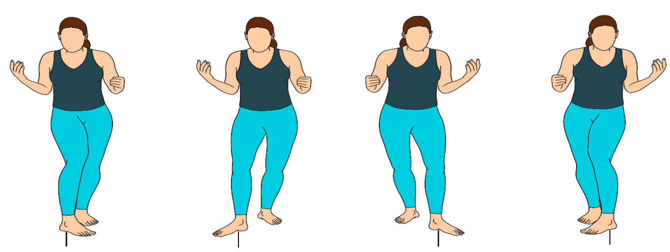


Figure 1: Foot tap test.

Cross Leg Stretch

In this stretch, the participant crosses the right leg over the left while keeping the knees straight and raises the arms over the head while inhaling. The participant then bends forward, keeping the leg and knees straight, exhales, and holds the position for 10 seconds (one breath in and one breath out). This sequence is repeated with the left leg over the right. For an advanced version, the exercise can be performed with eyes closed to increase balance difficulty (Figure 2).

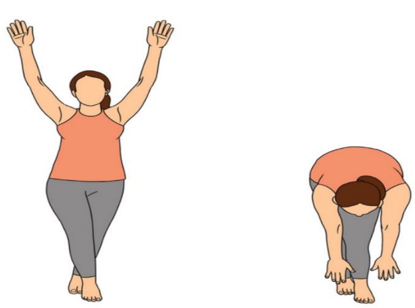


Figure 2: Cross leg stretch.

Stand and Balance

This balance exercise involves standing on the right leg and raising the left leg, with arms outstretched to the sides. The participant brings one finger to the nose for a count of six and then switches arms. The exercise is repeated on the other side. To increase difficulty, the exercise can be performed with eyes closed. Breathing regulation is important throughout (Figure 3).

Figure 3: Stand and balance.

Squat and Lift

The participant drops into a squat position with legs slightly wider than shoulder-width, tucks the bottom back slightly, and arches the back. In a bouncing motion, the participant lifts one foot to touch the hand with the sole arch of the foot, repeats twice, and then switches to the other foot. This sequence is repeated six times for each side, aiming for a total of 12 touches (Figure 4).

Figure 4: Squat and lift.

Advanced Leg Raise

This exercise involves raising one leg while maintaining balance and controlled breathing. The raised leg adds a level of complexity, challenging both physical coordination and cognitive focus. Participants are encouraged to use mindful breathing techniques to maintain balance and relaxation during the exercise (Figure 5).

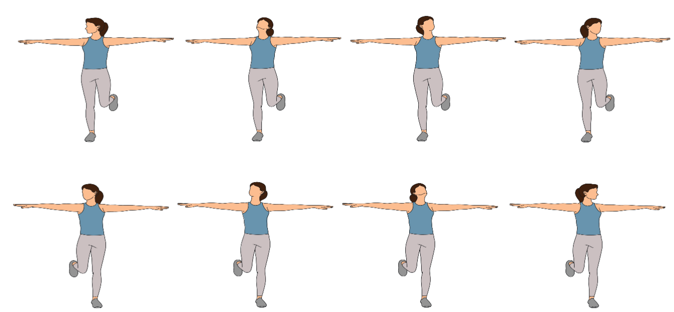
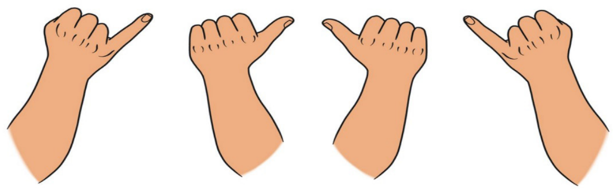


Figure 5: Advanced leg raise.

Shoulder Touch

The participant touches the left shoulder with the right hand, reaches to the side, and then brings the arm down. This is followed by touching the right shoulder with the left hand, reaching to the side, and bringing the arm down. This sequence is repeated 10 times, with the aim of increasing speed as ability improves. Breathing should be regulated throughout the exercise.



Exercise 6: Shoulder Touch.

Beginner Hand Movement Coordination

Starting with palms facing inward and fists clenched, the participant sticks the thumb out on the right hand and the pinky on the left hand simultaneously, then reverses. This sequence is repeated, with the goal of improving coordination and ensuring breathing regulation.

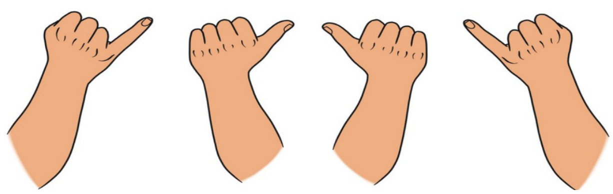


Figure 7: Beginner hand movement coordination.

Intermediate Hand Movement Coordination

In this exercise, participants raise one leg to a specified height while maintaining their balance. The exercise requires focus and motor planning, engaging the cerebellum to achieve and maintain balance. This activity is designed to promote stability and improve proprioception, contributing to overall physical coordination (Figure 8).

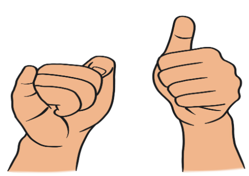


Figure 8: Intermediate hand movement coordination.

War and Peace

In this exercise, participants create different hand gestures while maintaining their balance. The variation in hand gestures provides cognitive challenges, requiring participants to focus on the sequence while maintaining physical coordination. The exercise is designed to engage both the cerebellum and prefrontal cortex through coordinated movement and cognitive processing (Figure 9).

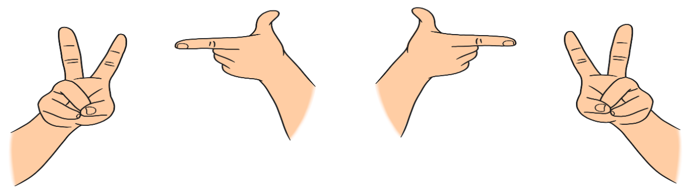


Figure 9: War and peace.

Intermediate Brain Hand Movement

This exercise requires participants to create a series of specific hand gestures in a predefined sequence. The goal is to increase cognitive load by focusing on the sequence while maintaining proper balance. This dual challenge encourages cerebellar stimulation and promotes coordination and focus (Figure 10).

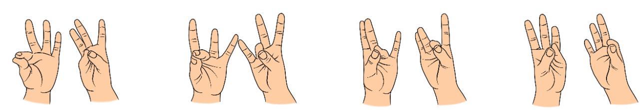


Figure 10: Intermediate brain hand movement.

Arm Raise and Switch

The participant raises the right arm up and the left arm out to the side, then lifts the left arm up and the right arm out in front, repeating this sequence 10 times. The sides are then switched, with the left arm up and the right arm out to the side, followed by lifting the right arm up and the left arm out in front, repeated 10 times. Breathing should be regulated throughout the exercise (Figure 11).

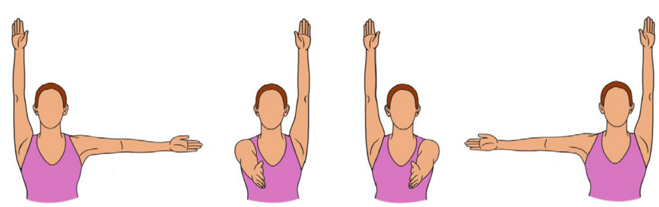


Figure 11: Arm raise and switch.