BrainAvatar—Flexible Individualization for Treating Autism, a Complex Disorder

Dick Genardi, PhD

Abstract

Autism is a disorder that manifests itself in a complex and varying array of dysregulations in areas of behavior, cognition, and emotion. Multidisciplinary scientific investigation has informed us about the underpinnings of this disorder in genetic, metabolic, nutritional, environmental, neural structural, and neurophysiological domains. One hopeful and exciting area of assistance in diagnosis and treatment of autism available today is the application of neuroimaging-based assessment and neurofeedback methods. But, in order for the neurofeedback clinician to take advantage of the latest developments in neurometric and neurofeedback approaches to the treatment of autism, it is important that one has knowledge of the scientific literature on autism as it applies to EEG assessment and neurofeedback. Access to a select group of such articlesis offered herein via a URL, along with resources on cognitive, behavioral, and emotional functions associated with specific brain areas—Brodmann areas, Regions of Interest, and the most common organization of those areas into functional networks. The article itself is devoted to describing for the clinician how to use the BrainAvatar software to target a neurofeedback intervention, individualized to the unique presentation of the patient before them, based on the network and autism literature resources accompanying this article.

Introduction

Autistic individuals present with several consistent patterns of behavior. The lack of communicative intent was initially used as one of the hallmark signs of identification. Some individuals never demonstrated language or gesturing with communicative intent, while others show normal development withtregression and loss of language and communication functions in the first few years of life. As a consequence, autistic individuals have trouble relating to others, miss social cues, have minimal eye contact, and rarely initiate social behavior. They are isolated individuals preferring to be alone. Autism is now seen on a spectrum of degree and extent of impairment; in more severe cases, if there is speech or language it may be echolalic or of unusual syntax. Stereotypic movements are often seen, as is the idiosyncratic use of objects. Behavioral routines are depended upon, and become rigid and inflexible. Deviation from the expected or shifting from one set or activity to another can result in behavioral tumult. Obsessive focus is not unusual, with some circumscribed area of interest being a primary focus, sometimes associated with a skill of savant proportions. Repetitive self- stimulatory behaviors may be present in some cases, occurring with such intensity that extreme injury is self-inflicted. Autistic individuals are often known to be easily overstimulated by environmental setting characeristics (sound level, number of items on walls, multiple objects in a room, room size, number of people present) and multiple choice options. Many of the difficulties in functioning seen in autism can be viewed from a neuropsychological systems perspective involving arousal, attentional, sensory integration and executive functions systems. Current diagnostic nosology defines autism as presenting along a continuum of severity of deficits in cognitive, social-behavioral, and emotional regulatory functioning. It is listed as one of several developmental disorders.

Through the link to the references on autism provided herein, the reader will find articles containing discussions on the causes of autism. Early studies show macrocephaly in autistic individuals with increased cerebral volume in posterior areas of the brain and decreased volume frontally. Findings of voxel-based magnetic resonance imaging studies, however, show significant reduction of total gray matter volume as well as frontal striatal and parietal network loss. Similarly, modern studies show reduced white matter in critical brain areas. Abnormal structural and functional findings in prefrontal cortex, temporal-parietal, and occipital-temporal cortices are expressed in connectivity aberrations in networks consistent with the varied impaired functions most frequently seen in autism

Numerous studies employing fMRI Blood Oxygen Level Dependent (BOLD), Magneto-encephalographic, Positron Emission Tomographic, and Electroencephalographic measures of temporally coactivated but spatially distributed regions help identify distinct functional networks; these various measures are known as measures of connectivity. In order to appreciate the findings of studies on autism most relevant to neurofeedback practice wherein patterns of aberrant connectivity are identified, the reader at least should be familiar with EEG connectivity measures of asymmetry—comparative measures for homologous sites, phase- timing of waveforms across frequencies and sites, and coherence—the consistency of phase relationships across time. This information is most easily acquired via reading three pivotal articles:

1. Robert Thatcher's lucidly presented paper, "EEG & Brain Connectivity: A Tutorial" accessible at: *http://www.appliedneuroscience.com/Brain%20Connectivity-A%20Tutorial.pdf*.

2. And pertaining to autism, *http://www.appliedneuroscience.com/PhaseresetDevelopment.pdf*.

3. Tom Collura's detailed exposition *Toward a Coherent View of Brain Connectivity* at *http://www.brainm.com/software/pubs/WNEU_A_343495_O.pdf*, is essential in discerning which connectivity measure to choose for training during a neurofeedback session. He illustrates how the values change for the various metrics for the same subject at the same 10-20 placement, as well as how the same connectivity measure can take on different values at a different electrode placement.

Connectivity Patterns in Autism—A Brief Overview

In their comprehensive overview of the conductivity patterns most often found in the quantitative EEGs of autistic individuals, Coben and Myers (2008) identified the following patterns in the literature reviewed:

- Frontotemporal Hyperconnectivity: frequently found in posterior frontal to anterior temporal regions; associated improvements with treatment include improved attention self-regulatory functions, enhanced social behavior, and communication skills.

- Frontal (Orbitalfrontal) Hypoconnectivity: areas involved in social cognition and theory of mind.

- Mu Rhythm Complex over sensorimotor strip: biofeedback in this area results in improved mu rhythm suppression, believed to be an important index of the integrity of the mirror neuron system, essential in observing others as a basis for proper responding.

- Posterior (Occipital-Parietal-Temporal) Hypoconnectivity: associated with excess Theta activity with low conductivity in Delta and Theta and beta bands as well.

- Frontal-Posterior Hypoconnectivity: this pattern is consistent across studies produced in many research centers, representing the isolation frontal lobe input to numerous posterior processing centers; particularly significant as disconnection in the gamma frequency training primary visual cortex parietal integration areas and inferior frontal cortex containing mir-

ror neurons.

• Left Hemisphere Hypoconnectivity: decrease in connectivity throughout the legend in the language areas and for complex language processing tasks.

• Left Hemisphere Intrahemispheric Hyperconnectivity: increased connectivity in the Delta frequency band is seen in frontotemporal regions suggestive of abnormal lateralization language patterns in autistic individuals.

Even a casual review of the studies on autism made available through the URL provided herein reveal that in persons with this disorder, it is likely that there are aberrant measures associated in at least one of every commonly identified functional cortical network, such as those discussed by Raichle, Hagmann, Laird, Van Den Heuvel, Sridharan, Ye and many others. Thus, there is no pathognomonic EEG/qEEG sign for autism.

One very illustrative finding, however, is seen in the work of Thatcher et al. (2009) concerning phase reset in autistic individuals against age-matched controls. They found that:

1. Autistic individuals have shorter phase shift durations across frequencies, particularly in alpha 8–10 Hz (alpha 1) when compared to age-matched controls. Phase shift duration is posited to be a period of neuronal recruitment;; thus, autistic individuals are less likely to recruit sufficient neuronal assemblies to process information being passed from one functional unit to the next. Other studies have established that Alpha 1 (and theta) are involved in neuronal recruitment.

2. Autistic individuals have longer phase lock durations specifically in alpha at 10–12 Hz (alpha 2), which is involved in resource allocation and binding of neuronal units by phase locking.

3. Also, noted differences in phase measures were found in long distance as well as local surface electrode pairings.

Despite the complexity of the networks associated with the symptoms individuals with autism present, it is encouraging to note that significant treatment effect is reported in many of the studies published to-date from interventions with electrodes being placed at single 10-20 sites or two 10-20 sites using a bipolar montage.

BrainAvatar Overview

Exciting news for today's neurofeedback practitioner is that network analysis and treatment at the network level of problems associated with autism is now available. BrainAvatar is one of those software offerings now available. Using the BrainMaster 19-channel Discovery acquisition and training instrumentation along with the BrainAvatar software, allows for network-level analysis and treatment either using

BrainMaster's 19-channel PZOK (UL) surface ANI EEG-derived Z-score measures, live sLORETA when reviewing or training, or both 19-channel surface BrainMaster with ANI Z-score and BrainMaster proprietary sLORETA software modalities simultaneously.

Those neurofeedback practitioners already familiar with the benefits of one to 19-channel surface Z-score training with the ability to target outlier metrics, can now train any ROI or any network at any combination of frequencies at the voxel level as well, with those frequencies defined by the user to 0.0001 Hz precision, and at the same time be viewing one or more 3-D real time head maps of the ROIs being trained, or the impact of that training on the whole brain, displaying 6239 voxels at 5 mm resolution, either 8 or 32 times per second. In addition, the patient can also view, in real time, their own brain activity at the voxel level for the ROIs of interest. Clinicians using live 3-D head map voxel displays as a feedback modality report this as a powerful reinforcer for their patients. (This is very applicable to training the Default Mode Network (DMN), attention networks, mirror neuron groupings, a-p cingulate, insula, and other structures showing significant dysregulation in autism.)

At the same time, all of BrainMaster's training software works with the BrainAvatar Live Loreta Projector (LLP), including sound, CDs, DVDs, multimedia, etc. using the Event Wizard. Adding sound to the powerful visual 3-D head map is very compelling, as the visual and the sound together are a very rapid and accurate reflection of brain activity. Adding the DVD player is easy to do, and is a good feedback modality when using 19-channel surface ANI Z-score in conjunction with sLORETA training. Important in the treatment of the autistic patient, is that the composition of the feedback can easily be adjusted to the autistic patient's sensitivity level for input.

The reader unfamiliar with this neurofeedback approach can get a fuller perspective of the BrainAvatar offering through the following resources:

1. Links to videos posted at *http://www. brainm.com/kb/entry/483/*.

2. View general videos at *http://www.brainm. com/software/videos/*.

3. Observe instructional videos at *http:// www.youtube.com/playlist?list=PLEFB1E A9B03EE88A6*.

For the psychotherapeutic clinician it is important to note that the BrainAvatar software can be used entirely out of the realm of the "normalizing EEG" neurofeedback perspective. That is, it can be used as a brain imaging/monitoring system, useful during typical therapeutic dialogue/interventions and interactive assessments. By simply watching the brain activity live, without Z-scores, it is possible for the clinician to image and

"interact with" the client's brain in real time. Especially in the case of mood issues, frontal asymmetry can be observed live, changing in real time by watching gamma in the frontal lobes and seeing the amount of asymmetry of the activity (akin to Davidson's work), thereby actually witnessing whether the patient is having a positive or negative reaction independent of their self-report. Thus the therapist sees the patient's reactions to information live, on top of the patient's standing "trait" level of asymmetry.

Helpful in developing proficiency in viewing live current source density, LORETA spatial-temporal frequency distribution patterns is the recent chapter by Sherlin (2009).

Since BrainAvatar uses a proprietary method that is approximately 100 times faster than other implementations, it generates full 3-D images in which every voxel is turned into a real number quantity, in all of 16 frequency bands, up to 32 times per second. The produced image shows the CSD amplitude of every one of the 6,239 voxels, represented with coloring indexed to CSD value, changing in real time at 8–32 frames/second (a new image every 125 to 31.25 milliseconds), thus providing true live animation of brain activity.

Also, the actual number of voxels that are maximum depend on the individual, and are in essence an individual signature. In a personal communication, Tom Collura likened this aspect of using the BrainAvatar software by saying that ordinarily, when using a Z-score normative approach, if one were trying to analyze a face for example, the assumption would be that everyone's eyes are in the same place, and the Z-score obtained would be the deviation of the patient's eyes from the normative average. But, the BrainAvatar method finds the actual location of the eyes of the specific individual in question, even more precisely, the center of the iris, rather than comparing everyone's face with an average face. Brain Avatar's images are currently showing the true current source density, which is like a functional image of what the brain is doing. Z-score images show deviations from normal, hence only show where the activity is different from normal, a population average.

With BrainAvatar you can specifically target brain locations with user-defined bands, and train each location in different directions. So if it makes sense for a particular patient, the practitioner could for instance "train down theta on the anterior cingulate" and "train up beta on the left insula." This is equivalent to surface target training of a specific metric when doing 19-channel surface Z-score training.

Great flexibility is provided to the practitioner in that BrainAvatar also allows, through its Z-Builder option, defining one's own reference database or "normative" EEG. For instance, the practitioner can currently image and train sLORETA Z-scores using the patient's own EEG, sampled from a period when the patient is asymptomatic,

or when functioning at some peak or desired level. Thus, the therapist can capture the EEG of an autistic individual who, at the time of EEG acquisition, is reporting a more comfortable 1:1 social interaction, and use that EEG to create a reference database, to be used in neurofeedback training while the practitioner introduces more persons (shapes tolerance) into the room during an on-going session. In this way the practitioner has established individual-specific, yet clinically valid training criteria with increased likelihood of treatment generalization. In short, it is an alternatively valid way of comparing the sLORETA with a reference brain.

It is important to note the implications of the information given above. Training delivered using the BrainAvatar implementation adheres strictly to the principles of operant learning found essential to successful neurofeedback: 1) Relevance and Specificity, function directly mapped to the area(s) of training; 2) Contiguity-Immediacy (1 & 2 allowing for contingent reinforcement, not superstitious training); and 3) Providing a reinforcing event that is very powerful/engaging/motivating.

sLORETA

BrainAvatar offers true sLORETA neurofeedback, an advancement of LORETA. The reader unfamiliar with the differences between sLORETA and LORETA may find the following informative.

The differences between LORETA and sLORETA are basically as follows:

1. sLORETA has 6,239 voxels versus about 2,200.

2. sLORETA has a voxel size of 5mm versus 7mm.

3. sLORETA has guaranteed zero error in the presence of a single dipole, which LORETA does not.

4. sLORETA assumes maximum smoothness of the sources.

5. sLORETA takes a maximum likelihood approach which LORETA does not.

6. sLORETA does not include the amygdala, which is not possible to localize from the surface.

The basic approach for LORETA and sLORETA however, is the same; it is a linear transformation matrix applied to the surface field to generate an estimate of the underlying sources. sLORETA actually produces a probability of current-source density for every one of the 6239 voxels, using a maximum smoothness condition.

In addition, BrainMaster has announced an sLORETA live Z-score implementation in which every single voxel is converted into a Z-score eight times per second in ten bands, and it uses a published, FDA-registered normative database. This provides true live imaging of the full 6,239-voxel images using normative referenced Z-scores, and when used for training, would thus also provide live sLORETA Z-score training in addition to live raw sLORETA imaging and feedback.

As previously mentioned, in this system, the practitioner can have multiple sLORETA images running concomitantly, so it is possible to view a live Z-score sLORETA image, and also a raw amplitude sLORETA image simultaneously. This design also includes sLORETA connectivity graphs, and sLORETA dipole images, which are entirely unique to this implementation. All of these images are live, at eight frames per second in any (or all) of sixteen different user-defined frequency bands (onlyten frequencies are in the database).

So, in summary, one performs an analysis of the autistic patient's presenting complaints, reviews known brain-behavior relationships based on extant neuroscience literature, and conducts an adequate neuroassessment; then, if a convergence is found amongst these information sources, a BA, ROI, or Network can be targeted and treated with great flexibility through the assistance of the BrainAvatar software.

Setting Up a Network to Train

Benefit from the following section requires that the reader have at least a trial version of the BrainAvatar software and be familiar with its basic use.

For the reader to easily implement the training of a Brodmann area or more complex Region of Interest grouping as discussed in this article, a template for BrainAvatar settings file may be found at the following URL: *http://www.brainm.com/kb/entry/511/*. It is called "TryIt-19ChanSurfZScore&sLORETA."

In this regard, also provided for the reader is a Word document with the Brodmann areas already written in Event Wizard equation format for all the Hagmann networks,

Laird Interconnectivity Networks (ICNs) and Raichle networks. It is these equations which are used to implement the sLORETA trainings. This is accessible at *www.brainm.com/documents/Publications/ROIInfo.pdf*.

In addition, the reader will find a Region of Interest Table document at *http://www.brainm.com/kb/entry/461* containing a listing of Lobe ROIs, Gyrus ROIs, and Brodmann ROIs which may then be used to write one's own equations in Event Wizard format for training specific targets in sLORETA.

- Please note the format for specifying a Region(s) of Interest to be trained. It is x=LoretaROIA(####,#). The four numbers before the comma reference the ROI as listed in the table with numbers that begin with 1 referencing Lobes, those beginning with 2 referencing Gryri, and numbers starting with 3 referencing Brodmann areas.

- The single number after the comma identifies the frequency being trained. That is, Delta =1, Theta=2, Alpha =3, Beta =4, Lo-Beta=5, High Beta=6, Gamma=7, User=8.

- Right- or left-sided ROI training is implemented by adding left-right designations as follows- x=LoretaROIAL(####,#) and x=LoretaROIAR(####,#).

A description of the settings file follows.

- Events 1 through 5, which can be viewed in the Events Wizard, are devoted to defining the parameters for the 19-channel surface Z-score normative database training.

- Events 6–9, and 9–11 are used for the training of sLORETA ROI(s) at a particular frequency, as specified by the Event Wizard equations listed in the "If" condition of Events 6 & 9. Using E6 & E9 together allow the training of the same network at two different frequencies at the same time. (Recall that BrainAvatar is infinitely flexible in that any ROI can be trained at any frequency in combination with any other ROI. Two separate
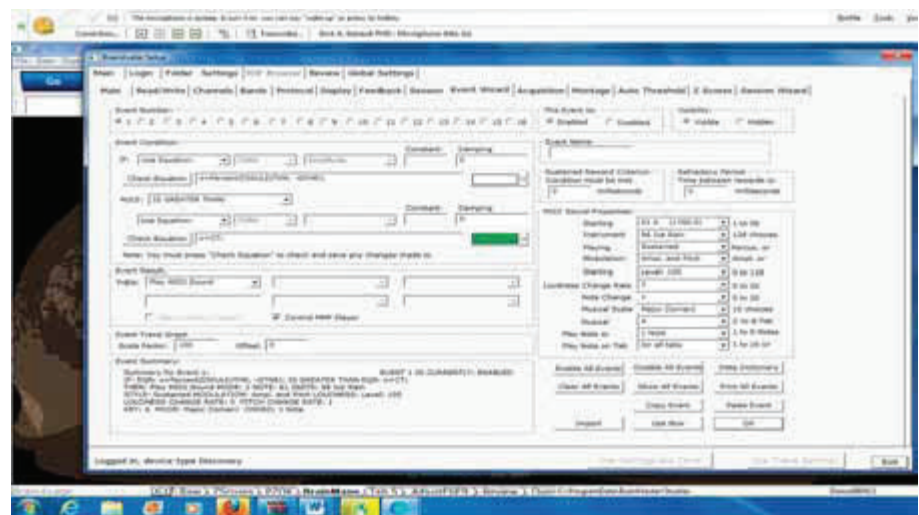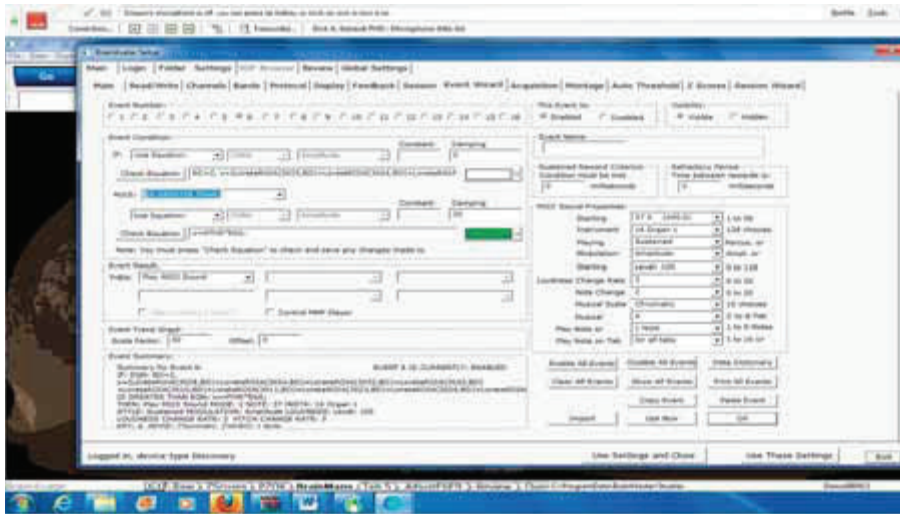

Figure 1

Figure 2

events are not required to do that. The author structured the settings file provided with this article for the purpose training a whole network using of cross frequency coupling. See Sauseng & Klimesh (references).

• Pre-written equations for the major networks provided in the Network Listings MS Word document mentioned above, can then simply be cut and pasted into Events 6 & 9. Entries for a single lobe, gyrus, or Brodmann area or combination are similarly written.

A screenshot of Event 1 is shown in Figure 1. Note that adjustments to sound and multimedia feedback can be made within this event. Also, the event may be disabled altogether by a simple click of the "Disable" button at the upper right portion of the screen portrayed in the image

A screenshot of Event 6 is shown in Figure 2. The reader will observe in the "If Condition" of Event 6, the individual region of interest entries for the ICN Default Mode Network (DMN). Please note that for this particular network there are several Brodmann areas entered and each must be trained at a frequency, as indicated by the number following the comma according to the following syntax x=LoretaROIA(####,#). In this illustration, the reader will see that after the comma there are the letters "BD" which stand for (frequency) band; with the actual number assigned to that band at the beginning of the equation. So, in the screenshot the whole Default Mode Network is being trained at a frequency where BD=2; that is to say, at the frequency of Theta. If the reader wished to change the frequency for the whole network to Alpha, all that would be necessary would be to change the initial part of the equation to read "BD=3." This feature thus allows the rapid editing of large-scale frequency changes within a complex network.

Also note that below the "IF Condition" is a rule drop-down box where the op-

tion to increase or decrease CSD activity within the ROI is chosen.

In the settings file provided, "TryIt-19 ChanSurfZScore&sLORETA," this author is currently using at Event 9 the same region of interest being trained in Event 6, but at a different frequency. For example, the frequency used in Event 6 is theta coupled with gamma being trained in Event 9.

The reader may train to increase or decrease the CSD of the ROI by simply changing the selection of the rule after the "If" condition in E6/E9.

At the bottom of the screenshot images, the reader will note a series of tabs labeled Raw, Z-scores, PZOK, BrainMaps, Adjust E6E9, and others. By clicking on the Raw tab the acquired EEG is displayed. The Z-scores tab displays a screen containing all the normative database Z metrics for the channels acquired. The PZOK tab shows a screen where the upper and lower Z-score training limits and the percentage of Z-scores falling within that target are adjusted.

Clicking the BrainMaps tab allows viewing the CSD activity of two 3D head

maps simultaneously. (More could be displayed if needed.) In the titled drop-down boxes, the ROI and the frequency of interest are selected for each map to display each voxel in color, mapped to the voxel's CSD value. The side-by-side placement of two head maps can be used to study cross frequency coupling in real time. The *in vivo* impact of sLORETA training as defined in Events 6 & 9 can be observed in any region of interest, even all 6,239 voxels, at any frequency, showing the dynamic patterning from anterior to posterior, left to right, or more local processing. Many practitioners use the 3-D head maps as visual feedback for the patient.

The AdjustE6E9 tab allows one to adjust the threshold of those events. (Figure 3). The h key is used to adjust the threshold upward for Event 6, the b key is used for Event 9. Using the Shift key with either h or b lowers the threshold value. The threshold works by multiplying the damped average of the CSD value of the ROI being trained at the specified frequency(ies) by the value of the h or b key.

Once a functional network is selected for the patient, sLORETA training can easily be implemented. Assuming that the practitioner has already created a folder for the patient and read in the "TryIt-" settings file. Then the practitioner should perform the steps given below.

• Access Event 6 via the Event Wizard. Highlight the equation in the "If condition" and delete it.

• Go to the Network Listings MS Word document and copy the equation for the network selected for training.

• Paste that network equation into the equation box in the "IF condition" of Event 6.

• Set the frequency by placing the appropriate band number in "BD = #" at the beginning of the equation.
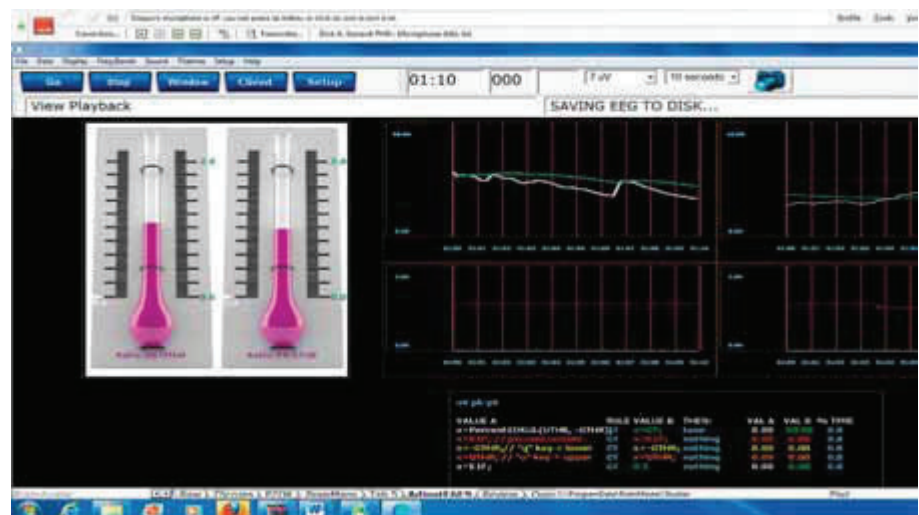
• Click "Check Equation" button.

Figure 3

- Repeat for Event 9.
- Close the window by clicking "use Settings and Close" button at the bottom right hand corner of the screen.

The program is now ready to run. It is that simple.

Brief Case Illustration

Mr. XYZ is a 50-year-old Caucasian male, diagnosed with autism at age five, during his first hospitalization. He attended special schools through high school; earned a two-year degree in accounting, and a certificate as an electronics technician. He has worked for several years, part time, in a sheltered setting. He has been prescribed neuroleptics and other psychotropic medications for extremes in mood and behavior for many years.

He frequently is unkempt. Initially he would present at the office pacing in the waiting room instead of sitting. When he did sit in a chair he bounced his legs. His facial expression was tense, eyes nearly exophthalmic. Gaze aversion was prominent.

He is socially isolated due to deficits in social pragmatics but has some desire for social interaction. He has communicative intent, verbal and expressive language appear within normal limits. However, careful attention to the flow of conversation reveals that the content of his verbal responses are not directly related to what came before. He is close enough in his responses that those conversing with him often fill in the gaps or continue the conversation in the new direction it has taken. His understanding of the meaning or implication of what has been stated is often idiosyncratic. Interests are restricted, making his initiating and maintaining conversation more difficult. More recently, he has successfully taken on the care of a pet cat.

Cognitively, he has high average intelligence, with near savant-level episodic memory recall.

Learning through reading is onerous for him. He is obsessively focused on legacy electronic devices, with encyclopedic knowledge of serial numbers of obscure parts. He is perseverative, has difficulty switching sets, and lacks ability to place input from oth-

ers and information from daily events in its proper context.

He was referred by his psychiatrist because of fear of the patient's behavioral outbursts and boundary violations. Neurofeedback is one of the treatments provided to this patient.

An initial qEEG was performed which is shown in Figure 4.

Given the role of the Default Mode Network in a Theory of Mind and its impact on the regulation of other networks, the initial training selected for this patient was conducted with the Brain Avatar software using a protocol comprised of 19-channel Z-score, that is the PZOK (UL) version, in conjunction with sLORETA training of the ICN-13, the Default Mode Network as defined by Laird et al (2011). Frequency pairings used in training included Theta-Gamma, and Alpha2-Gamma.

A second qEEG was taken at the end of the eighth session. It is shown in Figure 5.

Subsequently, the patient received one session of training of the anterior cingulate and precuneus. A screenshot of the two 3-D headmaps used as the visual feedback given to the patient is shown. The 3-D headmaps display the CSD activity in theta at Brodmann area10 and in gamma at the precuneus. Auditory feedback was also given; it was based on CSD activity of additional Brodmann areas also included in the anterior cingulate—i.e. Brodmann areas 24, 25, 32, and 33. This feedback display can be seen in Figure 6.

Behavioral improvements to date include the patient being able to stop leg bouncing and maintain it when cued by the author. Gaze aversion is less. During conversation patient is more easily redirected to focus on the topic of discussion. Patient had one recent social visit with a workmate from the sheltered workshop where he is employed. He was accompanied by an aide. Ability to place information in proper context has shown no change. ᛙ

References

Assaf, M , K Jagannathan, et al (2010) "Abnormal functional connectivity of default mode sub-networks in autism spectrum disorder patients " *Neuroimage* **53**(1): 247–256

Coben, R and T E Myers (2008) "Connectivity Theory of Autism: Use of Connectivity Measures in Assessing and Treating Autistic Disorders " *Journal of Neurotherapy* **12**(2–3): 161–179

Coben, R and I Padolsky (2007) "Assessment-Guided Neurofeedback for Autistic Spectrum Disorder " *Journal of Neurotherapy* **11**(1): 5–23
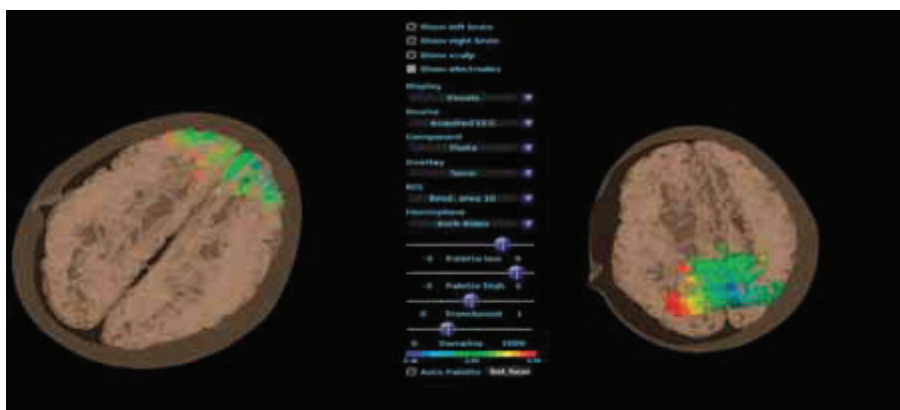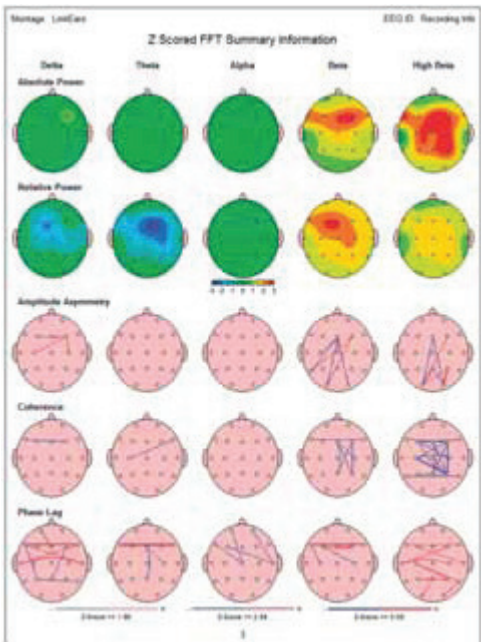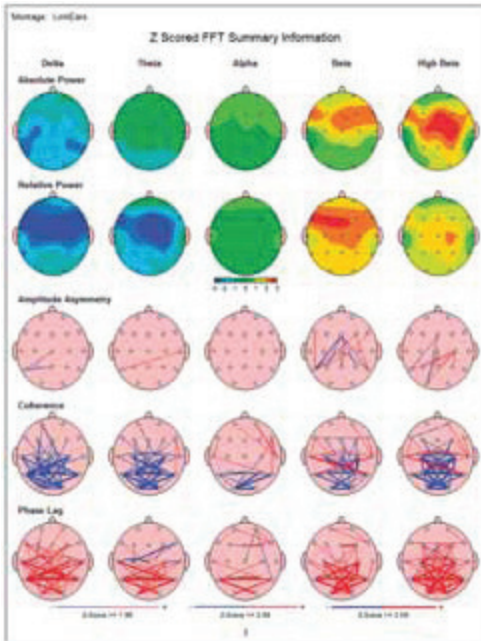
Courchesne, E , K Pierce, et al (2007) "Mapping early brain development in autism " *Neuron* **56**(2): 399–413

Dennis, E L , N Jahanshad, et al (2011) "Altered structural brain connectivity in healthy carriers of the autism risk gene, CNTNAP2 " *Brain Connect* **1**(6): 447–459

Duffy, F H and H Als (2012) "A stable pattern of EEG spectral coherence distinguishes children with autism from neuro-typical controls—a large case control study " *BMC Med* **10**(1): 64

Hagmann,P , Cammoun,L , et al (July 2008), "Mapping the

From top left Figures 4, 5, and 6