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Neurofeedback Interventions in Adult ADHD: A Case Study on Symptom Mitigation

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Abstract

This study aims to examine the effect of neurofeedback on an adult female presenting with severe ADHD. The project was undertaken to assess if neurofeedback alone could ameliorate ADHD symptoms without the additional use of medication. This study used a baseline electroencephalogram (EEG), as well as the IVA-2 and BRIEF-A to assess ADHD symptoms before and after neurofeedback treatment. The quantitative findings between the baseline and post-intervention EEG showed improvement across multiple Brodmann networks. For the BRIEF-A, the greatest improvements were seen for the Inhibit component measure and the Plan/Organize component. This was consistent with the results of the IVA-2 which indicated a reduction in speed/quickness after treatment. We conclude that neurofeedback treatment is an effective therapy for decreasing ADHD symptoms in adults.

Keywords: ADHD, neurofeedback, mental disorders, EEG, treatments

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental and behavioral disorder most often associated with children. The onset of ADHD begins early in children, before the age of 12, and can be detected as early as age four. However, some individuals continue to experience symptoms into adulthood (Gillig et al., 2005). Although the symptoms of ADHD may begin to diminish with age, possibly because of maturation, the use of learned coping skills, or substance abuse, they can have a significant impact on adulthood, leading to academic and career underachievement, relationship difficulties, addiction, anxiety, and depression (Justman, 2015). According to Gentile et al. (2016), roughly 30–60 percent of children with ADHD go on to experience symptoms of ADHD in adulthood. Stueber and Cuttler (2022) report that around 4.5% of adults have experienced ADHD-related symptoms at some point.

The presence of comorbidities with other mental disorders such as depression, anxiety, other mood disorders, antisocial personality disorder, bipolar disorder, borderline personality disorder, and other medical conditions can make ADHD in adults challenging to detect, especially in individuals who were not diagnosed during childhood (Gentile et al., 2016). Furthermore, untreated ADHD may lead to the development of comorbidities that would not otherwise be present (Ginsberg et al., 2014). Therefore, early detection and treatment of adult ADHD are important.

There are several ADHD treatment options available for adults. Medication and cognitive behavioral therapy (CBT) are the most commonly used treatments and are known to provide a significant reduction in ADHD symptoms (Cherkasova et al., 2020). Despite being the most accepted treatment for ADHD, behavioral therapy and psychostimulant medications may not be entirely effective (Felt et al., 2014). Furthermore, it is suggested that other alternatives could be considered to increase the effectiveness of these treatments (Pellow, et al., 2011).

Several research studies suggest that neurofeedback may be a viable treatment for ADHD symptom reduction (Enriquez-Geppert, et al., 2019). Neurofeedback, also known as Neurotherapy, is a non-pharmacological and non-invasive treatment technique developed in the 1960's, that uses operant conditioning to shift the neural activity of the individual (Murphy & Bassett., 2017). This technique utilizes EEG equipment (electroencephalogram) that is typically used to monitor the brainwave activity of patients in a health care setting

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as well as specialized computer software that can display the EEG data in real time. The software is programmed to produce visual or auditory cues when specified brainwave patterns are detected. The process usually involves the patient sitting in front of a computer or other electronic device while EEG sensors are placed on the patient's scalp to monitor the neural activity in the cortex. Shifts in the patient's neural activity are identified as cues such as a blinking light or an audio beep. When displayed to the patient, these cues act as a 'sixth sense' to help them monitor and "correct" the electrical signals (either brainwaves or other physiological behaviors). Through practice and concentration, this type of therapy can prove effective, as it teaches the patient to gain more control over their brainwaves. It can also help patients attend to unwanted distractive thoughts so they can try to reduce them (Dashbozorgi, et al., 2021). Over time, this practice can prove to be effective in minimizing ADHD symptoms.

Several studies have concluded that neurofeedback could provide large-scale improvements in inattention and impulsivity and significant improvements in hypersensitivity (Arns et al., 2009; Enriquez-Geppert, 2019; Lin, et al., 2022). A 2013 review stated that neurofeedback is a "significant treatment" for ADHD in adults (Sonuga-Barke et al.). Researchers have concluded that around 30-40 sessions of neurofeedback are more effective than the traditional methylphenidate, in treating symptoms of hyperactivity and inattention in adults (Duric, et al., 2012; Meisel, et al., 2013).

While some studies have shown promising results using neurofeedback as a plausible treatment option for ADHD, some researchers have suggested that this form of treatment may be ineffective, incomplete, or require further research. A meta-analysis by Cortese and his collaborators (2016) suggested that there was incomplete evidence to clarify the significance of neurofeedback as a treatment and that further research was required. It was further stated that there might be possible design flaws in studies that confirmed the technique's efficacy.

Although the research on this treatment technique is limited, most studies suggest that neurofeedback may be a promising treatment for ADHD if used as a complement to other traditional treatments, such as medication and cognitive behavioral therapy (Lin et al., 2022; Nazarova, et al., 2022). Although the current research on this topic suggests that it can cause significant changes in an adult's hyperactivity, inattention, and hypersensitivity, more evidence may be required to conclude the efficacy of this treatment.

The case study presented here examines the effect of neurofeedback on an adult female presenting with severe ADHD. The project was undertaken to assess if neurofeedback alone could ameliorate ADHD symptoms without the additional use of medication.

2. Methods

This study was conducted at the University of Louisiana at Monroe in the Neuro Behavioral Dynamics Lab. The participant was a 36-year-old female professional. Reported cognitive symptoms included issues such as working memory, distractibility, speech difficulties, proprioception, and time blindness; emotional difficulties such as frustration, agitation, anxiety, and mood instability, as well as sensory sensitivities and feeling overwhelmed. She reported experiencing symptoms of ADHD since childhood, although a formal diagnosis was not made until her late teens. She denied ever being prescribed any medication to attenuate ADHD symptoms.

A baseline electroencephalogram (EEG) and two other objective measures were used to assess ADHD symptoms before and after treatment. Baseline symptoms were measured using the computer-assisted Integrated Visual and Auditory Continuous Performance Test, also known as the IVA-2 CPT (IVA-2) (Shreve, 2018), and the Behavior Rating Inventory for Executive Functioning for Adults (BRIEF-A) (Roth, et al., 2013; McCandless & O'Laughlin, 2007) (Table 1). A second EEG, IVA-2, and BRIEF-A were administered post-intervention.

EEG testing was conducted using the Nexus Q32-F Mind Media amplifier and software system (Cassidy, 2016). The amplifier setup included a headcap with twenty-one sensory nodes and a sensory processor that was connected to the computer running the Nexus Mind Media software. A conductive gel called Electrogel was inserted into each node via a syringe. Once connectivity was established, the EEG baseline was recorded for five minutes while the participant sat calmly, eyes open, and then for five minutes with the participant's eyes closed. Afterward, several spectral analyses were applied, including the affected Brodmann areas.

The BRIEF-A, a product of Psychological Assessment Resources Inc., is a standard measure used to assess adult ADHD (Roth & Gloria 2005). It consists of 75 questions, and the test reports results for nine components and three composite indices related to executive functioning. The participant completed the assessment via computer, and the results were uploaded and processed at www.PARInc.com. A report was generated and then downloaded.

The IVA-2 provided a measure of attention and impulsivity. This performance-based test included 500 trials in which the participant was required to selectively respond to visual and auditory stimuli presented via computer. The results were uploaded to www.braintrain.com for analysis. The site generated a report, which was downloaded for review.

The Nexus Q32 Mind Media amplifier and software were also used to conduct fifteen, 30-minute neurofeedback protocol trainings over a period of seven weeks beginning in June of 2022. The training was designed to stimulate the sensory motor rhythm (SMR) strip of the brain (Hayashi et al., 2020). Trainings were conducted using the head cap sensors located at CZ, FZ, FP1, and FP2. The participant performed all the sessions in isolation.

The neurofeedback reward stimulus was chosen based on the subject's preference. The subject chose a visual reward stimulus with no sound component. The image was a mandala that transformed in shape, size, color, and orientation based on the neuro-sensory input received. When the SMR threshold value was exceeded, the mandala would increase in size, change color, and rotate (some components rotating clockwise and others counterclockwise). The speed of the rotation and other changes were determined by the SMR values, with higher values resulting in faster and more elaborate changes in the visual stimulus. Instances of SMR values over the threshold were recorded as “hits” by the software. Initially, the threshold was set at the reward level of five feedback signals. This gradually increased each session until reaching a high of 15, which is within the range of normal function for the majority of the population.

3. Results

3.1. BRIEF- A

The post-treatment results of the BRIEF-A showed a reduction in ADHD symptoms across all component measures (Figure 1). Results of a Wilcoxon Signed-Rank test comparing *T*-scores before and after treatment indicated this was a large significant difference; before treatment (Mdn = 78, n = 12), after treatment (Mdn = 62, n = 12), Z = -3, p = .002, r = -0.9. A total of ten out of twelve component scores fell in the significantly impaired range ($T > 65$) prior to treatment, compared to only four in the significantly impaired range after treatment. The greatest improvements were seen for the Inhibit component measure and the Plan/Organize component (each with a 24-point *T*-score spread).

3.2. IVA - 2

The IVA-2 results (Table 2) were presented as standardized quotient scores (Mean = 100, SD = 15) and Percentile Rankings (PR). Results were provided for nine Global Quotients, which included controls, as well as 37 primary and symptomatic quotient scales. Based on the results of a Wilcoxon Signed-Rank test, the treatment using neurofeedback protocols did not show effectiveness in ADHD symptom reduction for the majority of measures pre (*Mdn* = 96.5 ,*n* = 46) and post (*Mdn* = 91.5 ,*n* = 46), $Z = -2.2$, $p = .030$, r = -0.4 when comparing IVA-2 pre and post raw scores. Raw scores tended to be higher in the pre-IVA-2 than in the post-IVA-2. However, improvements were seen in several areas (Table 2).

For example, in the pre-intervention IVA-2 evaluation, the global Visual Sustained Attention quotient scale score for this individual was 51 (PR=1). This score was found to fall in the extremely impaired range. The post-intervention IVA-2 results showed that the global Visual Sustained Attention quotient scale score increased to 78 (PR=7). This score was found to fall in the mildly to moderately impaired range. The participant’s IVA-2 results showed the most improvement in Visual Vigilance and Visual Elasticity. Results indicated pre-Visual Vigilance was 65 (PR = 1) and post-results increased to 107 (PR = 69). Visual Elasticity showed 0 (PR = 1) pre-treatment and an increase to 108 (PR = 69) post-treatment. The participant’s Auditory Prudence score was 85 (PR = 16) pre-treatment. The post-treatment score increased to 106 (PR = 66). This indicated that she was able to control her responses and was not excessively distracted by auditory stimuli in her environment.

Alternately, the participant’s scores decreased in multiple areas post-treatment (Table 2). Pre-treatment, the Auditory Stamina quotient fell in the exceptional range at 132 (PR = 98). Post-treatment, the quotient dropped to 93 (PR = 31). Although the score was lower, impairment was not indicated. However, decreases in other areas did result in scores that indicated impairment. Results indicated the participant had the most difficulty with Auditory Speed, Auditory Quickness, Visual Swiftness, Visual Sensory/Motor, and Visual Speed, and Visual Quickness. The post-treatment score on each of these quotients fell in the moderately to severely impaired range.

3.3. Brodmann Areas

Figures 2 & 3 represent the participant’s responses as seen in Brodmann’s areas (BA). The charts are visual depictions of z-scores for several neural networks, where each network is known to correspond to distinct cognitive functions. z-scores are statistical indicators that quantify the extent to which a value deviates from the mean of a set of values, expressed in terms of standard deviations from the mean.

Each spider chart represents a distinct network of Brodmann areas and their related cognitive function. These networks are labeled based on the specific brain functions or behaviors to which they are linked. The radial lines depict distinct Brodmann areas, which are cortical regions hypothesized to be linked to diverse and sometimes overlapping cognitive functions.

The circles in each spider chart represent z-scores, with each concentric circle indicating a distinct z-score value (e.g., 0, ±1, ±2, etc.). The lines, with the darker line representing the right hemisphere, display the z-score value for each Brodmann area inside their corresponding network. A z-score of 0 indicates that the activity is at the average level, while scores higher than zero suggest deviance from the norm.

For example, when examining the Attention network in Figure 2., it is evident that BA9 (shown by the dark circular line) exceeds the 0 circle (z-score 6). This observation indicates hyperactivity or heightened activation in comparison to the normative data. Regarding the Executive network, it is observable that both hemispheres exhibit activity in regions such as BA9 (baseline z-scores 6 and 7) and BA46 (baseline z-score of 6 and 8). This suggests the possibility of dysfunctional activity in those specific areas.

When comparing pre-intervention (Figure 2) to post-intervention (Figure 3) Brodmann areas, one can hypothesize that the treatment protocols were effective in reducing ADHD symptoms. Note the movement of the radial lines toward the center in the post-intervention in Figure 3. For example, when comparing Attention pre-and post-intervention, the change in z-scores signifies a movement in BA9 and BA46 from z-scores 6 and 8 respectively to z-scores of 3.5 and 4 respectively. While one cannot definitively make diagnoses based on Brodmann area z-scores, when combining them with the other tests' results, one can infer the protocol interventions had a significant impact on the symptoms of ADHD.

4. Discussion

The participant in this case study was a 36-year-old adult female who reported experiencing ADHD symptoms from childhood. Several testing measures were administered before and after neurofeedback sessions to determine if neurofeedback was effective in decreasing ADHD symptoms.

The IVA-2 assessed performance in the areas of visual and auditory attention to the given task of responding to computer-generated stimuli. After treatment, the participant improved in multiple areas on both the IVA-2's visual and auditory task components. Low percentiles showed higher levels of impairment and high percentiles indicated less impairment. Two areas showed significant improvement after treatment - visual vigilance and visual elasticity ranking in the 69^{th} percentile. Visual vigilance refers to the ability to maintain focused attention over a period of time on visual tasks. Visual elasticity refers to the ability to adapt and shift attention between different visual stimuli or tasks, meaning that an individual can efficiently manage changes in the environment or task demands by adjusting their focus and cognitive strategies accordingly.

The BRIEF-A showed significant reductions in scores when comparing the pre-intervention and post-intervention neurofeedback protocols. Areas that showed the most improvement were inhibition and planning/organization, while areas that remained significantly impaired were task initiation, working memory, task monitoring (making adjustments while completing tasks), and a composite measure for overall executive functioning.

Brodmann areas also indicated a likely reduction of symptoms. Brodmann's areas, discovered by Korbinian Brodmann during the early 20th century, categorize 52 sections of the cerebral cortex according to cellular structure and arrangement (Bruner, 2022). Distinct functions are associated with different parts of the brain, such as area 4 being responsible for motor control and areas 17, 18, and 19 being involved in visual processing. These areas play a crucial role in neurosurgical procedures and neuroimaging, aiding in the identification of brain activities and the diagnosis of disorders.

ADHD impacts specific sections of the brain that are categorized in Brodmann's areas, particularly those related to executive functioning and emotional regulation (Kerson et al., 2023). The complex symptomatology of ADHD is primarily driven by the interaction of these regions of the brain due to the involvement of dopaminergic pathways that are essential for reward processing and motivation.

One of these areas is the prefrontal cortex, which contains Brodmann areas 9 and 46. Both areas were highly abnormal for our participant, and both areas showed improvement after treatment. In the Brodmann Network groupings, Brodmann area 9 is grouped with Attention, Executive, and Salience, while Brodmann Area 46 is grouped with Addiction/Reward, Executive, and Mirror.

Another significant brain area is the anterior cingulate cortex, which plays a role in executive processes and attention. Malfunction in this area contributes to the fundamental symptoms of ADHD. This area of the brain encompasses parts of Brodmann areas 24 and 32 which are associated with the regulation of emotions and is grouped under the networks involving Mood, Pain, and Salience. Area 32 is also involved in the Addiction/Reward network.

Brodmann areas 46 (Addiction/Reward, Executive, and Mirror), 47 (Addiction/Reward, Mood), and 10 (Mood, Anxiety, Executive, Default and Salience) were the most impaired. Each of these improved by at least two z-scores (equivalent to two standard deviations) following treatment. Almost all Brodmann areas either remained the same or showed improvement following treatment. However, in a few cases, functioning became more abnormal. For example, area 40 in the Mirror network became more impaired, moving from a z-score of four to a score of six for the left hemisphere. Several areas in the Pain network also increased, with areas one through five increasing slightly from a z-score of four to a score of five. This was not considered unusual because the participant reported experiencing pain on a variable bias due to another condition.

The results presented here suggest that the participant experienced a significant decrease in ADHD symptoms across multiple areas, as well as a valuable increase in cognitive functioning following treatment with neurofeedback protocols. Enhanced neurofeedback training may elicit a calming effect on the "mind spinning" she reported initially, as well as a reduction in the perception of stress, anxiety, and feeling "hectic". All measures of pre-intervention baselines compared with post-neurofeedback protocol training suggest that properly modeled treatments may have significant symptom reduction in adult females experiencing ADHD.

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Table 1. Components measured in the BRIEF-A

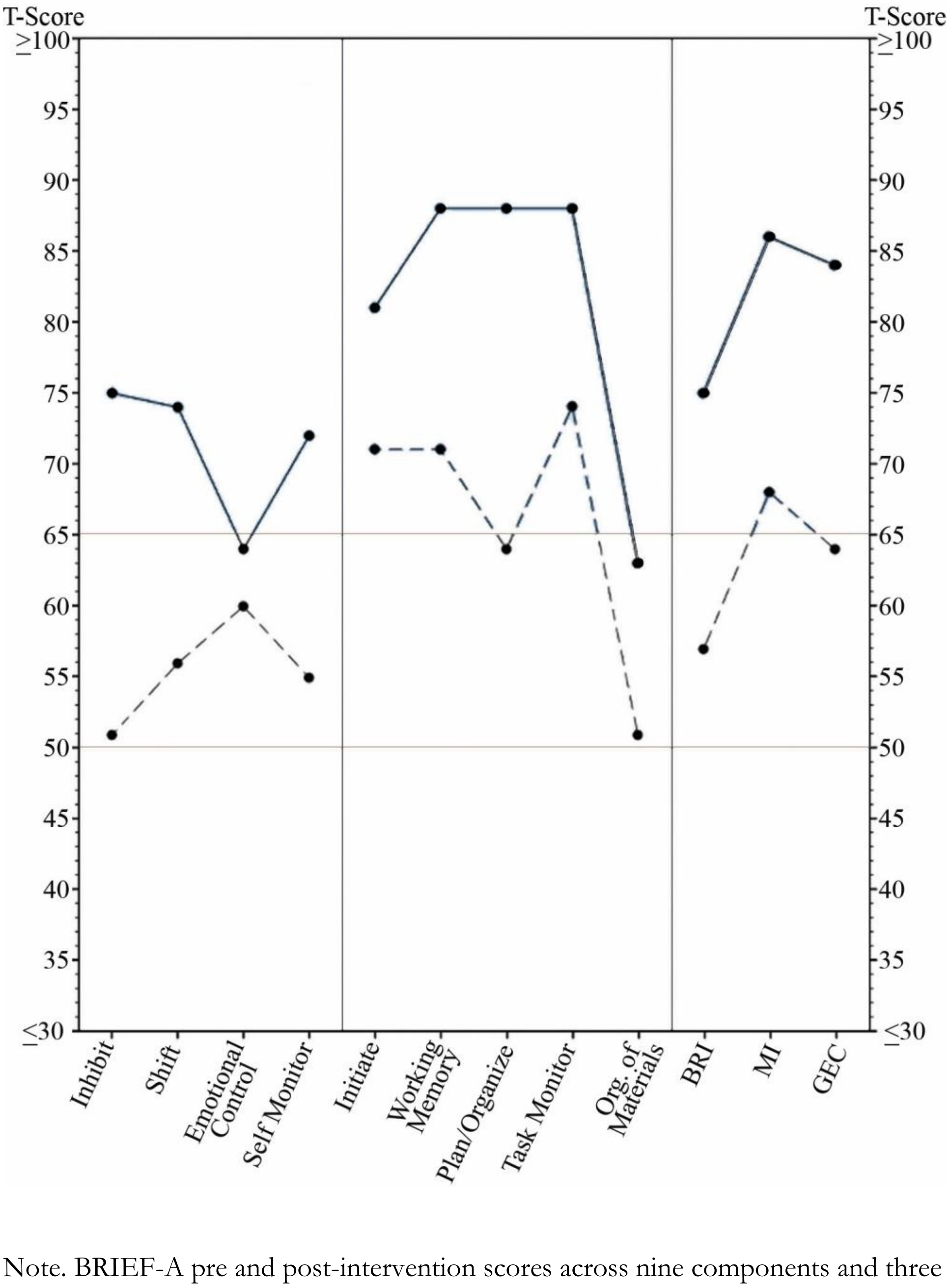
Component	Description
Inhibit	The inhibitory component measures the ability to resist responding to a stimulus that is presented repeatedly.
Shift	The shift component represents the ability to switch between tasks or stimuli.
Emotional Control	The emotional control component represents the ability to regulate emotions and control impulsive behavior. In other words, it measures the ability to stay calm and focused in the face of distractions or stressors.
Self-Monitor	The self-monitoring component represents the ability to monitor one's own performance and make adjustments as needed.
Behavioral Regulation Index (BRI)	The Behavioral Regulation Index (BRI) component represents the ability to control behavior and maintain attention in the face of distractions and stressors. It is a composite index of the IVA-2's inhibit, shift, emotional control, and self-monitoring components.
Initiate	The initiate component measures the ability to start a task and to maintain focus on the task.
Working Memory	The working memory component measures the ability to hold information in mind and manipulate it.
Plan/Organize	The plan/organize component measures the ability to plan and organize a task.
Task Monitor	The task monitor component measures the ability to monitor one's own performance and make adjustments as needed.
Organization of Materials	The organization of materials component measures the ability to organize materials in a way that is efficient and effective.
Metacognition Index (MI)	The metacognition index is a composite index of the initiate, working memory, plan/organize, task monitor, and organization of materials components. It measures the overall ability to use executive function skills.
Global Executive Composite (GEC)	The global executive composite is a composite index of the BRI and the metacognition index. It measures the overall ability to regulate behavior and control attention in the face of distractions and stressors.

Table 2. IVA-2 Pre and Post Comprehension Results

Scale/Index	Raw Score		Percentile Rank	
	Pre	Post	Pre	Post
Combined Sustained Attention *	79	80	8	10
Visual Response Control *	90	100	10	10
Visual Sustained Attention *	51	78	1	7
Visual Vigilance *	65	107	1	69
Visual Attention *	70	80	10	10
Visual Elasticity *	0	108	1	69
Auditory Prudence *	85	106	16	66
Auditory Stability *	90	92	2	2
Auditory Focus *	94	100	6	6
Auditory Persistence *	87	90	18	24
Auditory Stamina	132	93	98	31
Auditory Speed	94	67	34	1
Auditory Quickness	92	67	31	1
Visual Swiftness	79	57	8	1
Visual Sensory/Motor	89	68	24	2
Visual Speed	82	61	34	1
Visual Quickness	83	64	14	1

Note. * Denotes improvement in pre and post IVA-2 results

Figure 1. BRIEF-A Results



Note. BRIEF-A pre and post-intervention scores across nine components and three composite indices. Solid line indicates *T*-scores pre-intervention. Dotted line indicates *T*-scores post-intervention. *T*-scores greater than 65 indicate significant impairment compared to the general population.

Figure 2. Pre-intervention z-scores for specific Brodmann areas grouped by associated cognitive function, taken from report generated by Applied Neuroscience,
Inc.

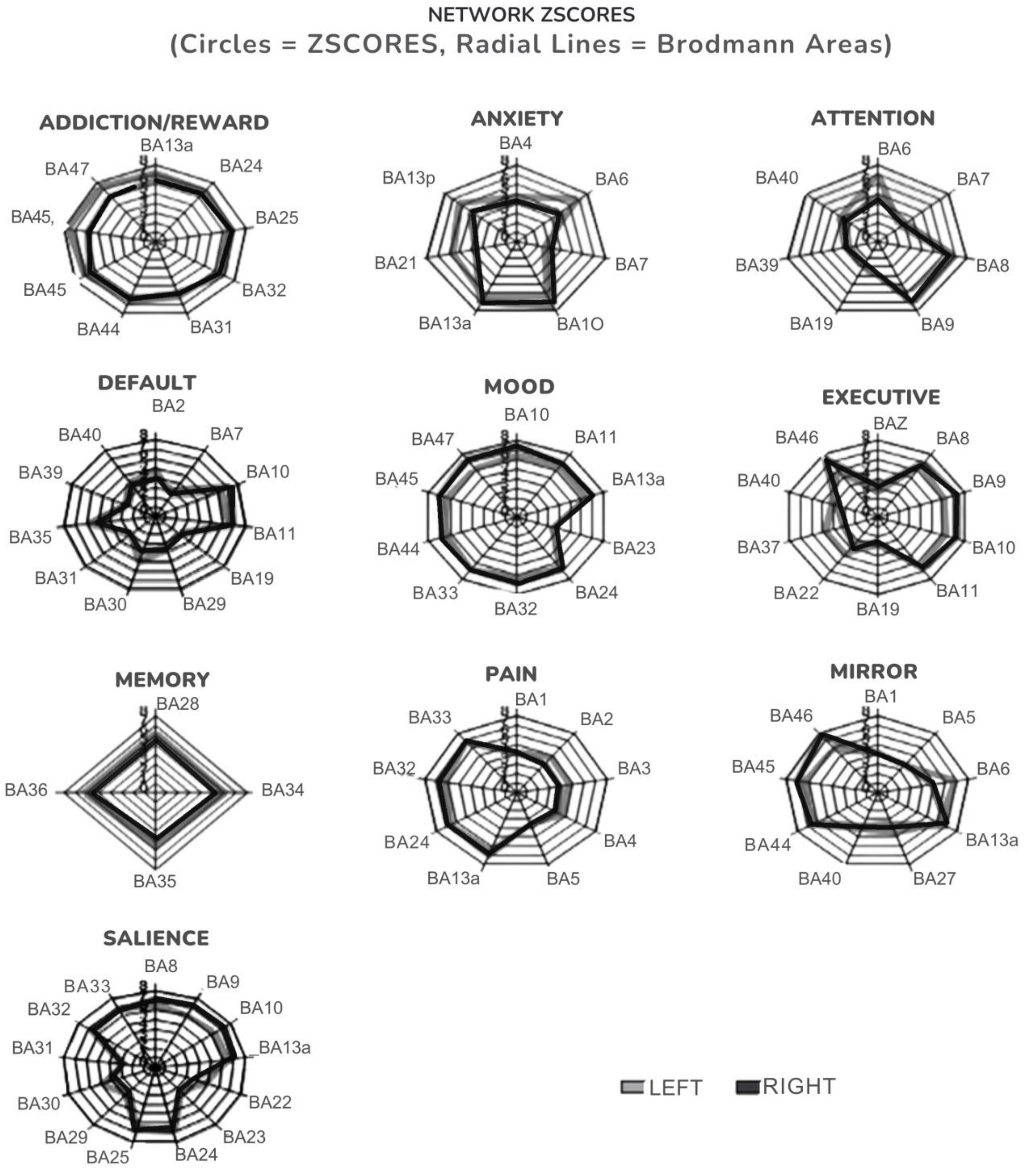


Figure 3. Post-intervention z-scores for specific Brodmann areas grouped by associated cognitive function, taken from report generated by Applied Neuroscience, Inc.