Chapter 6 - NEUROENGINEERING - BRAIN RECOVERY METHODS AS APPLIED TO SUBSTANCE ABUSE RECOVERY

"In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practicable methods for measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be." Lord William Kelvin (1824-1907)

Introduction – Alcoholism and Other Drugs (AOD) abuse is a global health issue. Individuals recovering from substance abuse have a recovery course that is, at best, troubled with recurring periods of relapse and, at worst, ends in death. AOD abuse is recognized as a brain disease, subject to brain dysfunctions that affect the individual's ability to think and make well reasoned decisions, and contributes to self-awareness and self-regulation challenges. These same brain dysfunctions are known to affect behavior and contribute to the relapse cycle. However, few in-patient or out-patient treatment programs assess or treat dysfunctional neurocognitive aspects of AOD abuse.

In this chapter describes an evidence-based, bio-behavioral, brain-based assessment and treatment program. This approach addresses metacognitive shortfalls in thinking abilities, self-awareness and self-regulation due to neurocognitive deficits related to AOD abuse. The assessment and treatment programs are based upon neuroscience, neuropsychological, and neuroengineering methods. Neuroengineering is an emerging interdisciplinary field that combines neuroscience and engineering techniques to design solutions to problems associated with neurological limitations and dysfunctions. The central goal of the neuroengineering field is to solve brain-based (neuro) related problems and provide rehabilitative solutions for nervous system conditions.

In addition, this chapter reviews the global severity of the addiction problem and the nature of the addiction cycle. Included is a brief discussion of the prevailing theories used to perform the analysis and treatment with the focus on the necessary neuro-systems that need repairing including the role of the brain and brain-based behaviors in addiction recovery. The chapter concludes with a description of the results from a mixed-methods study of polysubstance recovering subjects (n=300).

To date, our research indicates that not only is there adequate research available to develop a brain recovery program, but also that such a program, when augmented with traditional behavioral treatment programs, has a greater than 80% efficacy. This claim is supported by documented evidence indicating that after 18 months, individuals who successfully augment their conventional addiction treatments with targeted brain-based recovery models are achieving substantially higher sobriety rates that exceed 80% vs. the 20-40% typically achieved from traditional in-patient and out-patient programs.

1.0 The BrainRecovery Program Framework

Overall, a neuroengineering approach to solving brain-based behavior issues is categorized as a cognitive remediation technique that uses modern applied neuroscience methods. The general analysis and remediation methods described below have evolved and developed over the last thirty years as a practical application to many clinical problems that did not respond successfully to conventional treatment methods. The approach works with most brain based dysfunctions. The analysis approach is called NeuroCodeX®, while the remediation technique is called NeuroCoach®. The combined analysis and remediation method, when applied to substance abuse recovery, is called the BrainRecovery Program.

The BrainRecovery program was designed to accommodate multiple delivery options that range from inpatient recovery centers, private outpatient clinics, and in the privacy of one's home using our remote TeleHealth delivery format. Presently, the program is located in select inpatient recovery centers, private outpatient clinics and remotely in the client's home setting in conjunction with one of our staff. Currently our clients access us through the web site www.smartbrainsolutions.com.

This chapter discusses the design process used in developing these methods and the study results that demonstrate the program's effectiveness when applied to a sample of subjects participating in an addiction recovery program. It is important to note that when applying the process to substance abuse recovery, the BrainRecovery Program is considered a treatment that augments traditional recovery programs by focusing on repairing neurophysiological underpinnings that anchor cognitive distortions.

The NeuroCodeX® brain analysis approach differs substantially from conventional methods. In this neuro-engineered approach, primary behavior measures are obtained using neuro-electric indicators of neuro-circuit performance. In contrast, many conventional methods *infer* neurochemical imbalances from statistically derived classifications based upon self-reported data. While the NeuroCodeX® model focuses on neuro-circuit performance, it also includes insights from conventional statistical classifications plus structural and biochemistry measures. However, the important distinction is that it includes these as secondary measures, rather than primary measures. These secondary measures are used to indicate the health status of the nervous system or possible behavioral performance limitations due to brain structural abnormalities. In this manner, the NeuroCodeX® analysis method is able to identify brain challenges that are *not* observed by strict anatomical measures obtained from MRI or CAT scans, nor strictly metabolic activity within the brain as measured by SPECT or PET scan, nor assumed to be biochemical dysfunctions based upon a client's self reporting. In short, the NeuroCodex® analysis is considered a targeted and personalized approach, based upon objective measurements of neuro-circuits of the brains functional performance.

Equally important, each NeuroCodex® report is individualized and specialized to a specific behavioral complaint that includes brain injuries, child development, substance abuse, and/or adolescent and adult regulation challenges such as depressions or anxiety. Providing measures of neuro-circuit responses can aid in the determination if the treatment should be conventionally focused or brain repair focused.

The NeuroCoach® remediation approach differs from conventional approaches as well. NeuroCoach® does not focus on pharmacological medications nor conventional psychotherapy as the primary treatment modality. Instead, it focuses on strengthening dysfunctional neuro-circuits that contribute to dysfunctional behaviors. This is accomplished using an advanced form of Cognitive Rehabilitation Training (CRT) methods in combination with techniques derived from BCI-EEG-neuro-monitoring, Biofeedback, Cognitive Neurodevelopment, and Cognitive Bias Modification (CBM).

The NeuroCoach® program is delivered through a worldwide network that consists of a gateway system, individually assigned client portals, and a NeuroCoach® workstation. For both inpatient and outpatient programs, the NeuroCoach® workstation, consists of a computer (desktop or laptop), with an Internet connection that allows the client to access their unique remediation program remotely anywhere in the world. Each station is equipped with a copy of our propriety NeuroCoach® software and includes a neuro-monitor (hardware) that reads brain activity. Clients connect the neuro-monitor to their head using EEG-leads and the use specific client training protocols derived from the NeuroCodex® evaluation. The complete program and protocols are accessed remotely through individually assigned client portals that connect directly to the gateway system.

CRT methods focus on ***strengthening*** specific areas of the brain that create our cognitive abilities; such as the ability to attend or exert self-control required to moderate behavior. Especially for those in AOD recovery, strengthening one's ability to exert self-control allows greater access to one's will power. This then permits greater *moment-to-moment* control over unwanted impulses or desires. An individual's remediation program may include several NeuroCoach® activities as identified from their NeuroCodeX® evaluation, each addressing specific areas of the brain.

Neuro-circuit strengthening is achieved through targeted activities that are delivered typically in a game format, in combination with real time brain monitoring. Real time brain monitoring allows NeuroCoach® to directly influence the operation of the activity based upon the level of performance of the brain. Using a propriety BCI-EEG-neuro-monitoring interface, NeuroCoach® is able to instantaneously monitor neuro-circuit performance levels and then influence the difficulty level of the activity based upon the user level of brain strength or fatigue.

For example, when strengthening the attention system, the user has the ability to choose from a set of activities that range from academics (reading, math, school work) to fun computer games as a primary activity. The client will consciously engage with the activity via a NeuroCoach® computer workstation. Attention, a brain function, requires the brain to preform many sub-functions necessary to consciously perceive what is being focused on. However, these attentional sub-functions operate non-consciously in a reflexive or automatic manner, but use specific measurable neuro-circuits to preform the task. NeuroCoach® views the activity (academics or game) as a distractor that distracts the conscious mind by giving it something to focus on. NeuroCoach™ operates on the non-conscious elements required to preform such functions as shifting attention, sustaining attention, or being able to divide one's attention "in the moment".

Based upon the results of the NeuroCodex® evaluation, NeuroCoach® monitors the brain's performance integrity level of one or more aspects of the attentional subsystems while the client performs the chosen task. From a user's perspective, he or she is simply reading a book, or playing a game, but when their attention drifts to another thought, they will see the computer activity screen fade. In other words, as one's attention drifts, NeuroCoach® will immediately measure which neuro-circuit is drifting and subsequently indicate this loss of attention by 'fading' the screen. Fading occurs if one or more of the neuro-circuits being monitored falls outside the specific performance level required to properly support the attention system. Assuming the conscious mind's intention is to maintain proper focus, this fading of the activity directly signals the attentional sub-functions to adjust in order to maintain proper focus, unconsciously. This constant unconscious feedback and attention system readjustment over time teaches the brain to properly maintain focus and strengthens the neuro-circuits involved in attention. This is much like exercising muscles for a fit body by going to the gym, but in this case for the brain.

In writing this chapter I was asked to describe the user's NeuroCoach® experience, which as one could imagine would be difficult, since my experience with the program would be different. Therefore, I've chosen to include a user experience from a client that I worked with personally using our TeleHealth program. **J.E.** "… our sessions involved wires, dimmer games, and Skype calls, but overall the NeuroCoach program was very easy to use. It took a while to get the hang of connecting the electrodes to my head in the correct places, but now I can perform the necessary preparations in fewer than five minutes. I am a full-time student with a part-time job, so I appreciate the fact that our sessions are brief and to the point. I began noticing incredible changes in my behavior and mental faculties. I liken the program results to watching your hair grow. You don't notice it on a daily basis, but after a few weeks or months, the change is obvious.

I didn't realize what I had lost until the BrainRecovery program helped me find it again. From my keys to my age, I seemed to lose track of just about everything. I had grown accustomed to functioning at such a low level that I was a bit insulted when it was suggested that I could return my brain to working order. I had already been doing relatively well for myself – both in school and at work.

It wasn't until I began making headway (pun intended) with this program that I realized how hard I had previously been working to maintain the appearance of normalcy. Before I started working with the program, every day was a struggle – simple tasks were major events, conversations were unbearably uncomfortable, and emotions were always powerful and overwhelming.

After only a few months, I have noticed a dramatic difference. Thankfully, I can now remember my name and age at the drop of a hat, but the improvement of my memory is not what I have been most pleased to notice.

The difference this program has made in my ability to manage my emotions is incredible. I have never been able to remain calm in difficult situations, never been able to logically think through trying circumstances – until now. It's almost as if this program has allowed me to move from adolescence into adulthood. The program has undoubtedly helped me reverse the damage I have done to my cognitive abilities, but in addition to doing so, he has helped me reach higher levels of functioning than I thought possible.

My social anxiety has decreased, my sleep has improved, and my relationships have become more meaningful. I am far more efficient when I am working, and far more relaxed when I am not. My overall quality of life is better. Far better. Quite frankly, that is what it boils down to for me. Years of therapy and a plethora of various medications do not come close to accomplishing what the program has accomplished in a short amount of time. I cannot speak highly enough of the difference this program has made in my life. "

2.0 Approach to the Design Process

I was asked to prepare the background and design criteria used to develop this specific approach to brain recovery. Admittedly, my academic and professional background, in combination with personal life events, heavily influenced the design process.

Academically, my training includes advanced degrees in two fields: Aerospace Engineering and Psychology. The engineering emphasis was in theoretical mechanics and systems engineering, mostly applied to obtaining imaging data from space, while the emphasis of the psychology degree was in Health Psychology and Behavioral Medicine. I have applied this knowledge, in combination with my engineering background to developing remediation programs for neuro-dysfunctional behaviors.

On a personal level, two significant events related to brain traumas significantly influenced the design approach. The first was a personal, accidental medically induced neuro-trauma that did not respond to conventional treatment methods. The second event was my stepdaughter's developmental issues developed as a result of premature birth and the subsequent birth traumas. Both events resulted in brain-based impairments: for me, loss of brain function; and for my stepdaughter, inhibited development. Neither sets of brain-based impairments responded to conventional skill-based or pharmaceutical based treatment modalities, thus necessitating a different approach to getting better.

I consider myself a research engineer, in which my professional career began with JPL-NASA and my work related rocket science. This work expanded to the field of neuro-engineering. Professionally, my work for NASA included space projects that imaged every planet in our solar system, landing a vehicle on Mars, and various manned missions. My professional skills were further sharpened while participating on Department of Defense projects. Using my enhanced knowledge and these experiences, I refined and redirected that knowledge to the field of psychology and neuro-engineering. I have developed brain analysis and remediation programs that address developmental delays in children and adults, and head injuries and substance abuse recovery. These programs can be delivered either in a home setting or in a multi-center clinic environment. To my satisfaction, this method has been successfully applied to many thousand individuals over the last thirty years. The choices made in developing NeuroCodeX® and NeuroCoach® processes were based upon logical engineering research and development methods influenced by personal experiences. It is hoped that in explaining how the process was developed, this might spark an idea or two in others in the field of applied psychology as they develop clinical applications designed to help their clients.

Scientific design processes subdivides into three segments: 1) pure research; 2) research and development; and 3) manufacturing. In general, research scientists study how nature works and focus on pure research. Engineers, on the other hand, create new things. Engineers, in general, focus on product development and manufacturing, while research engineers bridge the scientific fields by focusing on research and development of new applications. Scientists and engineers express the scientific design process differently, as they contribute their specific knowledge to the world. For example, a scientist will use the scientific method to make predictions about the world and test their forecasts. Scientists ask questions, develop experiments, and then answer their experimental question by following a prescribed scientific method. In this manner, scientists contribute knowledge about the theoretical underpinnings that explain the physical phenomena they are studying. In contrast, engineers are considered problem solvers, who use the engineering design process and problem solving method to create solutions to problems. Engineers identify specific needs, such as '***who needs what'***, '***because why'***, and then create solutions to meet those needs. There is no fine line between science and engineering, as scientists often perform engineering work, and engineers frequently apply scientific principles.

Both the scientific method and engineering design process can be segregated into a series of steps. The scientific method is linear in nature. Once a scientist begins the experiment, the experimental steps are sequenced to completion without any deviations. At the end of the experiment, the results of the experiment are analyzed and reported to others who may be interested. In contrast, the engineering design process, even though it too is logically sequenced, is not considered a linear process, but an iterative process. As the project design progresses, the results *of the step* is examined for possible improvements. At any point in the process a new or better idea may be considered and sequenced back through the system. The reintroduction of ideas allows for a continuous improvement of the design until the engineer either comes to a final solution or exhausts his resources. This chapter will discuss the steps of the engineering design process used in the development of the BrainRecovery for Addiction program.

3.0 Identifying and Establishing the Need - Severity of the Addiction Problem

The NeuroCodeX® and NeuroCoach® programs were initially developed to assist individuals with head injuries and/or assist children to overcome learning issues and developmental delays depending on their brain-based challenges. Good engineering quality assurance requires precise monitoring of the process. Therefore, results have always been closely monitored throughout the analysis and subsequent programs during multi-center deployment. This practice has been solidly in place since inception for two practical reasons: 1) quality assurance – to assure proper delivery of the program; and 2) to provide a means to continuously improve program results.

As the centers using NeuroCoach® increased their client base, the variety of clients and their specific needs also increased. While the centers had addiction recovery individuals in the NeuroCoach® program, those individuals typically were post-recovery and had been clean and sober for several years. These clients were interested in improving their neurocognitive abilities, memory issues, and overcoming difficulties under stress. This new population in recovery was treated as if they had an acquired head injury due to AOD use and our program results indicated they responded accordingly with expected results. Due to the exceptional results, various centers began receiving referrals from addiction recovery inpatient facilities. However, these new referrals were new to recovery and their behavioral complaints were different. Even though the clients were facing similar issue as others in recovery, their lives were further complicated by the need to resist relapsing. This new need (resisting relapsing) stimulated the redesign of the current head injury program and the development of the BrainRecovery for Addiction program.

The first step in the process was to verify that the data was, in fact, identifying a new need that was not being satisfied by another program. This prompted the question: Is there really a need for a new solution that the program was not solving or had the problem already been solved? To answer the question required the identification and then establishment of the real need, as opposed to a perceived need and a subsequent determination whether the need was currently being fully satisfied. This prompted the need to address the following questions with the resultant responses.

1. Does addiction really exist as a general problem or is it limited to a small part of the population?
2. Why is it important to solve the addiction problem?
3. What problem does the BrainRecovery for Addiction program need to solve?
4. Who needs the BrainRecovery for Addiction program?

Does the problem really exist? According to the World Health Organization (WHO), the cost of the worldwide extent of AOD use is estimated at $223 billion dollars[1, 2]. The economic impact has been estimated to be as high as 6% of some country's gross domestic product [3]. Medical costs are approximated to be 300% higher for an untreated alcoholic than for a treated alcoholic [4]. Further, AOD users account for over 12% of all deaths each year. However, despite the high prevalence of AOD use, fewer than 20% of AOD users develop clinical signs of addiction, meaning the vast majority of AOD users may not seek treatment2. One could easily infer that addiction issues *do* exist on a worldwide level and are not limited to a small population. In fact, it is estimated that addictions affects 9% of the U.S. population.

Why is it important to solve the problem? On a national level, according to Substance Abuse and Mental Health Services (SAMSA), AOD dependency and associated mental health disorders are among of the most severe health, economic, and social problems facing the U.S.2. Drug addiction is a leading cause of poor health and has enormous societal impact [3,]4. It is estimated that AOD affects 9% of the U.S. population with 40% of these individuals having concurrent mental and physiological components [3]. About 70% of addicts are employed, with their addiction contributing to absenteeism, turnover costs, accidents/injuries, decreased productivity, increased insurance expenses, and workplace violence. AOD use robs companies, government, and families of millions of dollars in health care costs, rehabilitation costs, family resources, and time away from work for those who care for the AOD individual. The economic costs are not the only costs involved. Social ramifications are significant when families are split apart. AOD affects all children, spouses, parents, and other relatives. Due to the social and economic impact, it is important to contribute an application that assists those treating addiction problems. This raises additional questions as to what problem or aspect of addiction needs to be addressed. Clearly, addiction is a vast and very expensive social and economic problem and contributes to additional collateral societal issues.

What problem does the BrainRecovery for Addiction program need to solve? A literature review has shown that while *initial* experimentation with drugs of abuse is principally a voluntary behavior, continued AOD use gradually damages neural functions that eventually impact the capacity to ***exert free will*** 4. This process ultimately turns AOD use into automatic and compulsive behaviors that consequently lead the individual into a perpetual relapse cycle. This is especially true in individuals with genetic vulnerabilities and who may suffer from chronic stress or comorbid psychiatric conditions.

Research demonstrates that addictive drugs can trigger epigenetic mechanisms that modulate gene expressions implicated in neuroplasticity4. Briefly, when gene modulation is disrupted, neurotransmitter signaling is modified, resulting in changes in information processing in multiple neuro-circuits. This modification includes reward/antireward signals that affect executive function/control, interoception/ awareness, mood/stress reactivity, and other personality expressions4. Consequently, the resultant behavioral dysfunctions are observed as addictive behaviors caused by a disruption of multiple interacting brain systems. Therefore, the BrainRecovery Program needs to address brain-based issues that occur due to addictive neuro-circuits modifications. Specifically, the BrainRecovery Program needs to target neuro-circuits that contribute to reward/antireward, executive function/control, interoception/ awareness, mood/stress reactivity, and personality expressions.

Who needs the BrainRecovery for Addiction program? Until very recently, addiction treatment research has focused mainly on behavioral and personality aspects of addiction, thus restricting the prevailing insights and subsequent treatment strategies. Behavioral studies have provided a rich understanding of how inherently complex the different phenomenological experiences and struggles can be that are encountered in addiction recovery. Respectively, these studies have also provided insights into various aspects of addictive behaviors that need to be addressed during treatment. Areas to be addressed include providing information about the addictive process, personal therapeutic insights into a person's addiction, developing skills to maintain sobriety, and the ability to express self-control over impulsive behaviors.

From behavioral research, most current AOD treatment models address the various addictive behaviors by including assorted forms of psycho-education, traditional therapy, pharmacology and/or a 12-step recovery model in their programs. However, absent from the addiction treatment literature are outcome reports on addiction treatment that includes treatment focused on brain recovery or actual brain repair. Without the necessary brain repair treatment, meta-analysis outcomes on AOD treatment programs report that the average short-term abstinence rates are 21% for untreated individuals, compared to 40% for treated individuals [5,6,7,8]. Overall, these reports suggest that treated individuals achieve higher short-term remission rates than do untreated individuals. However, these figures also suggest that 60% to 80% of individuals seeking treatment fail in their quest to maintain sobriety, making the relapse rate unacceptable to many family members of recovering AOD individuals. Clearly, the BrainRecovery Program needs to enhance existing treatment programs to improve the relapse rate for those newly in recovery by providing a brain recovery solution that augments their current treatment protocols.

In summary, the answers to the four questions in this phase of the engineering design process have been addressed. Addiction issues *do* exist as a worldwide significant problem, effecting up to 12% of the worldwide population - 9% of the U.S. population or over 27 million Americans, not to mention the toll on society in general and family members, specifically. Equally, the economic impact can be severe, up to 6% of a country's gross domestic product. Even more importantly, 60% to 80% of those who enter a treatment program currently are not successful at maintaining sobriety. Therefore, a need *does* exist to develop an application that may assist those recovering from AOD use. Further, contributing an application that aids in solving AOD issues is important not only on a family level but also on society at large. Specifically, the BrainRecovery Program would be required to target neuro-circuits that support self-control and expressions of free will. This information was critical to the next phase of the engineering design process – defining the real problem.

4.0 Setting the BrainRecovery for Addiction Program Goal

Program development began by interviewing previous recovery clients and their families to better define their experiences and struggles with recovery. There were three primary goals that needed to be achieved: 1) did the experiences of the families and those in recovery match the current research; 2) what were the common themes experienced by those in recovery that contributed to their relapse; and 3) clarifying the BrainRecovery Program goals to ensure that the program addressed the needs of those in recovery.

Almost universally, the supporting family members' common theme was their disappointment that the recovering family member had such difficulty in reintegrating back into society. Even more disappointing for the family was the recognition of their loved one prior to addiction and that individual's unmet potential was not being met even after going through an inpatient treatment program. A second theme included the frustration of the number of years it took just to determine if their loved one could maintain sobriety. A third theme was a concern whether the condition was due to a personality issue (i.e., sickness of the soul, a physiological issue, or an un-repairable brain disease.

A series of general, open-ended questions about their relapse experiences were collected from existing and previous recovery clients. The interview process ultimately included sampling over 300 individuals in recovery known to be prone to relapse. This group consisted of numerous cases that the therapeutic community considered "recovery resistant", many of the hardest cases imaginable. The average interviewee was 33 years old, had been a polysubstance user for 17 years, with an average of 10 residential treatment program failures. The focus of the interview was to determine what the interviewee felt or believed caused their continual relapse behavior.

Several themes emerged from the interviews. The most common themes included: "my intention was to remain sober and I really want to… for some reason I don't have the ability to control my impulses"; "It's my ADD issue, but ADD medications got me here in the first place, and when I take them I relapse… I am ADD so I am F…."; "It's the stress, even little things push me over the edge"; "I don't know, it seems like I can't think" or " the idea that it is bad doesn't come to me till afterwards"; " I must be a bad person, since I know something is wrong, but I don't seem to be aware of it 'in the moment' … only later when it's too late"; and more. These common statements were distilled into categories that aligned with the brain systems and specific neuro-circuits. From a behavioral perspective, the thematic categories included:

- Lack of self-control;
- Lack of self-regulation;
- Reflective thinking ability, resiliency, and impulsive behaviors.

Accordingly, this information was integrated with how AOD use modifies specific neuro-circuits that affect behavior. It highlighted an important insight into the heart of the problem, which had not been adequately addressed by the recovery programs experienced by the study group as a whole. This newly aligned information provided the needed clarification required to target the BrainRecovery Program goals. The revised primary goal of the program was to now provide a program that aids those in recovery to avoid relapse and reintegrate as a productive individual back into society, as a way to augment conventional addiction treatment programs. This new definition was supported by experiences with previous clients, close relatives and friends.

5.0 Problem Definition and Specifying Program Requirements

As an aerospace engineering undergrad, it was impressed upon the class that 50% of the solution to any problem is to be found in the definition of the problem. Moreover, all failures to problem solving can be traced back to improperly defined problems. As I worked on spaceflight projects over the years, these two problem-solving principles proved to be true time and time again. To create a proper solution to a problem required that the problem be properly defined, otherwise the missing part of the definition would invariably create a new problem that represented a failure in the engineering design.

Consequently, ill-defined solutions are defined as lacking clarity and specificity in their goals and solution paths. In contrast, well-defined problem solutions require specific goals and clearly defined solution paths that are properly aligned with the physical reality of the problem. Both clear goals and well-defined solution paths allow for constructive abstract thinking as the designer creatively solves the problem.

Clearly defined goals give the designer a clearer picture of what the application needs to accomplish. Goals provide a means to measure the application's effectiveness by specifying what goal the program is to accomplish and intermediate problems that require solving. For the BrainRecovery Program, the general program goal was evident from the program goal description – improve the individual's relapse rate and their quality of life. However, the phenomenological data needed to be revisited to gain a more precise definition of the intermediate program goals. This produced eight key program requirements:

(1) Improve the ability to maintain long-term *personal* goals in spite of distracting stimuli.
(2) Improve the ability to inhibit unwanted habitual or emotional impulses.
(3) Improve the ability to adapt behavioral dispositions to changing task demands.
(4) Improve the ability to modify behavior in response to errors, negative feedback, or unexpected action outcomes.
(5) Improve the ability to reflective thinking.
(6) Improve the ability to maintain an internal sense of self.
(7) Improve the ability to maintain a greater cognitive load under stress.
(8) Provide the ability to monitor key brain functions under stress and provide feedback to the status of those functions

Solution paths are defined by understanding the problem's physical nature, including constraints, and what stresses are being experienced. Defining the solution pathway is not an intuitive process, even though it becomes second nature to most experienced engineers. This is due, in part, to previous application experience, but also how the engineer understands the strengths and weakness in applicable modeling theories. Specific to the BrainRecovery Program, this requires an understanding of the nature of the addictive personality, the limitation of theoretical models, where a person is in the addiction cycle, and environmental addiction triggers.

In the field of engineering and physics, solution paths are chosen by the problem's nature and by the theoretical model chosen to model its nature in order to arrive at the desired solution. In the hard science fields, choosing which mathematical and/or theoretical model to use is straightforward. Different theoretical models that model the same physical phenomena are simply describing the phenomena from different perspectives. These unique points of view give the engineer not only the ability to observe different aspects of the phenomena, but also offer the ability to use different variables that may not be seen from another perspective. For example, when using Newtonian physics to model light or gravity, the relativity aspects of the phenomena are not observable. If the problem doesn't require relativity measures, Newtonian models are acceptable. On the other hand, if one is looking at how light is bent around the sun or a planet and the timing of when this occurs, it requires the use of Quantum physics. Both problems are dealing with light, but the solutions use different models, depending on the problem's clearly defined goal.

Likewise, in developing applications that model human behavior, the theoretical framework cannot be ignored. Many psychological theories describe the same behavior, but from different schools of thought or perspectives. However, just as in engineering, the designer should not forget that each model is describing the same physical or psychological phenomena, but highlighting different aspects from different perspectives. For example, addictive behavior from Erickson's classical conditioning theory may be described differently than from Freudian theory. Addictive behavior from a classical conditioning model does highlight many reasons behind environmental triggers, but may not provide insight or solutions to psychological wounds that may also trigger addictive behaviors.

Psychological models of mental disorders are becoming transdiagnostic[9]. This development is linked to a shift from a categorical symptom model to a dimensional perspective of mental disorders. Defining mental disorders from a dimensional perspective is bridging categorical symptom observations with the biological basis of behavior. One means that this bridge is occurring is through the use of core cognitive endophenotypes. Neuroscience research is establishing fundamental cognitive endophenotypes of psychopathology that underpin many common mental dysfunctions[10,11,12,13]. These endophenotypes offer clinicians the ability to target specific cognitive dysfunctions that contribute to the mental disorder *rather than* treating symptoms[12].

Core cognitive endophenotypes of brain-behavior models are broadening our understanding of many mental disorders by explaining the importance of unconscious schemas, motivational processes or learning and reinforcement principles, and how they relate to psychopathology[10,11,12,13,14,15]. Cognitive endophenotypes are specific cognitive traits (deficits) found to underlie part of the symptoms of a mental disorder and are related to specific neurocognitive functions. These functions include memory, attention, executive functions, with well-defined neuro-circuit definitions and measures. Impulsivity is an example of a meaningful cognitive endophenotype. Impulsivity has been recognized as a core endophenotype for several disorders including ADHD and AOD use [15]. The BrainRecovery model incorporates the core cognitive endophenotypes concept as its primary theoretical framework.

Incorporating the core cognitive endophenotypes concept into the BrainRecovery model required the phenomenological data to be revisited. We needed insight into how treating therapists characterized their clients in recovery. In the needs analysis phase of the design process, data was collected from AOD treating therapists. They were asked how they characterized a person in recovery and what they thought would help them best treat their clients. In response, therapists characterized recovering individuals as intelligent, highly engaging, likeable, charming individuals, but were impulsively driven, made poor decisions, and were unreliable with poor memories. The therapists rounded out their assessments stating that the recovering addicts generally seemed unaware of themselves, others, or their surroundings. Additionally, it was noted by the therapists that with only a minimum level of stress, the recovering addict would exhibit some sort of co-morbid psychopathology that separates them from society and does not allow them to integrate. Moreover, the vast majority of the therapists were convinced the issue was absolutely an attention and impulse control issue, with co-morbid psychopathologies, and nothing more.

When the phenomenological data was reexamined from a behavioral perspective, it was easy to draw a similar conclusion – these folks clearly had difficulties controlling impulses, in addition to exhibiting attentional and antisocial behaviors. However, after distilling the same information from a cognitive endophenotype perspective, the conclusion was different. The data clearly highlighted a disruption in cognition **not** attention. This included being aware and cognitively present. The data also indicated disruptions in the ability to self-regulate and exercise self-control of impulsive actions.

Cognition functions from various cognitive domains as an integrated system. These domains include, but are not limited to, arousal, perception, attention, memory, learning, thinking, mental organization, affect (feeling) and expression, plus executive functions. Addiction and neuroscience research consistently defined many brain regions and associated neuro-circuits that aligned with the cognitive endophenotype concept. More importantly, six theories collectively provided a framework that explained much of the phenomenological experiences of the addicted brain. Table 1 details the resulting targets of the BrainRecovery Program in the final problem definition.

Table 1 Specific Issues Addressed by the BrainRecovery Program

ISSUE		SOLUTION PATH THEORY
Improve ability to be present and aware – Access to conscious will power to be at choice		
1	Improve true sense Self-Efficacy by clarifying beliefs regarding one's ***current ability to function*** cognitively, perceptually, interpersonally, physically, and emotionally.	Self-Awareness Theory
2	Improve the ability to be present and self aware in the moment.	
3	Improve the sense of personal continuity across time including feelings of self with regard to community.	
4	Improve the ability to reflect on past experiences and integrate them with present events.	
Improve actions in the world – either unconscious/conscious and self -aware actions		
5	Improve processing balance between Reflexive-Emotionally Hot-Reflective Thinking Cold Systems.	Addiction Dual Process theory
6	Eliminate cognitive biases including attentional biases, memory biases, and approach/avoid biases.	
7	Improve ability to reflectively think by improving cognition, being emotional neutral, cognitive flexibility.	
8	Improve resiliency to stress.	
Improve the ability to self-navigate ones trajectory in the life		
9	Improve the ability to hold in mind the commitment to be sober as a goal.	Self-Regulation Theory
10	Improve the capacity to alter thoughts, emotions responses, and change behaviors.	
11	Improve self-control processes that regulate urges, juggle competing goals, and sustain attention.	
Improve the ability to maintain the mental Stamina to achieve Self Goals		
12	Improve Mental Stamina.	Ego Depletion Theory
13	Monitor Mental Fatigue as a relapse trigger.	
Improve the ability to accomplish task		
14	Improve cognitive load task capacity.	Cognitive load Theory
15	Improve the ability to maintain the cognitive load capacity under stress.	
Improve the ability to expand and maintain a greater world view		
16	Improve the narrowing of "consciousness" the myopic or tunnel vision effect.	Load Theory of Attention & Cognitive Control
17	Improve the ability to be cognitively accommodating ("shift gears") and be cognitively flexible.	
18	Improve attentional control.	

6.0 The Nature of Addiction and Related Concepts

The BrainRecovery Program assesses mental issues and disorders from a dimensional perspective, specifically from a core cognitive endophenotype framework. From this perspective, the BrainRecovery model has converged to characterize the nature of addiction as a failure in the decision-making neuro circuitry as described by the Addiction Dual-Process Theory. Equally important, the BrainRecovery model recognizes that several key areas of the brain are adversely affected when they fail to process information properly, and relapse to addictive behaviors is most likely to occur. The brain failure modes are supported by data results that are consistent with several psychological theories that comprise of Self-Awareness, Self-Regulation, Ego Depletion, Cognitive Load and Load Theory of Attention and Cognitive Control.

6.1 The Nature of Addiction - The Addiction Dual-Process Theory

To describe human judgments and actions, behavioral economists proposed a useful heuristic dual-process model of brain function based on two modes of operation (automatic vs. analytical)[16,17,18]. The general model has been applied to many aspects of human behavior with a unique focus on psychopathologies including addictive behaviors. The general dual-process model suggests that behaviors are guided by a balance between two distinct cognitive systems: A "hot" system, a phylogenetically older emotionally based, system that is associative in nature, operating through fast automatic viscerally based processes, while a the "cold" system, a phylogenetically newer, cognition based, thinking based system, operates through slower controlled processes that are propositional or logical in nature[19,20,21]. Several researchers have presented evidence that the two systems are strongly influenced by stress and the dynamic interactions among genetic, epigenetic, developmental, and environmental factors. This shapes the structure, connectivity and function of the brain and the resulting mental landscape4[,22]. Further, according to the addiction dual-process theory, imbalances in the interaction between the hot and cold systems result in lack of willpower that produces relapse behaviors.

Using a "hot-cold" dual-process framework, Metcalfe and Mischel [20] explained how the interaction of the two systems clarified the processes that undermine will power and self-control. The process is described as involving two distinct interacting systems of thought and behavioral responses "hot and cold". The hot emotional system is specialized for quick emotional processing that combines with automatic, intuitive brain processes. The hot system is the basis of all emotional expressions, including fears and passions and is independent of language and logic. The hot system relies on heuristic methods to interpret experiential evidence. This includes the ability to recognize patterns from experiences, and makes associations with similar experiential cues, schema or scripts. Likewise, this non-analytic process is holistic in nature, depends on context and domain specific perceptions, thus is pragmatic, rapid, non-conscious, and automatic or reflexive in nature.

Hot emotional actions are expressed as visceral urges such as hunger, thirst, pain, AOD use, and sexual arousal. These urges are expressed either constructively or destructively. Constructively, hot expressions are often explained in terms of tacit or intuitive knowing [23,24]. According to Polanyi [25], tacit or intuitive "knowing" represents practical understanding of a topic and is akin to a gut feeling of "knowing how".

In contrast, destructive hot emotional actions are expressed impulsively, in response to externally or internally stimulated cues that produce urges requiring immediate need for satisfaction. Impulsive visceral urges are the driving force behind uncontrollable cravings, such as hunger, thirst, pain, AOD use, and sexual arousal. The key feature of this system is that once an impulsive urge engages, it presents with an immediate uncontrollable need for satisfaction. It is this need for immediate satisfaction that helps explain why some people sometimes make unhealthy choices when unchecked or loosely checked by other more rational brain systems[24], even if they "know" better.

The hot emotional system in our model is particularly sensitive to environmental cues. The hot emotional system has been shown to be highly responsive to outside stimuli, and operates under classical stimulus response principles [26,27,28,29]. Conditioned responses then form biases in cognition known as cognitive biases. These external environmental cues act as unconscious triggers. Once triggered, they are experienced as impulses, or in our case, as AOD cravings.

Three predominate sources of cognitive biases have been identified as a learned behavior: selectively capturing attention (attentional bias), positive/negative memory associations (memory bias) and approach/avoid behaviors (approach/avoid bias). Research has shown that any one or more of these biases predicts AOD use [26,27,28,29], especially in individuals with low cognitive control abilities including working memory[26,27,28,29] or poor response inhibition. Moreover, recent meta-analyses are finding that implicit cognition is a strong and reliable predictor of substance use [26]. Elimination of cognitive bias is an important element in the BrainRecovery Program. A Cognitive Bias Modification program was implemented to address this aspect of the addiction dual-process theory.

In contrast to the hot system, the cool cognitive system specializes in complex thought. The cool system is characterized as a cognitive thinking system that engages thought processes and includes the ability to evaluate behaviors and express our will. Characteristics of the cool system include cognition, emotional neutrality, reflective, flexible, integrated, coherent, slow, episodic, and strategic. These processes depend upon language acquisition and involve the mental and cognitive faculties associated with abstract and logical thinking. The process is rule based with analytic processes and thus requires the utilization of working memory. The process is domain general and independent of context, with slow, serial operations. This is the foundation of scientific reasoning. Above all, the cool system is considered the seat of self-regulation and self-control for self-directed behaviors [20,21,22,26]. It is important to note that, reflective thinking is a mental processing state that operates iteratively. Reflective thinking continuously processes and reevaluates current information available in the moment and compares it to whatever topic is being reflected upon. In the case of maintaining sobriety, this would include evaluating and reevaluating the pros and cons of AOD use and then activating and sustaining the will to engage in required actions needed to resist AOD use. Similarly, as in the case of the hot system, this description of how the cool system operates dictates that any addiction recovery program must account for dysfunctional neuro circuits that would weaken or disrupt ones thinking abilities. A Cognitive Rehabilitation Training program was implemented to address this aspect of the addiction dual-process theory.

For those in recovery, the health of the processing integrity of both the hot and cold systems is of particular concern especially when integrating the concept of self-awareness. The study data indicates those suffering from an over active hot system or weak cold system includes, but is not necessarily limited to, anxiety, interrupted sleep or insomnia, anti-social behavior, oppositional-behaviors, borderline behaviors, and a compulsion to use. Aiding those in recovery to become more self-aware "in the moment", and quieting the hot system, while simultaneously strengthening the cold system, proved to be three of the most important markers affecting long term sobriety.

6.2 Failure Mode (1) - Self-Awareness Theory

Self-Awareness theory is defined as the capacity to recognize the "self" objectively, while simultaneously maintaining a sense of subjectivity about the "self" [30]. Moreover, individuals only become self-aware when they reflect on past experiences while maintaining a feeling of self as being distinct from the rest of the environment across time[31,32]. Self-Awareness involves incorporating an accurate sense of self-efficacy regarding one's ability to function cognitively, perceptually, interpersonally, physically, and emotionally[31]. This definition is important for our brain recovery model as it helps to clearly define the solution path and the remediation program requirements, including areas of the brain that need to be addressed.

Self-Awareness theory also makes an important distinction between being simply conscious and being self-aware. First proposed by sociologist George Herbert Mead, consciousness is described as processing incoming environmental information without regard to self or self-knowledge[33]. Individuals not self-aware but purely conscious are able to successfully process environmental information, respond to it adaptively, *but without any regard to how they feel or what the consequences may be to their own life* [34,35]. This suggests that many of the experiences expressed in the thematic portion of our study, occurred while those in recovery were mainly conscious, but not self-aware. When reviewing the quantitative data study results, this factor is noted as a key relapse failure mode.

More practically for our model, self-awareness consists of three important measurable constructs that have been incorporated as part of the progress tracking module in the NeuroCoach® program. These constructs include metacognitive or global awareness, emergent awareness, and anticipatory awareness[36]. Metacognitive awareness is required to successfully complete a task in the context of everyday situations. It includes the awareness of the task characteristics and strategies in addition to a personal sense of self-efficacy, one's beliefs and affective states. More importantly, it includes knowing how and when one's characteristics and abilities influence the outcome of task[36].

Emergent awareness requires self-monitoring of one's cognitive state in order to recognize errors, to self-regulate to adjust performance, and to self-evaluate to compare beliefs and perceptions with performance outcomes. Emergent awareness is defined as the ability to recognize difficulties as they occur moment-to-moment during task performance. Emergent awareness uses the brain's self-monitoring, self-regulation and self-evaluation neural systems during task performance to operate. These neural systems are constantly interacting with each other providing information to each system and adjusting based upon information received from each other. This fact requires the performance fidelity of each system to be integrous due to their interdependency. Finally, anticipatory awareness is defined as the ability to predict the effect of personal deficits on future performance, such as encountering relapse triggers.

This description of the levels of self-awareness and its constructs provided practical neuro-circuit targets required for assessing and monitoring of self-awareness. This is critical for recovery. However, while self-awareness or lack of self-awareness helps us understand one major contributing factor in relapse prevention, the Self-Awareness model only explains a portion of the experiences reported by those in recovery. To gain further insight, we turn back to the Addiction Dual-Process theory to understand what happens when a person experiences a lack of self-awareness or being present in life. This has a direct influence on the ability to remain sober.

6.3 Failure Mode (2) Self-Regulation

According to Bandura[37], human behavior is motivated and regulated by self-influences that are guided by the self-regulatory system. From Bandura's perspective the self-regulatory system mediates the effects of external and internal influences that allow successful completion of desired outcomes through purposive actions that are regulated by forethought. The social cognitive school of thought uses self-regulation interchangeably with the terms *willpower, self-discipline,* or *self-control* and describes self-regulation as the ability of the self to exert control over the self [37].

Self-regulation refers to the mental capacity to alter thoughts, emotions, and change behaviors[37]. Moreover, self-regulation relies on the brains' self-control processes that regulate urges, juggle competing goals, and sustains attention. Self-regulation allows people to make plans, choose from alternatives, control impulses, inhibit unwanted thoughts, and regulate social behavior. Self-regulation is especially important for those in recovery. The ability to express self-control, especially under times of temptation, can be the defining key ingredient that allows one to remain sober or relapse.

According to Bandura[37], self-regulation operates through three self-regulative mechanisms. These mechanisms include (1) *behaviors* - self-monitoring of one's behavior, its causes and effects; (2) *thoughts* - judgment of one's behavior in relation to personal standards and environmental circumstances; and (3) *emotional responses* - self-evaluative reactions. Bandura further stresses that self-regulation also encompasses self-efficacy which further highlights the importance of the need to be properly self-aware.

Bandura explains that intentional and purposive action is deeply rooted in how the brain represents future events. Future events are represented cognitively in the present as thoughts in the mind. These representations are then the foundation for personal motivators and regulate future behaviors, thus shaping or guiding actions, thoughts and emotional responses. What is important to note is that these representations shape the future (i.e., committed will power, when expressed as a causal agency, actually resides and is anchored in one's conceptualized forethoughts). Furthermore, the self-regulatory system translates these forethoughts into incentives that guide all purposive actions. For those in recovery, this means that one must not only have the goal of staying sober in mind, but also the internal commitment to remain sober. More importantly, the brain must be capable of self-regulating and expressing this willful commitment. Weakness in the brain self-regulatory system will produce self-regulatory failures that promote relapse. Using the knowledge of the self-regulation system operation in conjunction with the dual-process model hot-cool system functionality, clarifies many contributing relapse factors. A good intention, with an inability for the brain to self-regulate, paves the way for relapse. Equally true, failure in maintaining a good intention, even with strong self-regulation abilities also paves the way for relapse. The next three failure modes address possible areas in the brain that contribute to intentional failure.

6.4 Failure Mode (3) Ego Depletion Theory

Most everyone has experienced times in their life when they were either tired or overwhelmed and simply went along with the flow. This behavior often results in decisions that are ultimately regretted. These are times when the sense of self or sense of ego is weak. These times have been shown to affect our ability to hold and execute proper intentions[38,39].

Psychoanalytic theory defines the ego as the part of "self" that experiences and reacts to the outside world. It is this part of the self that adapts through one's intentions and sets the mediation tone between primitive drives and the demands that society dictates, including the physical environment. It is the seat of our 'I'ness. When it is weak, so are our intentions. Weakness in ego strength paves the way for primitive drive expressions, lack of social adaptability, and allowing psychopathology behaviors to dominate, regardless of our good intentions or the strength of our brain processing abilities[38,39,40,41].

Baumeister [39], in his Ego-Resource Depletion model, described how one's ego strength fluctuates depending upon cognitive effort and how it affects ones self-regulation abilities. Baumeister proposed that self-regulation, like many other cognitive domains, fatigues with extended effort. In the ego-resource depletion model, ego-resource capacities are not fixed, but fluctuate throughout the day. In this manner, the ego-depletion model casts self-regulation as an *inner* ability that relies on an *internal* resources or energy that is limited. Neuroscience studies support this concept by demonstrating that self-control is mediated by fatigue in specific brain areas involved in various aspects of behavioral regulation. Demands on self-control resources have been shown to increase behavioral impulsivity, including disinhibition and prompt myopic decision-making. Further, evidence suggests that ego depletion detrimentally effects executive function, self-control and has been found to predict AOD behaviors. From our study data, ego depletion contributes to relapse. This is based upon reports of the feeling 'brain-dead', which then promotes the need to escape this reality, and is therefore, experienced as a relapse trigger and promotes lack of self-awareness and the inability to reintegrate appropriately back into society.

6.5 Failure Mode (4) Cognitive Load

The Cognitive Load concept is more generally used in the field of computer science when describing the limits in a learner's information-processing ability. This concept is used in conjunction with the flow of information through the mind's processing structures and how those structures interact. These structures are comprised of working memory, long-term memory, and schemas of how they operate. In research, this concept has become a central theme for instructional design of learning systems with predominate focus on the effects of the working memory capacity. Learning system developers understand that the amount and type of information presented to the learner affects the learner's rate of learning or amount of information retained by the learner. Focusing on increasing the learning rate of computer applications has benefited our understanding of how to measure cognitive loads using neuro-electric measurements.

Similarly, in our work with developmentally delayed or learning challenged children, this concept has proven to be true. However, we noticed that cognitive load effects are more far reaching than just supporting the ability to learn. From our data, cognitive load capacity also is crucial to the child's maturation cycle, their ability to develop self-regulation abilities, to attend, focus, concentrate, and then to learn. More importantly for both children and adults, the concept of cognitive load also is apparent in task execution. We have found that low working memory capacity or its resiliency to stress contributes to high errors in task performance that result in short tempers, histrionics, avoidance, acting out behaviors and depressions. These observations are supported by research studies that report low working capacity contributes to executive dysfunctions and are found in many psychopathological disorders involved with self-regulation dysfunctions[44,43]. In fact, several studies reveal that low working memory capacity even predicts alcohol use[64,60,63,43]. Our BrainRecovery Program model includes the measurement of cognitive load capacity under different stress conditions that simulate stress conditions in a real world situation.

6.6 Failure Mode (4) Load Theory of Attention and Cognitive Control

Load Theory of Attention and Cognitive Control provides a framework for understanding the cognitive mechanism involved in ego depletion. These mechanisms include attention, awareness, and cognitive control. In Load Theory, perceptions are limited by the brain's capacity to receive and process information (the brain has a sensory component to working memory)[42]. Moreover, perception is an involuntary automatic action that occurs when the brain is conscious. More importantly, it cannot be shut down at will. This is an ongoing process that occurs regardless if one is self-aware. For those treating individuals in recovery, this information is important because those in recovery are susceptible to environmental cues and it cannot be assumed those cues can simply be ignored by "willing" them away. This detail about how perception works helps explain why those in an inpatient recovery facility are able to have a bit more control while in an inpatient setting, but lack control once they leave the inpatient facility. The lack of environmental cues reduces the craving triggers during their stay. Additionally, this understanding also further reinforces the need to reduce cognitive biases towards AOD use as outlined in the Addiction Dual Process theory.

Of extreme importance to our Brain Recovery model is what occurs when the brain is under task. Load Theory also states that perceptual capacity too fluctuates from moment to moment, based upon the level of difficulty of the task at hand. Load Theory divides tasks into four separate categories, based upon high or low loading factors and which system is being utilized under task - the perceptual system or the self-control system. Load Theory asserts tasks with high perceptual loads (or attention) are not just fully engaging, but also fully use the brains perceptual capacity. Examples of such tasks are passionate intellectual pursuits in the arts or sciences, fully engaging problems, being fully absorbed in reading a book or even playing video games. The commonality with these tasks is that the outside world appears to disappear, along with our inner dialogs, due to the perceptual capacity of being fully engaged. The result is that irrelevant internal or external stimuli are automatically screened out. Hence, irrelevant distractors are not within the brains' conscious awareness. In Load Theory, this phenomenon is called attentional blindness, since the brain literally does not perceive anything other than its current focus. Surprisingly, this phenomenon is not an attention deficit issue, as heard from many parents and adults. It is however, how the attention system works with highly engaging and absorbing tasks. The brain simply becomes fully absorbed or lost in the task at hand.

In contrast, low perceptual tasks do not require usage of all the brains' available perceptual capacity. As a consequence, this allows the brain to receive or process more information than necessary for the task at hand. Since perception acts in an involuntary manner, the brain will continue to attend to information (external or internal) until its perceptual capacity is filled. This automatic process allows irrelevant information to involuntarily be available for processing. Examples of this process is observed as mind wondering or being distracted by folks just passing by. Again, it is important to note, this is not an attentional issue, but how the attention and perceptual system operates under low perceptual loads. The extent, to which unwanted, irrelevant, distractors are prevented from gaining control over behavior, depends on the operations of the brain's cognitive control functions.

The brain's cognitive control system has a limited functional capacity too. As in the perceptual capacity, cognitive control capacity is defined as either low or high and is a function of working memory operations. High cognitive loading tasks include tasks that use virtually all of the available cognitive control resources, while low cognitive load tasks are tasks that use only a portion of the cognitive control resources. Research has demonstrated that participants under high cognitive load have impaired self-regulation. For example, dieters under high cognitive load exhibit unrestrained eating in comparison with participants under low cognitive load[43,44]. Similarly, Muraven and colleagues[41] showed that participants who engaged in an effortful thought-suppression manipulation subsequently displayed impaired impulse control and drank more alcohol than did control participants. It was important for our Brain Recovery model to consider the brain's perceptual capacity. Perceptual capacity is dynamic and changes based upon health conditions and fatigue. The functional health and resiliency of the perceptual system is measured and monitored throughout the recovery cycle.

7.0 BrainRecovery Program Brain Targets and Specifications

Design specification details exactly what will be required of a product and how to achieve the goals before it is designed. Specifications are the performance standards that the design must meet. They are quantitative, measurable criteria that the product must satisfy. In order to be measurable and unambiguous, specifications must contain a metric, an engineering unit, and a target value. For the BrainRecovery Program this includes neuro-circuit definitions, neuro-electric measurement indices and how they interrelate.

Contemporary neuroimaging studies offer evidence that the brain is a dynamic self-organizing system[45]. This dynamic system consists of a collection of anatomically dissimilar but functionally relatable brain regions[46,47] with measurable coherent neural activity that occurs when the brain is at rest and when actively engaged[48,49,50,51,52,53]. These relationships are classified as brain connectivity. The BrainRecovery model uses three classifications of brain connectivity: structural, functional, and effective connectivity. *Structural connectivity* refers to regions of the brain that are linked anatomically by white matter tracts. *Functional connectivity* refers to brain regions that are linked by timing measurements, irrespective of whether they are directly linked anatomically. *Effective connectivity* refers to connections derived through measurements of direct causal effects that one brain region produces in another. Collectively the different kinds of brain connectivity are described as networks, designated as either structural or functional neural networks. Neural network systems have been shown to operate through a top-down and a bottom-up set of neural mechanisms[54]. Failures in these mechanisms are implicated in contributing to cognitive impairments.

Top-down neural mechanisms are the cortical neuro-circuits that exercise cognitive control on behaviors, predominately derived through thoughts, or the cold system in dual-process theories. For example, a deficiency in top-down prefrontal functional neural mechanism is associated with impaired non-adaptive learning[55,56]. Bottom-up neural mechanisms are the mechanisms that are subcortical driven, the hot emotional system. These mechanisms are the neural circuits that drive our passions and when dysfunctional, impulsivities. For example, increased functional connectivity (a dysfunctional connectivity) of bottom-up mesocorticolimbic structures with prefrontal regions has been associated with enhanced reactivity to AOD stimuli[57]. In alignment with dual process theory, the operation of these two networks suggests cognitive impairments and addictive behaviors may be attributed to differential functioning of brain networks with overlapping regional areas of the brain. Moreover, this alignment suggests that by examining the integration of task-related regional brain activity with known functional networks allow identification of the functional (or dysfunction) levels of specific neural mechanisms that underlie cognitive impairments[57]. This principle has been successfully applied to the NeuroCodeX® analysis in the examination of clinically relevant measures and is also used to monitor treatment progress.

The BrainRecovery targets six primary brain networks required to solve the problem outlined above. Three networks were chosen to improve mental stamina, reflective thinking abilities, self-referencing, resiliency to stress, self-regulation and three were chosen to improve self-regulatory abilities.

8.0 Creating the Final Solution

To summarize, the BrainRecovery Program goal was distilled as follows: *To provide a program that aids those in recovery to avoid relapse and return back into society, and that augments conventional addiction treatment programs*. Both the program goal and problem definition use a dimensional diagnostic framework. During the phenomenological data collection and review phases, two measures of program effectiveness were identified that included a relapse rate and a measure of quality of life. The problem definition design phase classified eight key program requirements, including addressing disruptions in cognition that directed the solution path. The solution path analysis resulted in modeling the nature of addiction using the addiction dual process theory. This phase of the design process identified 5 key brain failure modes, 18 key problems that need to be addressed along with 18 key areas of the brain that require monitoring during recovery, with the resultant discovery of being substantially closer to solving the problem at hand. The next task was to create the program by finding solutions to the problems previously defined.

This next phase of the design process should inherently create multiple solutions that will solve the problem, which would lead to the determination of the appropriate solution. The final step resulted in the development of a working prototype. For this phase, the data collected during the program goal and problem definition phases was applied. While this phase generated several iterations, the program continues to be improved as new information is learned about the brain.

Strict behavioral psycho-educational and pharmacological solution approaches were immediately ruled out based upon several criteria: 1) they are currently included in the conventional addiction treatment approach; 2) neither approach directly affect repair of brain circuits; 3) the phenomenological data didn't support a pharmacological solution based upon one of two commonly voiced themes by those in recovery – a)" I threw the medications away because I didn't like how they made me feel" or b) I am a drug addict and these meds are stimulating my relapse"; and finally 4) the phenomenological data didn't support a pure behavioral solution based upon the theme - "I couldn't remember what was taught".

More importantly, this decision was based upon a comparison that makes the choice more apparent. Using a racecar analogy, assume there is a high performance racecar and a highly capable driver driving entering a race. There are at least three major domains that affect the performance and end result of the race; the car's mechanics; its fuel mixture; and, of course, the driver. If the racecar isn't mechanically sound (say has a flat tire, bad fuel injectors, or bad wiring) this will affect its racing ability, regardless of the quality of the driver or fuel that is in the tank. However, if the mechanics are superb, but the fuel mixture is off, there is an equal likelihood that the race performance will be intermittent or stall. And finally, if the driver is a novice (lacks racecar driving skills), even with excellent mechanics and superb fuel mixture, the outcome of the race may nonetheless, be adversely affected. It takes all three domains in combination to be in good running order for the best outcomes.

Conventional approaches to addiction treatment currently only address the driver (by focusing on behaviors and skills) and the fuel mixture (medications). Treatment results indicate that these treatments are only 20% to 40% successful. Therefore, logically, our efforts were focused in the direction that wasn't being addressed, the "mechanical" aspects of the problem (i.e., the brain's wiring and functional performance).

Based upon our vast experience working with clients with brain injuries and learning issues, the most obvious implementation for the BrainRecovery Program was to extend the current NeuroCodeX® and NeuroCoach® programs to incorporate the needs of the addiction community. For the NeuroCodeX® analysis, additional performance measures were added that addressed the core cognitive endophenotype models of self-awareness, self-regulation, cognitive load, self-referencing, resiliency to stress, and self-regulation.

With regard to the NeuroCoach® program, its foundation is based upon cognitive rehabilitation training methods. Cognitive rehabilitation therapy is a treatment that was originally developed at King's College in London to assist cognitively impaired individuals in order to restore normal brain function[58]. The method has been successfully applied to patients with schizophrenia, brain injuries, children and adults with ADHD, as well as cognitive deficits associated with major depressions. Over the years, the NeuroCoach® remediation program has followed CRT principles. It has now evolved to include many brain exercises that promote proper brain function. A unique addition to the CRT methodologies is the inclusion of the use of brain wave monitoring technology. In order to strengthen and shorten treatment duration, the NeuroCoach® program incorporated brain wave monitoring technology to monitor how the brain performs while undergoing the brain exercises, giving both the therapist and client instantaneous feedback on brain performance while under task.

Traditionally, the CRT method uses repetitive drills and practice to facilitate improvements in cognitive domains that include memory, cognitive flexibility, attention and executive problem solving, without the use of brain monitoring or biofeedback assistance. The repetitive drills are regularly focused on specific skill sets that need to be *re-acquired* as opposed to the underlying neuro-circuits that need to be *repaired* to perform the skills.

Traditionally, the CRT programs can last several months to several years before long-lasting training results are observed. When traditional CRT methods were applied to a child with development delays, there was improvement in the area of the brain being trained. However, the skills often did not generalize to other cognitive functions nor promote further maturation. These two facts, in combination with a daily reminder that my stepdaughter was falling further behind her peers, prompted the need for improving the traditional CRT methodology. Our version of the CRT method evolved to include the ability to monitor neuro-circuit responses. We also took a neurodevelopment perspective and aligned the cognitive repair exercises with how core endophenotypes develop.

Over the years, working with developmentally delayed children and using the same engineering design process outlined above, the NeuroCoach® program has resulted in a set of brain based exercises that target specific areas of the brain required for brain maturation. With regard to behaviors (child or adult), two key principles were discovered in the process. First, the functional outputs of a core cognitive endophenotype developed in a specific order, and the different core cognitive endophenotypes are interrelated. Additionally, when one system was immature, related systems would be as well. This immaturity resulted in challenging behaviors at best, regardless of age. Second, each cognitive system had to perform at an age appropriate level. If not, immature behaviors would be the natural result.

For example, regardless of the age of the child, when the capacity of the auditory short-term memory did not measure to age appropriate levels, primary speech development was negatively affected. Further, the quality and fluidity of speech also was directly related to auditory capacity of the short-term memory. The greater the auditory memory capacity, the more fluid the speech, until it reached adult capacity. In addition, the capacity of the auditory system fluctuated based upon stress and the resiliency of the nervous system, and this fluctuation affected behavior. For example, when the auditory working memory system was under stress, its capacity was reduced. If the reduction was below a certain capacity level, the result was some form of acting out behavior. This was true not only with children, but also with adolescents and adults. The difference in adults and adolescents was that the behaviors were often expressed as anxiety or explosive tempers. Later, this observation was extended to include behavioral response from several other brain systems. When we applied these principles to the addiction population, we found these two principles held true for this population as well, and contribute to co-morbid diagnoses. Our study data also highlighted that one of the consequences of AOD use is that many of the cognitive endophenotype functions lose their natural resiliency under stress. The observation coincides with expressions of co-morbid psychological behavior expressions that after treatment went away.

Based on these documented observations and recorded expressions, the NeuroCoach® program has evolved to an advanced form of CRT methodology. At this time, the program is now able to address 17 of the 18 intermediate problems that required resolution. This last intermediate problem required us to reconsider how the NeuroCoach® program was designed. Initially, intermediate problem number 6 – Eliminate *cognitive biases including attentional biases, memory biases, and approach/avoid biases,* didn't appear to require strengthening of any core cognitive endophenotypes. From our understanding, cognitive biases were associatively stored memories that were situational evoked. This assumption proved to be only partially correct. However, after revisiting the quantitative data, what we found was a non-conscious emotional response that weakened one's ability to exercise self-control in the moment when a cognitive bias cue was stimulated. This meant that problem 6 definition could have one of three solution paths: 1) reduce the strength of the associative cognitive bias memories; 2) strengthen one's self-control ability when emotionally provoked by environmental cues; or 3) provide an integrated solution that both reduces cognitive bias associations and strengthens self-control during cue reactivity times. To address this combined problem, we implemented a module based upon Cognitive Bias Modification (CBM) methods in the NeuroCoach® program that operates in conjunction with strengthening the self-control neuro circuits. The CBM methods are targeted at ***decreasing*** non-conscious automatic processes and have been found effective at altering attentional bias[59,60], memory bias[61,62], and approach/avoid bias[63,64].

9.0 Test, Redesign and Refine the Solution

The final steps in the engineering design process consist of testing the product to determine how close the product results match the design specifications and then refining the product until the design converges to meet the design requirements. These requirements included the effectiveness of the BrainRecovery Program at reducing the relapse rate and the program's effectiveness at aiding recovering individuals' productive reintegration into society.

To determine this viability three important outcome measures were required to demonstrate positive effects. Two of these measures were a result of the problem definition phase. Answering the intervention causality question required the third measure. The outcome measures needed to reflect: 1) improvements in the rate of remaining sober, 2) positive changes in social reintegration, and 3) positive causal treatment effects resulting from the BrainRecovery intervention. Of the original 300 individuals we randomly chose 150 individuals, who completed the training program, and followed them for 18 months post treatment. The average interviewee was 33 years old, had been a polysubstance user for 17 years, with an average of 10 residential treatment program failures. The following describes the study results post treatment.

Did the treatment demonstrate improvements in the sobriety rate? At the 18-month follow up, 89% of the follow-up group maintained sobriety, 98% had transferred from sober living facilities and were maintaining their own residency. The 89% sobriety rate is a substantial improvement as compared to the 20% to 40% sobriety rate reported in the literature, indicting that the BrainRecovery Program was successful at improving the sobriety rate and did augment existing inpatient/outpatient treatment programs.

Did the treatment demonstrate positive changes in social reintegration? To answer this question pre and post measures of individual resiliency, personality, and quality of life data were examined. In addition to improvements in the sobriety rate, resiliency scores collected from the Connor-Davidson Resilience instrument indicated a significant positive pre-test and post-test changes in-group level score. Resiliency is defined as the ability to become stronger, healthier, or more successful after encountering an adverse event. From the initial collected data, group level resilience scores averaged at 49 points, which is consistent with previous PTSD and AOD studies[65]. However, post treatment group average scores made significant improvements by 32.5 points up to 81.5. These scores were now consistent with the general population. Further, an examination of pre and post quality of life phenomenological data also revealed equally significant changes.

Pre-test scores of quality of life data indicated that the group was highly dependent, not self-supporting, had difficulty with employment and/or had drop out of school, and in constant legal issues of one kind or another. In contrast, the post-test data indicated that 98% of those monitored for 18 months post treatment program reported no arrest records or new legal issues, were employed, in school or in vocational training. The positive report of no new arrest records, employment, school attendance or vocational training, in conjunction with maintaining their own residency demonstrates a positive social reintegration effect derived from the BrainRecovery Program.

Nonetheless, these measures only partially yield insights into how well the self-regulation system is responding. To gain further insights into the strength of response we examined reports from data collected from the Millon Clinical Multiaxial Inventory-III. This segment of the examination addressed two primary concerns: 1) were there significant global reductions in personality issues, including externalizing and internalizing behaviors; and 2) did the symptom changes result in clinically significant results. Rushton & Irwing's[66] General Factor of Personality (GFP) framework was used to model the GFP and the externalizing and internalizing behaviors factors. The examination documented a GFP general reduction of 42% in general harmful behaviors, 38% reduction in harmful externalizing behaviors, and 48% reduction in internalizing behaviors. These results indicate a positive treatment effect. Additionally, the second examination question used the same personality data and also indicated a significant clinical effect. Table 2 depicts the clinical significant factors along with the associated reduction in undesirable behaviors.

Table 2 Significant Clinical Changes based upon Millon Clinical Multiaxial Inventory-III

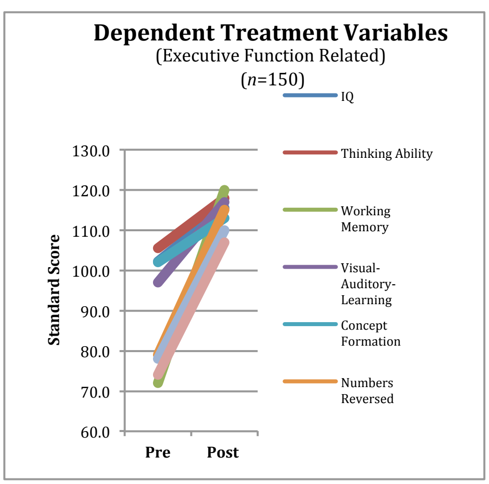
Clinical Patterns	Clinical Significant		Symptom Reduction		Clinical Patterns	Clinical Significant		Symptom Reduction
	Pre	Post				Pre	Post	
Avoidant	Yes	No	48%		*Anxiety*	Yes	No	53%
Depressive	Yes	No	41%		*Major Depression*	Yes	No	55%
Dependent	Yes	No	46%		*Dysthymia*	Yes	No	53%
Antisocial	Yes	No	38%		*Somatoform*	Yes	No	54%
Borderline	Yes	No	42%		*Thought Disorder*	Yes	No	42%
Paranoid	Yes	No	44%		*Delusional Disorder*	Yes	No	39%

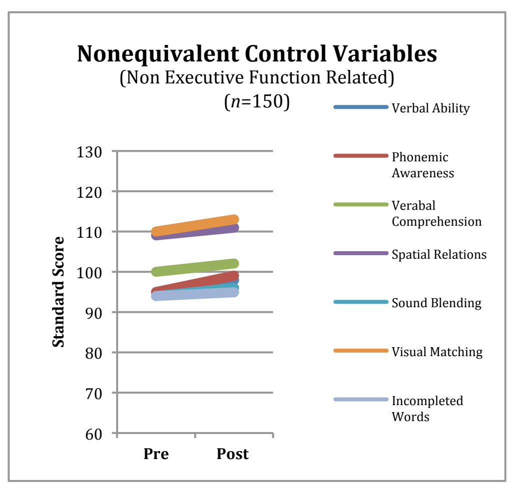
Did the treatment demonstrate causal treatment effects? A quasi-experimental non-equivalent dependent multivariable design was used to answer this question in conjunction with the Reliable Change Index. This design was chosen over a traditional randomized control design for clinical and ethical considerations. It was determined that a study that employed randomized assignment to a control group and treatment group in which all subjects are actively seeking sobriety and control over their relapse rate would not have benefited those seeking clinical help and therefore deemed unethical for the study. Therefore, a quasi-experimental method not only aimed at demonstrating causality between an intervention and an outcome result, but also supported a single group non-control experimental design was chosen[67].

Two little used methods of demonstrating significant changes statically and clinically are Non-equivalent dependent multivariable designs and the Reliable Change Index calculation[68,69]. Non-equivalent dependent multivariable designs continue to be recommended as a preferred choice in demonstrating clinical effectiveness for many medically based treatments[68]. This scientific design uses one or more variables not subject to treatment as a control variable in order to demonstrate causal inference. The design involves the inclusion of one or more primary dependent variables along with one or more nonequivalent dependent variables and can be used with a single subject group. A nonequivalent dependent variable is defined as a control variable that acts like a control group. The variable is required to be affected in the same way by history, maturation, and other single group internal validity threats as the treatment variables. However, not so much alike that it is affected by the treatment. Both classes of dependent variables are required to assess similar constructs, in our case brain performance measures, such as the ability to recall information (dependent variable) and phonological awareness ability (nonequivalent dependent). The key that makes this method effective is that both classes of variables are influenced by similar non-treatment factors and confounds. However, only the dependent variables are exposed to an intervention (i.e. treatment addresses memory neuro circuits, but not the auditory processing circuits). After treatment, dependent variables are expected to change based upon the interventions applied (better ability to recall information). In contrast, nonequivalent dependent variables are not expected to change after treatment (no change in ability to hear sounds). Treatment effectiveness including casual inference conclusions is demonstrated by the resulting outcome comparison of the expected pattern (expected changes only with the dependent variables and little to none in the nonequivalent variables)[67,68].

For our study, eight dependent measures and seven nonequivalent measures were chosen from the Woodcock Johnson Cognitive Abilities III Assessment Battery (WJIII). The WJIII is a set of intelligence tests based on the Cattell-Horn-Carroll (CHC) theory of cognitive abilities. The CHC theory provides a comprehensive framework for understanding the structure of cognitive information processing abilities in performing cognitive tasks. Dependent variables were chosen from the WJIII that are effected by executive function changes, while the nonequivalent control measures were chosen based upon sensory system measures that were not expected to change due to treatment. Figure 1 and Figure 2 depict pretest and posttest group scores. As anticipated when applying the pattern match step to the analysis, the study results demonstrated a positive pattern match for a causal inferential response to treatment, thus allowing a positive conclusion that the BrainRecovery Program treatment does positively influence the areas of the brain that are involved in executive thinking and control.

Figure 1 *Treatment Dependent Measures* **Figure 2** *Nonequivalent Control Variable Measures*





The Reliable Change Index (RCI) was developed to provide a measure of both *statistical* and *clinical* significance of changes due to a treatment. This measure is very useful as a statistical measure of category membership and can demonstrate the effectiveness of a rehabilitation program[69]. The RCI demonstrates how much, and in what direction an individual has changed, and whether those change are reliable and clinically significant. The study results were examined using a variation of the RCI that accounts for practice effects [103-106]. Statistical and clinical significance is indicated when RCI values are equal to or greater than 1.96 (the 95% confidence interval)[69,70,71,72]. Table 3 depicts normalized RCI values. The RCI values were normalized by the minimum RCI value that signifies statistical and clinical significance. Values of 1 or greater signify that the treatment changes are both statistically and clinically significant. As anticipated, dependent cognitive measures met or exceeded the minimum 95% confidence interval requirement, while nonequivalent dependent variables did not.

Table 3 Treatment and Non Treatment WJIII Cognitive Abilities Variable RCI values

Treatment Variables	RCI		Non Treatment Variables	RCI
IQ	2.84		*Verbal Ability*	0.77
Thinking Ability	1.72		*Phonemic Awareness*	0.85
Working Memory	1.14		*Verbal Comprehension*	0.72
Visual Auditory Learning	1.90		*Spatial Relations*	0.41
Concept Formation	1.30		*Sound Blending*	0.59
Numbers Reversed	1.19		*Visual Matching*	0.35
Auditory Working Memory	1.87		*Incomplete Words*	0.61
Visual-Auditory-Learning Delayed	3.26			
Cognitive Efficiency	1.08			

10.0 Chapter Conclusion

The development of the BrainRecovery Program used a neuroengineering approach in order to solve brain based behavior issues. Further, the BrainRecovery Program applied to AOD recovery has consistently demonstrated through evidence-based documentation significant improvements in recovery outcomes. A focus on strengthening self-control neuro-circuits allows greater will power to be exercised *in the moment* over unwanted impulses or desires. The program outcomes have also demonstrated that the cognitive repair techniques used in the program, when properly applied to the areas of the brain impaired by substance abuse, allow productive reintegration into society. In this manner, the BrainRecovery Program has demonstrated that this approach can and does define brain challenges that are *not* observed by strict anatomical means nor based upon a client's self report. The BrainRecovery Program, when used in conjunction with traditional AOD therapies, has been shown to further reduce AOD behaviors, assist those in recovery to overcome relapse challenges, and aid in proper social reintegration.

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