The Evolution of NeurOptimal® from a Linear Training Approach to a Non-linear Dynamical Model of Neurofeedback.

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Those of you familiar with NeurOptimal® have heard it described as a non-linear dynamical system. But what on earth does that mean? Why would it matter? Why would you care? While you may be forgiven for yawning this early in the article, the distinction is a crucial one. It directly affects the safety of the system, the far-reaching and all-encompassing nature of the effects you can expect, and how easily and cheaply you can access training. Individually, these are not minor considerations. Together, they are remarkable.

At the time Val and I began seriously thinking about producing our own software, I had a busy full time practice as a Clinical Psychologist in New York. As a Clinical Psychologist I was very much part of the medical model of practice. Indeed, I was on the medical staff of not only my local hospital but also the academic medical center at the State University of New York at Stony Brook Health Sciences Center. I also lectured regularly at various institutions, including medical institutions. Yet when Val and I began thinking about creating a new neurofeedback software, our vision was far from one based on a medical model. Why was this? It is because the medical model is fundamentally based on the diagnosis and treatment of disorders. While this model has been extraordinarily successful in so many ways, we believed strongly it was not the most functional approach for training the brain. So what was the alternative? By definition, the brain fulfills criteria for definition as a non-linear dynamical system and there is a whole area of research that deals with how you can control such systems. While use of the word "control" is discomfiting to us as psychologists, it is actually describing the means by which you can impact such systems. If we were then to apply these means to impacting the brain, we reasoned, one of the big advantages would be that diagnosis (and the related testing and evaluation) becomes irrelevant. This factor alone immediately reduces the level of expertise required in the user, considerably improving the economics of care.

Our view was relatively simple and straightforward — we thought. (It turned out to be a much tougher journey than we anticipated due to unexpected and vehement opposition and antipathy it triggered among many of our colleagues, a very real phenomenon that Val in particular, weathered for years). We knew we wanted to base the technology on the brain being a non-linear dynamical system. We wanted it to be safe, effective, and as mentioned above, not require diagnosis. Val had already made important in-roads in all these respects with his Five Phase Model *(more on that later). But we also wanted it to be easy to use, requiring neither special education nor particular expertise. We both fundamentally feel that you, as an individual, have the right to information about your own brain and ideally would not have to go through an expert to access brain training. Astonishingly, our desire to make it simple was probably the biggest factor contributing to our unpopularity in the field, its simplicity placing it well outside the medical model embraced by our colleagues. It challenged the dominant paradigm. In the early days we were working with a software designed by a prominent manufacturer and had been invited to spend a weekend with the owner and the head software engineer to offer our input. At one point I offered a suggestion that I believed "…would make it simpler". The designer's response amazed me: "I don't want to make it simpler. It should be hard. People who use our software should be highly trained". He thought harder was better! I realized then this was a world view diametrically opposed to how both Val and I thought. Although I was highly trained (actually more so than some of our critics), I fundamentally believed that one of my roles was to make it as easy as I could for others. These philosophies informed our design in a way that determined the evolution of NeurOptimal® in fundamental ways we could not have foreseen back then. In fact, its evolution ran so contrary to our everyday view of reality, that had you described to me back then what we were going to do today, I would not have believed it could have worked. So let us begin at the beginning, with where the field was, back then.

As I have written elsewhere (Brown, 2011, 2016), when I entered the field of Neurofeedback, practitioners were doing one of two things, with no interchange between the two. Some were doing

SMR-beta training for Attention Deficit and related Disorders. Others were exploring consciousness with alpha-theta training, which later was applied with some success to the treatment of Alcoholism (Peniston & Kulkosky, 1991). Both approaches involved training with very limited frequency ranges, augmenting either SMR (13-15 Hz or 12-15 Hz) and beta (15-18 Hz) or alpha (usually 8-13 Hz) and suppressing theta, considered to be 4-7 Hz. Neurofeedback was used for treating medical disorders and the impetus of the field as a whole was (and still is) to gain acceptance within the medical community. In contrast, Val had published his Five Phase Model (Brown, 1995) which took all clients, regardless of diagnosis, through a structured series of training steps featuring all the frequencies then currently available (SMR, beta, alpha). In addition to this universally applicable form of training, he identified 3 Hz as fundamental to disorder. He described its behavior as much like a hurricane, co-opting the energy of the central nervous system and leaving little for anything else. As 3 Hz quiets during training, the brain is able to apply that energy towards the many other frequencies that allow healing to occur. In fact, 3 Hz is so fundamental that if I could do only one thing, I would down-train 3 Hz over and above everything else. In his Five Phase Model Val was suppressing 3 Hz with a 2-6 Hz suppress, allowing 7 Hz to roam freely. He did not up-train 7 Hz, but described it being a little like a breeze. You can't make it happen, but you can open the window to let it come in. He identified 7 Hz as a crucial component of realization, or what we came later to call the "Aha! Response". This difference from the rest of the field (suppressing specifically 3 Hz and leaving 7 Hz alone) does not sound like much, but the clinical ramifications are huge. Pulsing 3 Hz carries trauma and is a major contributor to side effects during training, so down-training 3 Hz made training for clients significantly more pleasant, proceeding without elicitation of old traumas and other unwanted side effects. This was a monumental contribution to the field in my view, but despite Val's many presentations on the topic, our colleagues disappointingly demonstrated little interest.

After Val and I got together as a couple in 1996 but before we had worked on our own software, we had another of the prominent manufacturers at that time make us a suppress filter that met our criteria. That same year I went to a workshop hosted by a colleague, which used the same major neurofeedback system I just referenced, but with their standard suppress filters. I had taken the week off and looked forward to personally exploring alpha-theta training more deeply. Instead I found myself supporting my fellow participants as they sank into tears and despair while I myself fought a continual migraine — all the results of not suppressing 3 Hz. One of the helpers at that workshop (who later went on to create his own neurofeedback system), knew that we were using a different set of suppresses to the standard, and at one point he asked me why. I told him it prevented the release of overwhelming emotions and other side effects, during training. He responded with a question that blew my mind — "What emotions"? I replied hesitatingly — "What we've been seeing all this week". He was so used to seeing these side effects everyday in his own work that he did not view them as a problem! My point to him was, you can have transformative neurofeedback without all these unwanted sequelae, but to my knowledge he, and our other colleagues, are still using a 4-7 Hz suppress. If they are not, Val has never been credited for the change!

Our desire to have safe neurofeedback accessible for everybody to use, not just experts, caused us (or mostly Val really, as he was the "front"), to become increasingly unpopular in the field. We were saying we have a safe and effective method of working that anybody can use, with diagnosis not only not necessary, but totally immaterial. This effectively made irrelevant the extensive training and diagnostic procedures of our colleagues, and understandably they fought hard against that. Despite our unpopularity though, when I would have a booth at a conference I had a steady stream of colleagues (including those with competing systems) wanting me to run them in sessions to assist them with jet lag and the myriad of issues that inflict those that travel. And two of them, still prominent in the field, would show up for "their session" every day!

It is difficult for current users of NeurOptimal® to imagine what running neurofeedback sessions would have been like back then. All the early systems offered just one channel of training, so if you wanted to train both sides of the brain it had to be done sequentially by moving the sensor during training. You had to choose exactly what you wanted to do ahead of time, meaning which frequency bandwidth to augment and what you wanted to suppress. If you wanted to make an adjustment, you had to stop the

training, exit the software, go somewhere else in the program to reassign values and begin again. It is important to note the 'toolbox' was extremely limited. The highest frequencies anybody worked with was 15-18 Hz. Above that was suppressed to avoid "muscle artifact"; then there was one low frequency suppress (4-7 Hz), and you could choose one of two augments — SMR or Beta, and one system also offered the possibility of augmenting alpha in a separate additional program. That was it. You would manually set a threshold (level of difficulty) that the trainee would work to reach to receive feedback, which was, if successful, a beep, a buzz or if really sophisticated — a continuous buzzing tone that would go up and down with the amount (amplitude) produced. Alpha-theta would have the additional sophistication of the sound of running water or the ocean in the background. The person doing the training had to put in considerable effort, and the clinician also by monitoring the client closely to watch for side-effects and other evidence of over-training. And of course, for those clinicians who were not using Val's Five Phase Model, they also had to correctly diagnose the client and decide what frequencies they needed to be trained with based on that diagnosis. Which, to say the least was complicated, especially when the presenting picture was not especially clear, or, as often happened, the client had symptoms of several disorders, all of which required different and sometimes opposing protocols! So you make one thing better by allowing something else to get worse. And the only way you know when to change training is by monitoring the client's side effects! This is called protocol-based training, and is the predominant model (outside of NeurOptimal®) in use today.

In summary, neurofeedback training at that time was what we at Zengar today call "traditional neurofeedback". It involved a sequence of training shifting from the left side of the brain to the right, using a limited set of frequency bandwidths which result in "states". Examples of these would be relaxed awareness versus sharp focus. These frequency bandwidths lay at the heart of the "toolbox" and if you have only one suppress and two augments to work with there is not going to be a whole lot you can do. Furthermore, there were some inherent problems with the choice of bandwidths, such as 4-7 Hz (theta) suppress and 15-18 Hz (beta) augment, both of which could trigger significant side effects. Setting thresholds was done manually, often having to stop the training to make the change, and the thresholds themselves offered no additional benefit to training. Sometimes the threshold was called a dynamic threshold because every few minutes it would adjust its level based on the average of the last little while of training. (This bears no resemblance to our dynamical thresholding). Efficacy of training relied on the conscious effort of the client ("try to make the balloon go up"), and session parameters, decided by the clinician, relied on diagnosis, evaluation of how the client had been during the week, and the side-effects the client experienced during the session.

So fast forward to where Val and I were before we had truly implemented non-linear dynamical methods. Why had we not fully implemented them? One of the main challenges for us was technology. There is a movie with Kevin Costner, in which a picture of the "person of interest" (which turned out to be the Costner character) was slowly "coming down the wire" using one of the dynamical mathematics we use. The process was so memory intensive that the picture came in line by line painfully slowly through a considerable portion of the movie while the Costner character tried to evade detection. We demonstrated this technique as a means of looking at data, at a presentation we did in Europe one year. It took the whole presentation for the image to slowly fill in. Today, we routinely use the same mathematics to show data for pre- and post-session recordings, and they take only seconds to show — because the technology is now powerful enough to do the transformations. So for years we were trying to implement the ideas on a technology that underperformed, nudging at the borders of what the technology would allow. So what were we doing at this time? And how did it differ from the linear models used by our colleagues?

NeurOptimal® (or NeuroCARE Pro® as it was called back then), had evolved conventional linear training. While we had started with one channel at CZ (in the middle of the top of the head), now we had two channels, we were lateralizing training, left and right. What we were doing differently from our colleagues was that we were training both sides of the brain at the same time, as opposed to their sequential training of first one side, then the other. One reason we could do this was our training completely bypassed the client's conscious effort. If a client is consciously trying to invoke a state, it would be challenging to evoke two very different states at the same time! Not using the client's

conscious mind made our training effortless for the client, who did not have to try to make anything happen. Instead, the brain responds to the information it is provided as part of an unconscious process that is way faster and more effective and efficient than is conscious effort. Another big difference between our colleagues and ourselves was the number of frequency bandwidths we used over a very wide range, including many that are unique to Zengar, and all were balanced left to right. Furthermore, we were targeting all of them at the same time, not in succession. Targeting, which is our non-linear way of managing threshold setting, was dynamical, which is neither dynamic nor static. What does this mean? A static threshold is when you set a challenge, such as a bar height at a particular level and the person works to reach that challenge. However, if you then periodically change that bar height based on how effective the person is at meeting the goal, you now have a dynamic threshold —it changes periodically to stay "in range" for the individual. These methods contribute nothing beyond simply presenting a goal to work towards. In contrast, NeurOptimal's®dynamical thresholds adjust themselves microsecond by microsecond, interacting seamlessly with the brain in response to its own efforts. A dance then starts, by the brain with itself, and that very process has an astounding effect — the dynamical thresholding process actually allows the brain to release its "points of stuckness". This represents changes in two things. One is the dropping away of the "same old same old" patterns of feelings and behavior that we all have and which are so very difficult to change through conscious effort. This shift manifests through the use of the suppress frequencies. The second change is an increased flexibility of enjoying a myriad of new ways of being in the world, realized through the augment frequencies. This powerful dance occurs all by itself, without any effort from the person being trained, who doesn't even have to know what was happening. Now that is miraculous!

At this time, we were still using frequency bandwidths (what we call targets) as either augments or suppresses. Meaning we were still using them to "tell the brain what to do". This is easy to understand if you are using the simple line (bar) thresholds of other systems. Above the line for an augment (what you want more of) is "in" or good, and below is "out"; for suppresses (what you want less of), below the line is good or "in" and above is "out". However, we were using box thresholds instead of lines, so for us the definition was a little more complex and yet logical. With an augment you were "in" or good if you were in the box or above it, for a suppress you were good if you were in the box or below it. The level of difficulty could be adjusted by changing the size of the box — a bigger box is easier to stay in than a smaller one. We used to do that manually by dragging the boxes in and out during a training session without the client even being aware, but later it was semi-automated by selecting a difficulty level (which was a number) and the software did the rest for you. You could then change that number "on the fly" if you felt you needed to. We also developed another means of affecting the difficulty or challenge to the brain. This was our "Zen modes", which ran behind the scenes. The Zen modes use different mathematical rubrics that alter whether the two sides of the brain can do their own thing (Zen 1) or whether they have to work together (Zen 2-4). They also control the precision of training as the more precise it is, the harder the challenge. The easiest is Zen 1 (warmup) and the hardest (most precise) is Zen 3.

Ultimately, once the technology could support it, we moved more fully to our non-linear model not only through the math we were using for the filtering and targeting, but also by looking at how we were defining our targets as "in or "out". This is where linear logic starts to fall away. Now any target was "in" only if it was literally inside the box threshold, not above or below it. For an "augment", if it was above, which we used to think was desirable, it was now considered "out". And with the suppress frequencies, only in the box was "in" and below wasn't, even though logically we thought that too was desirable. The astute reader will now realize that—amazingly — the definition for both the augments and suppresses is now the same! You are either in the box or you are out — there is no difference between them! So there are no longer any augment or suppress frequencies and with that, our "telling the brain what to do" had totally shifted to a purely non-directive, information-based model. We give the brain information about itself (hold up that mirror) and the brain will self-organize. Without any assistance from any outside agent, or indeed, even from the person's own consciousness!

This move had several other important consequences. One of them was that we were no longer training states of consciousness, which occur as a consequence (or by-product) of using augment frequencies.

Secondly, and related to the first, is that we now got even fewer side-effects as we were no longer giving guidance to the brain as to what we wanted it to do. We now were just holding up that mirror to the brain. The third effect was that now the dynamical quality of the targeting that had proven so useful in freeing up unwanted "stuckness" could now be tuned more precisely. This made it even more powerful. And this effect was further magnified by our implementation of AutoNav, which adjusted the difficulty level automatically. NeurOptimal® taking over this task not only released the trainer from having to be in the room with the client, it also adjusted the difficulty so much more efficiently than any human operator could that its potency was increased even further. Another way NeurOptimal® dances with the brain.

Today, many years down the road, we have confirmed NeurOptimal's® training effects over several million client hours. Together, NeurOptimal's® non-linear dynamical thresholding, in-line de-noising routines, AutoNavigation and adjustment of challenge via the ZenModes, offer powerful and safe training that, we believe, is unsurpassed in the field.

References

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