THE USE OF FOUR CHANNEL MULTIVARIATE COHERENCE TRAINING ON MILD TRAUMATIC BRAIN INJURY:

A COMPARISON OF NEWLY CONCUSSED AND REMOTELY CONCUSSED INDIVIDUALS

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OUTLINE

What is MTBI?

Epidemiology

EEG & Quantitative EEG Assessment

NFB Treatment

Coherence findings

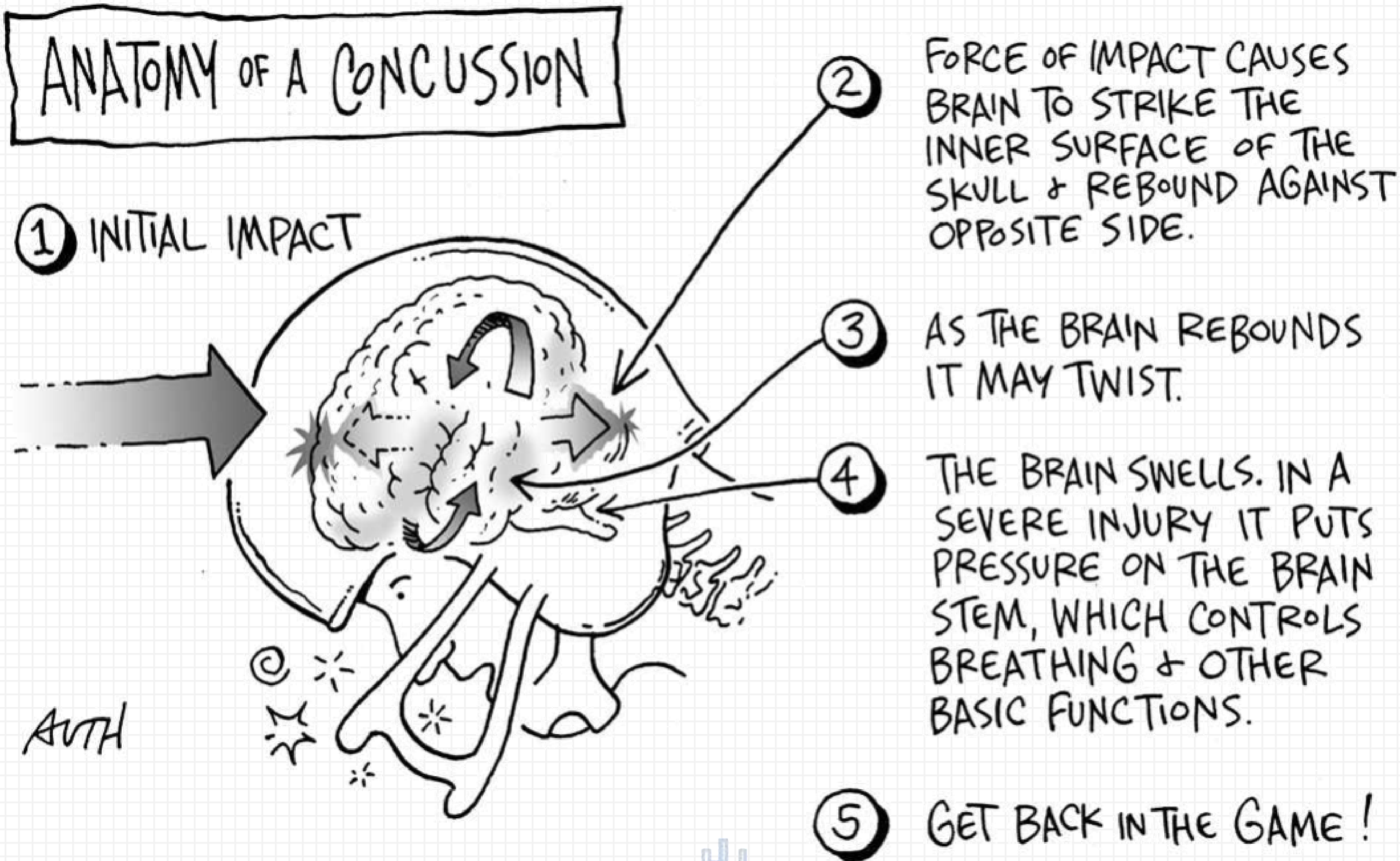
Methods

Results

Discussion

MILD TRAUMATIC BRAIN INJURY (MTBI)

- Brain injury caused by acute trauma to the head
- Commonly known as a concussion
- Affects reaction time, memory, balance, and planning skills
- Associated with significant symptoms such as fatigue, headaches, memory loss, poor attention, sleep disturbances, seizures, and feelings of depression


ANATOMY OF A CONCUSSION
1 INITIAL IMPACT
2 FORCE OF IMPACT CAUSES BRAIN TO STRIKE THE INNER SURFACE OF THE SKULL & REBOUND AGAINST OPPOSITE SIDE.
3 AS THE BRAIN REBOUNDS IT MAY TWIST.
4 THE BRAIN SWELLS. IN A SEVERE INJURY IT PUTS PRESSURE ON THE BRAIN STEM, WHICH CONTROLS BREATHING & OTHER BASIC FUNCTIONS.
5 GET BACK IN THE GAME!
AUTH

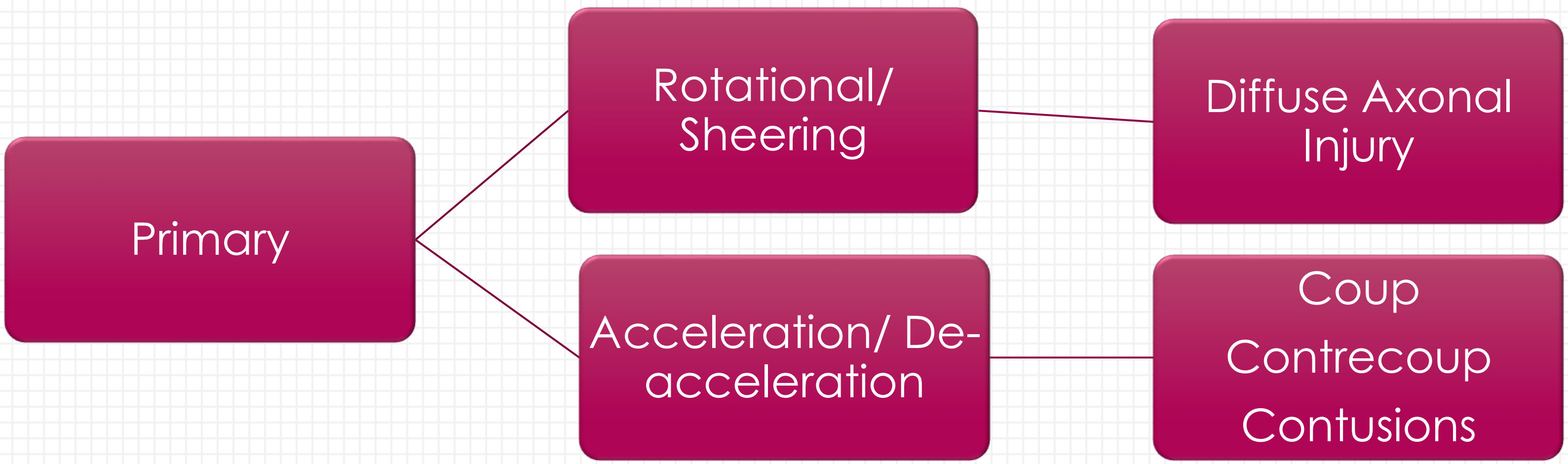
SIGN & SYMPTOMS

- Physical & Postural
  - Headache
  - Nausea/vomiting
  - Sensitivity to light/noise
  - Fatigue
  - Visual problems
  - Dazed
  - Dizzy
- Cognitive
  - Mental Fog
  - Feeling Slowed Down
  - Difficulty Concentrating
  - Forgetful
  - Repeating Questions
  - Drop in academic performance
- Emotion
  - Irritability
  - Sadness/Depression
  - Personality Change
  - Anxiety/Panic
  - More emotional
  - Apathy
- Sleep
  - Drowsiness
  - Sleeping more/less
  - Difficulty falling or staying asleep

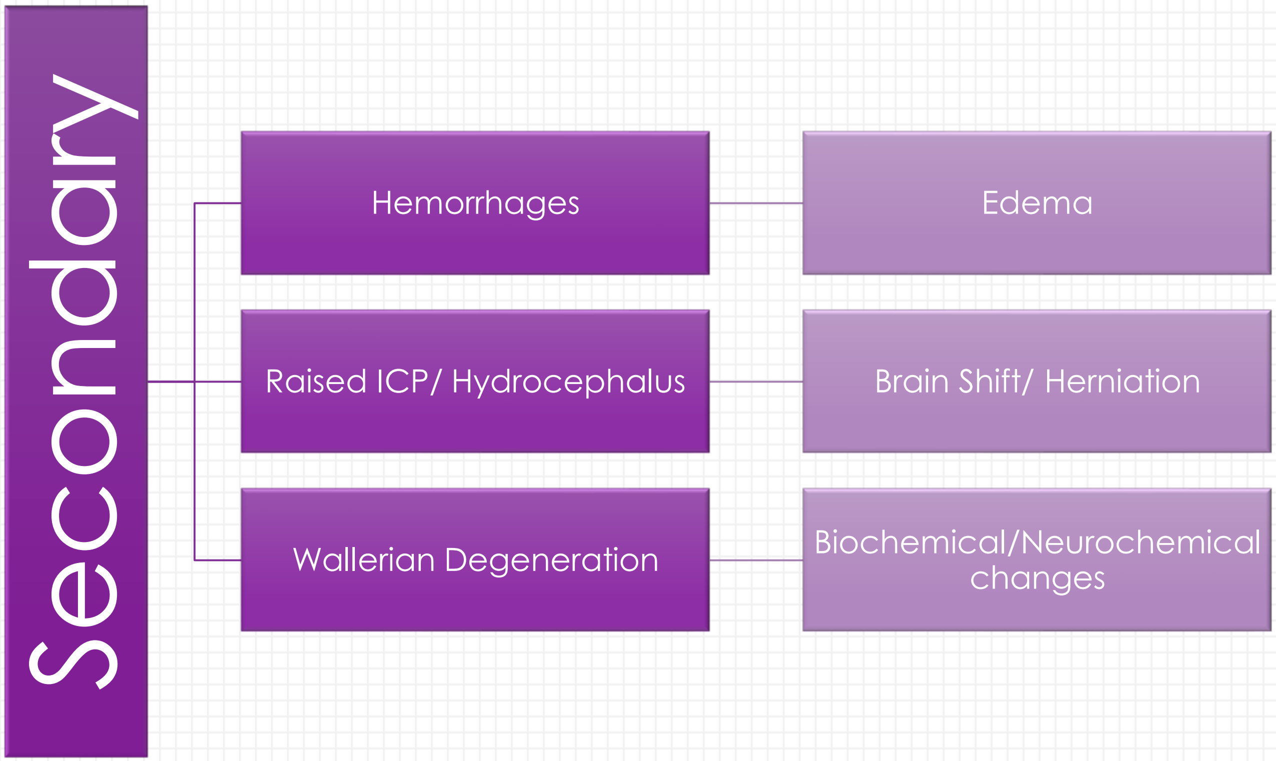




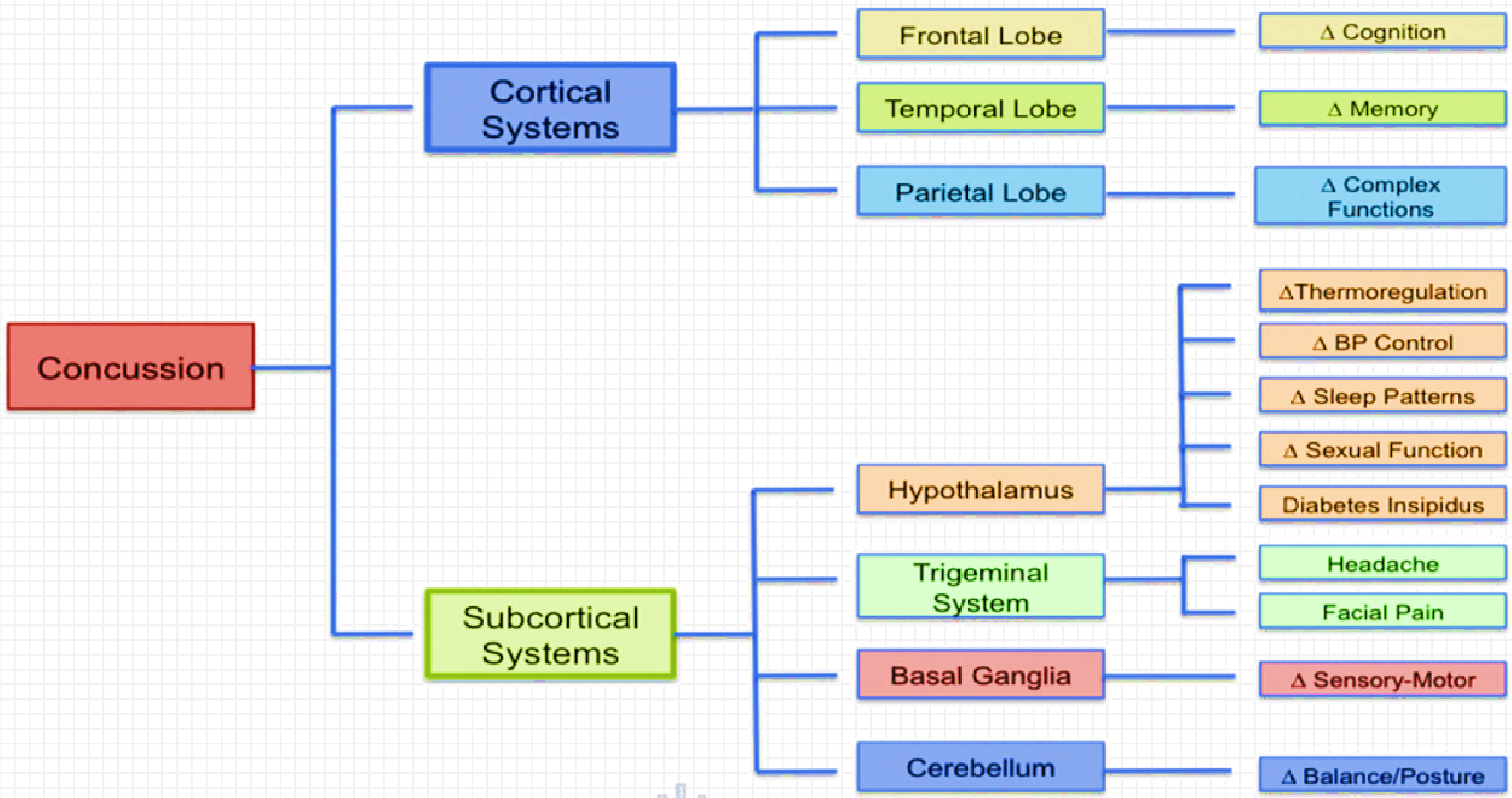
PRIMARY EFFECTS OF CONCUSSION



SECONDARY CHANGES TO HEAD TRAUMA



CONCUSSIVE SYMPTOMS ASSOCIATED WITH NEUROANATOMICAL LOCATIONS



EPIDEMIOLOGY

- In the U.S., estimated 1.7 million traumatic brain injuries (TBI) a year accounting for 1.365 million emergency room visits and 275,000 hospitalizations
- After road trauma, second most common cause of TBI for 15-24 year olds is sport related events
- Mild/moderate TBIs often not reported so prevalence is underrepresented
- Almost 100,000 more concussions/year for 10-19 year olds in 2009 versus 2001
- Average of 19 concussions per NFL team per 100 games

CONCUSSION IN ATHLETES

- Estimated 3.8 million concussions occur each year, in the United States during a sporting event or practice.
- AND…it is estimated that 50% of concussions go unreported.
- Only 5-10% of sports related concussions are evaluated at the Emergency Room.
- Each year, U.S. emergency departments (EDs) treat an estimated 173,285 sports and recreation TBI's, including concussions, among children and adolescents, from birth to 19 years.
- During the last decade, ED visits for sports- and recreation-related TBIs, including concussions, among children and adolescents increased by 60%.
- Overall, the activities associated with the greatest number of TBI-related ED visits included bicycling, football, playground activities, basketball, and soccer.
- 2008-2010 rates of concussion 36% higher than 2005-2006 rates among high school football players

RATES OF COGNITIVE AND SYMPTOM RECOVERY

- There are measureable impairments in cognitive functioning after MTBI without LOC, PTA or focal neurological deficits.
- There are signs of measurable improvement within minutes to hours.
- The symptom profile, cognitive screening follows a gradual course to complete recovery within a a week.
- NP recovery is also accelerated within a week and baseline will most often follow within 3 months.
- After 10 days of PCS, the course is described as a complex recovery. This usually accompanies headache, seizures and ongoing cognitive limitations

DESCRIPTION OF NCAA CONCUSSION STUDY, CONCUSSION PREVENTION INITIATIVE AND PROJECT SIDELINE

- A combined effort study with the NCAA, Concussion Prevention Initiative, and Project Sideline. High School and college athletes (n=16,624).
- Male, late teens, and football were most prevalent independent variables
- Assessed through the Grades Symptoms Checklist (GSC), Balance Error Scoring System (BESS) and Standardized Assessment of Concussion (SAC) and neuropsychological test battery .

METHODOLOGY AND RESULTS

- Athletes were administered the FSC, SAC and BESS immediately, 2-3 hours and within a week of the injury.
- Subjects were administered NP tests 2 and 7 days post injury
- Headache was the symptom that lasted the longest.
- 85% of subject report full recovery within a week. Ninety seven percent rate a full recovery within a month.
- Conclusions suggested that concussion screening instruments were sensitive and specific in accurately detecting impairments during the acute phase, but lack sensitivity for detecting impairments post-injury phase

NEUROPSYCHOLOGICAL ASSESSMENT

- Reasoning
- Attention
- Concentration
- Memory
- Executive Functions
- Language
- Visuo-spatial
- Sensory-Perceptual
- Psycho-motor
- Academic Skills
- Mood/personality

SYMPTOM AND COGNITIVE RECOVERY IN MTBI

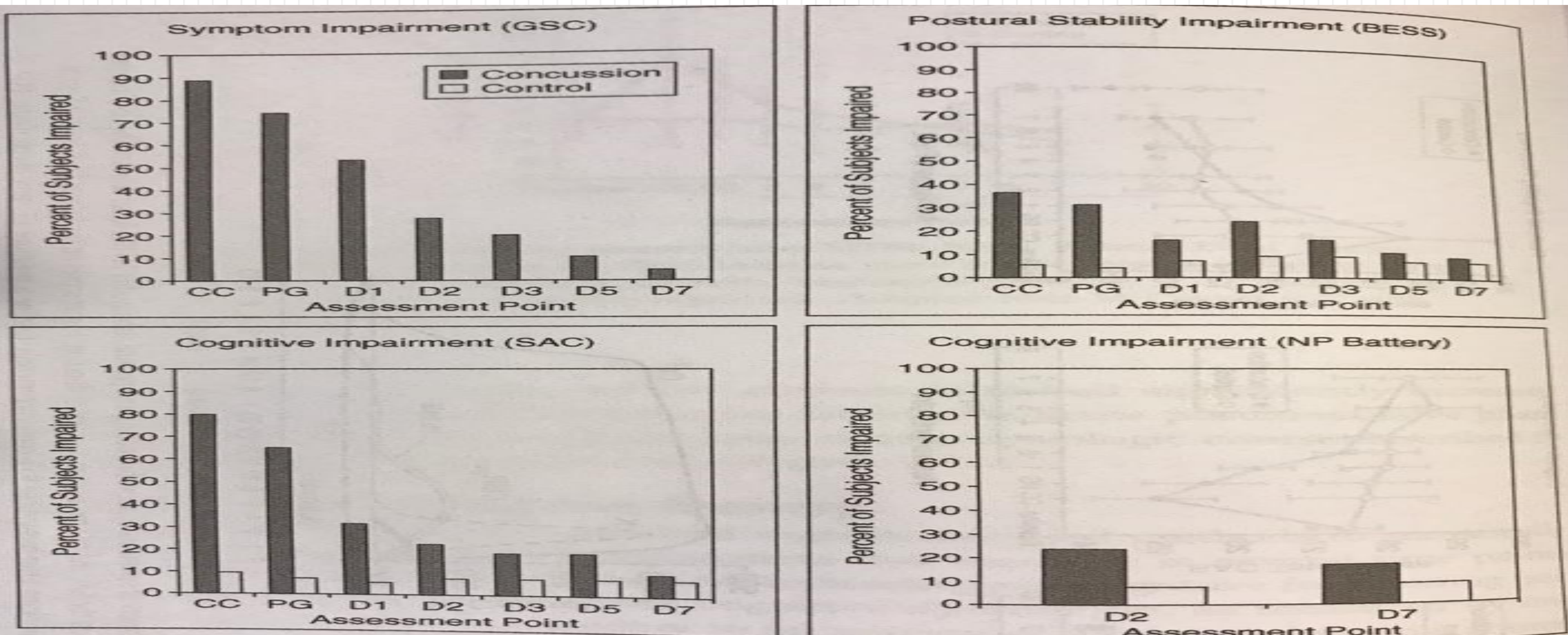
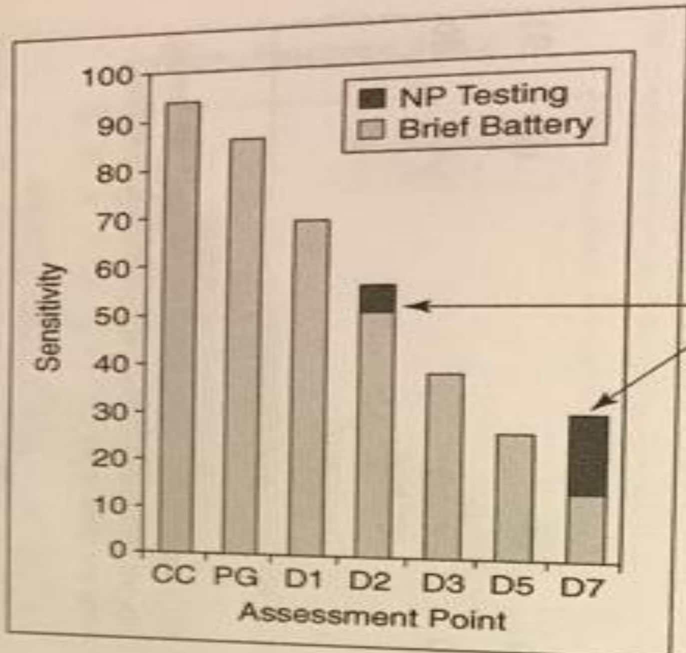


FIGURE 9.5. Percentage of concussion and control subjects classified as impaired based on symptoms, cognitive dysfunction, and postural stability problems from time of injury through day 7. BESS, Balance Error Scoring System; NP Battery, neuropsychological test battery. Assessment Points: CC, time of concussion; PG, postgame/postpractice; D1, postinjury day 1; D2, postinjury day 2, etc. From McCrea et al.[24] with permission.

RECOVERY OF NP SYMPTOMS



Added Value of Neuropsychological Testing

- Sensitivity: refers to probability of individual player abnormal on any measure (specificity > 84%)
- Brief battery: GSC, BESS, SAC
- Neuropsychological Testing: minimal increase (5%) in sensitivity over brief battery on day 2, but more than doubles sensitivity on day 7 (14% to 30%)
- Neurocognitive Impairment: delayed memory, processing speed, verbal fluency

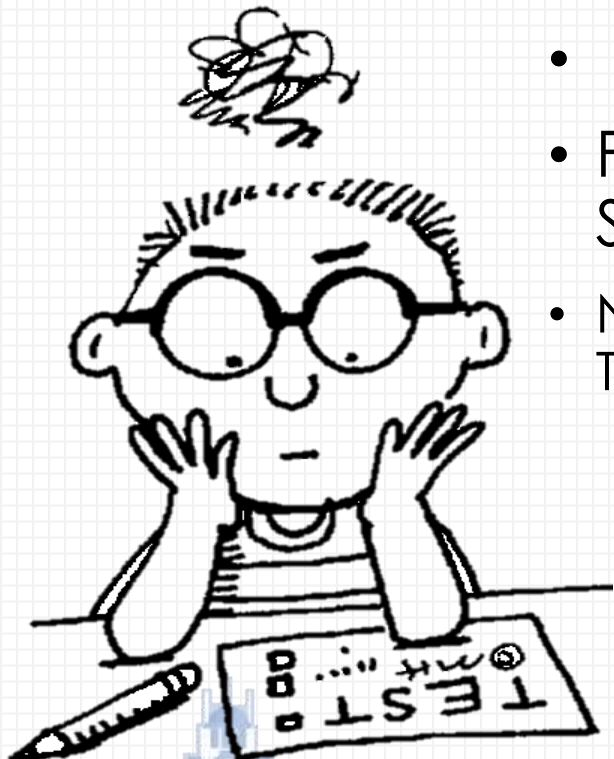
FIGURE 9.6. Incremental value of neuropsychological testing after sport-related MTBI. BESS, Balance Error Scoring System; NP Battery, neuropsychological test battery. Assessment Points: CC, time of concussion; PG, postgame/postpractice; D1, postinjury day 1; D2, postinjury day 2, etc. Adapted from McCrea et al.[24] with permission.

ASSOCIATIONS WITH A COMPLICATED RECOVERY

- Psychological Variables
- Personality Variables
- Legal Variables

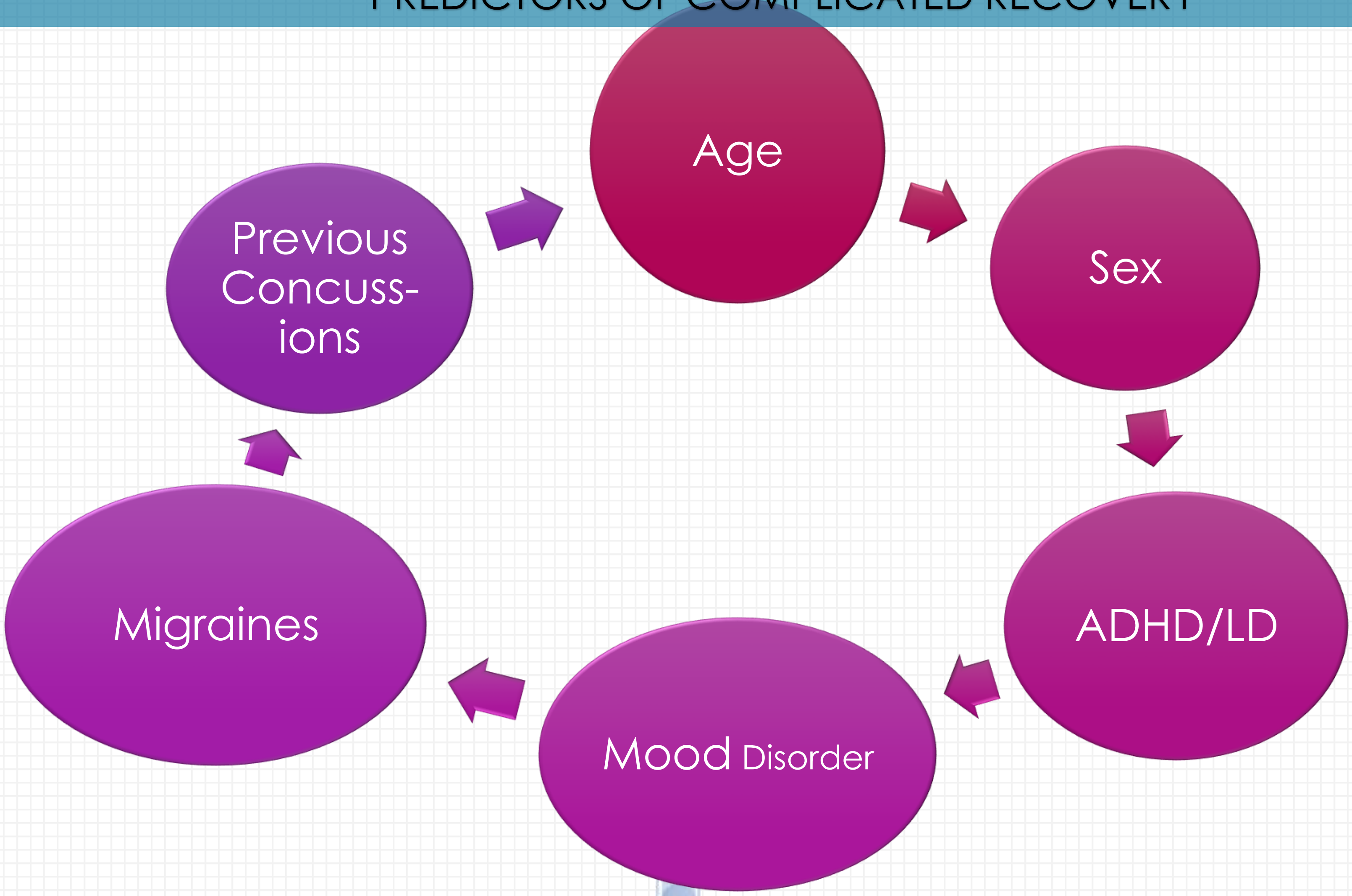
OPTIONS FOR ASSESSMENT: BEST PRACTICES APPROACH

- **Sideline to Day 7, post-injury**
- Neurological Assessment
- Symptom Checklists
- Balance Testing
- Brief mental status/cognitive testing
  - Paper/Pencil
  - Computerized, repeatable



- **1 week post-injury**
- F/U Neurological
- F/U Cognitive Screening
- Neuropsychological Testing
  - More sensitive and specific for cognitive, functional and psychological deficits

PREDICTORS OF COMPLICATED RECOVERY



EEG AND QUANTITATIVE EEG ASSESSMENT

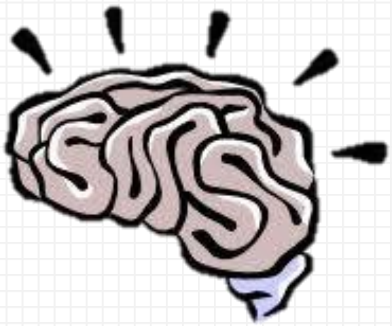
EEG CHANGES IN CONCUSSION
(HANEEF, Z, LEVIN, H., FROST, J., MIZRAHI, E., 2001)

- EEG may be more sensitive than a neurological exam in detecting head trauma.
- Post-concussion, 86% of patients will have an abnormal EEG
- Only 23% of those will have an abnormal neurological examination
- On occasion, resolution of EEG abnormalities may occur within 15 minutes
- PTA and unconsciousness predict longer EEG abnormalities

QEEG FINDINGS IN MTBI

Previous research supports:

- ✓ Reduced mean frequency in alpha
- ✓ Increased theta activity
- ✓ Reduced power in alpha and beta
- ✓ Increased frontal coherence



- ✓ Slowing in frontal and temporal regions
- ✓ Increased vulnerability in fronto-temporal regions
- ✓ Abnormality may last in excess of one year with persistent symptoms
- ✓ Decreased frontal to temporal coherence

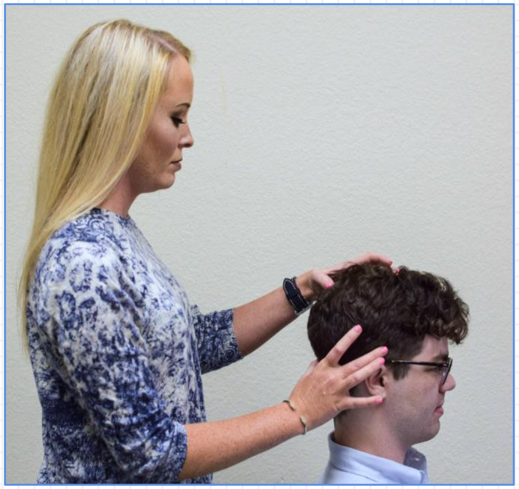
EEG CHANGES FOLLOWING MTBI (HOURS TO WEEKS)

- Animal studies suggest that immediately following the event, epileptiform activity (high amplitude sharp waves/high frequency discharges),
- This is followed by diffuse suppression of cortical activity, usually lasting 1-2 minutes
- Followed by diffuse slowing of the EEG which returns to base line within 10 minutes to 1 hours.
- Half of a sample of 31 patients with mTBI did not demonstrate EEG changes within 24 hours.
- Within hours, there is attenuation of posterior alpha along with generalized/focal slowing, particularly noted over the temporal regions

EEG CHANGES FOLLOWING MTBI, WEEKS TO MONTHS

- Majority of EEG abnormalities resolve by 3 months and 90% by one year
- Within the first weeks, there is often a 1-2 Hz increase in posterior alpha activity
- Some suggestion that on going PCS, for more than a year, increase likelihood of epileptiform activity.

NEUROFEEDBACK AND THE TREATMENT OF MTBI



EEG NEUROFEEDBACK THERAPY:
CAN IT ATTENUATE BRAIN CHANGES IN TBI?
(MUNIVENKATAPPA, ET AL., 2014)

- Case study of 2 patients; moderate head injury
- LOC: 1 hour; 1 week
- CT displayed diffuse axonal injury, blood in ears
- Moderately disabled according to Glasgow outcome score
- PCS
- <5th percentile on motor speed, mental speed, category fluency, visuospatial working memory, set shift, visual and verbal memory
- NFB and MRI completed one week before and one week after treatment
- 20 sessions of EEG NFB; 40 min/day; 3 days/week; protocol dependent on slow activity

EEG NEUROFEEDBACK THERAPY:
CAN IT ATTENUATE BRAIN CHANGES IN TBI?, CONT..

- Outcomes: Improvement in symptom reporting, NPE and MRI
  - Improvement in motor speed, metal speed, category fluency, working memory, mental shifting, encoding and memory.
  - Concussion symptoms
  - Significant decrease in theta, but not alpha excesses
  - Increased in cortical volume
  - Structural WM changes thalamocerebral connections, in WM tracts and cortical structures,
  - Improvement in functional connectivity-global and local efficiency

LITERATURE REVIEW

- Authors used Google Scholar, as it provided more citations that other search engines, such as Pub Med
- 999 articles were identified, but after review only 22 were deemed worthy to be a part of the study
- Of those, 8 were cohort designs,

TABLE 1
Classification rubric for levels of evidence

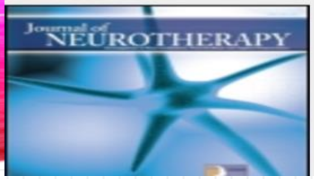
1	Anecdotal evidence
2	Uncontrolled case study
3	Historical control
4	Observational studies without randomization
5	Randomized wait-list or "intention to treat" controls
6	Within-subject and intrasubject replication designs
7	Single-blind, random assignment control design, either sham or active (behavioral, psychological, or pharmacologic) treatment controls
8	Double-blind control studies, sham or active controls, random assignment
9	Treatment equivalence or treatment superiority designs with placebo control
10	Other designs, eg, double dummy, Solomon four-group

TABLE 2

A summary of level 3 and 5 evidence

Level of evidence	Citation	Number of subjects	Description	Results
5	Tinius and Tinius, 2000[36]	16 NF patients and 15 healthy controls	Psychological and neuropsychological testing was performed before and after NF treatment; controls did not receive treatment	Broad improvement in NF group, significant after Bonferroni correction
5	Keller, 2001[37]	21 patients with a history of TBI	12 patients received 10 sessions of NF, 9 patients received computer attention training	Patients improved significantly relative to controls in measures of attention; patients showed increased time spent in beta rhythm during NF
3	Bounias et al, 2001[32-35]	27, grouped into 5 clusters	Patients were clustered based on symptoms, and response to NF was correlated with cluster type	More symptoms require more sessions; more sessions lead to greater improvement
3	Hoffman et al, 1996[39]	14 patients status post-mTBI from MVA	Unspecified	General improvement in symptoms, quality of life, and MicroCog™ assessment
3	Walker et al, 2002[40]	26 patients with a history of TBI	Coherence abnormalities on QEEG were corrected 1 by 1 until patients reported improvement	50% improvement or more by self-report in 88% of patients
3	Zelek, 2002[38]	10 patients with loss of consciousness of >30 minutes	QEEG and RBANS were given before and after 30 sessions of NF	RBANS improvement, with coherence abnormalities as opposed to power abnormalities predicting successful treatment
3	Rostami et al, 2011[41]	12 patients with a history of TBI	6 patients received NF and 6 were wait-listed controls	Statistically significant improvement in QEEG findings in the treatment group
3	Zorcec et al, 2011[42]	6 patients with a history of TBI	All 6 patients received NF training	Fewer perseverative errors in WCST; no reported change in the Stroop test

mTBI: mild traumatic brain injury; MVA: motor vehicle accident; NF: neurofeedback; RBANS: Repeatable Battery for the Assessment of Neuropsychological Status; QEEG: quantitative electroencephalogram; TBI: traumatic brain injury; WCST: Wisconsin Card Sorting Task.



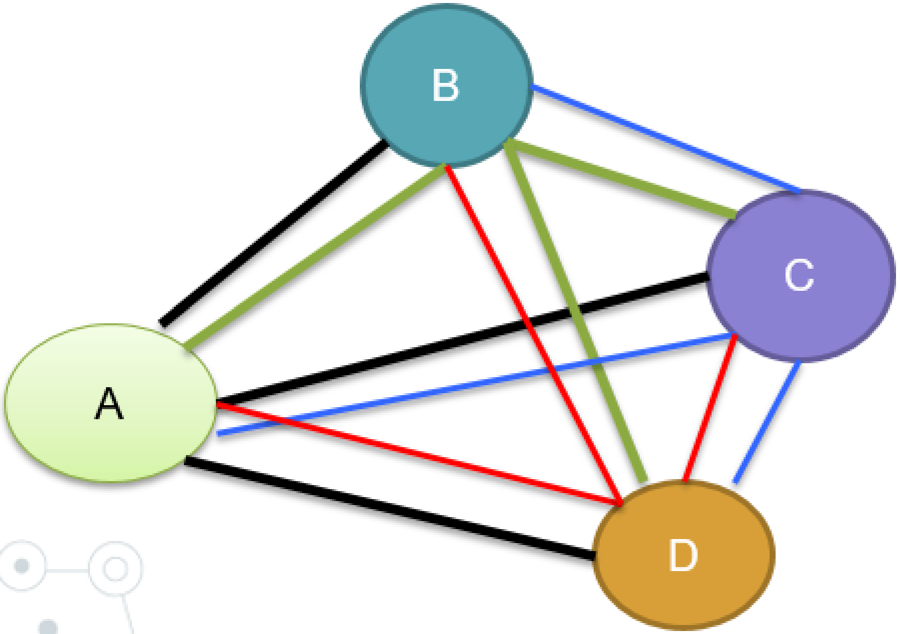
Journal
Journal of Neurotherapy >
Investigations in Neuromodulation, Neurofeedback and Applied Neuroscience
Volume 6, 2002 - Issue 2

Impact of qEEG-Guided Coherence Training for Patients with a Mild Closed Head Injury

Jonathan E. Walker, MD
Charles A. Norman, PhD
Ronald K. Weber, PhD

Methods. Twenty-six patients with persistent post-traumatic symptoms (PTS) were seen by the first author 3 to 70 months after a MHI and had a quantitative EEG (qEEG). Neurofeedback therapy designed to normalize abnormal qEEG coherence scores was provided to determine the effectiveness of this approach. Five training sessions addressed each qEEG abnormality. Training continued until the patient, by self-report, indicated that significant improvement had occurred or until a total of 40 sessions were given. Results. Significant improvement (>50%) was noted in 88% of the patients (mean = 72.7%). All patients reported that they were able to return to work following the treatment, if they had been employed prior to the injury. On average, 19 sessions were required, less than the average of 38 sessions required using power training of Cz-Beta in our previous unpublished study. Jonathan E. Walker and Ronald K. Weber are affiliated with the Neuroscience Cen

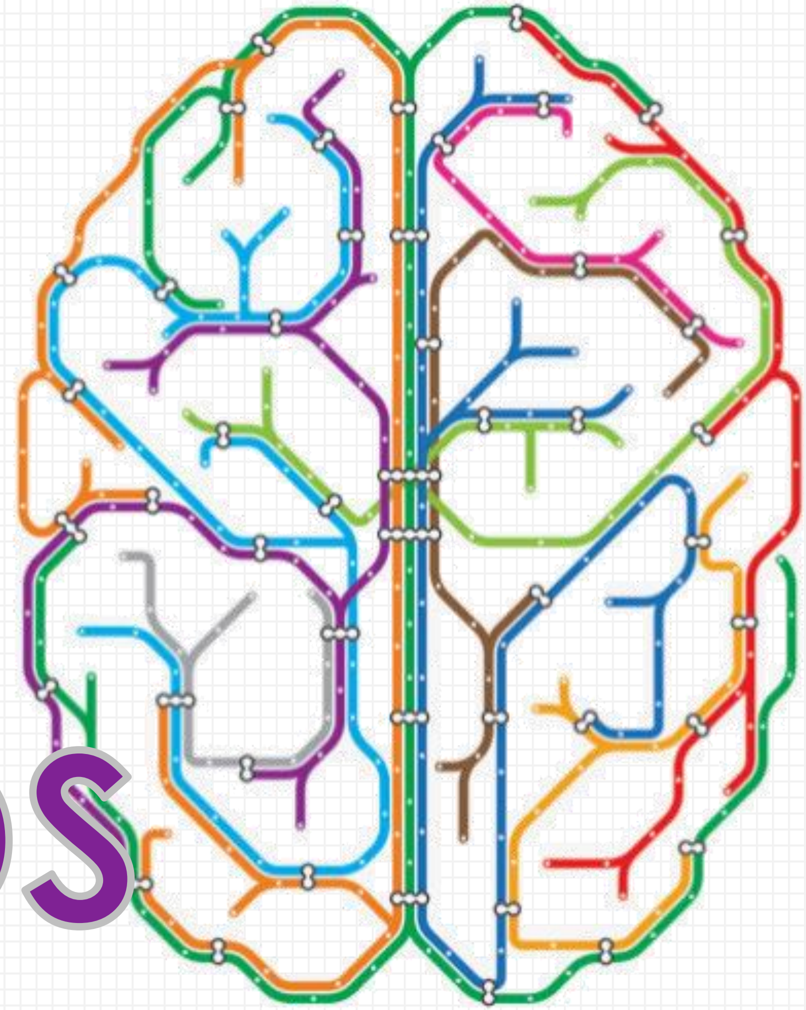
- A method of combining averaged psync values.
  - 4 channels of EEG
  - Each pair has a running psync calculation
  - For each channel, the 3 pairs of psync values are computed, averaged and this is used as the output reward value
  - If a raw channel is in artifact condition, the channel is not used in the averaging calculation



A = (AB + AC + AD)/3
B = (BA + BC + BD)/3
C = (CA + CB + CD)/3
D = (DA + DB + DC)/3

QPS Ave = (A + B + C + D)/4

METHODS



VARIABLES

Independent	Dependent

○ Months elapsed between initial evaluation and treatment.
○ Grouped into three groups
  ○ 0-1 Years
  ○ 1 to 5 Years
  ○ 10+ Years
	○ Global Coherence Change Scores
	○ Band Specific Coherence Change scores
	○ Neuropsych Composite Index change scores
	○ Self Report Composite change scores

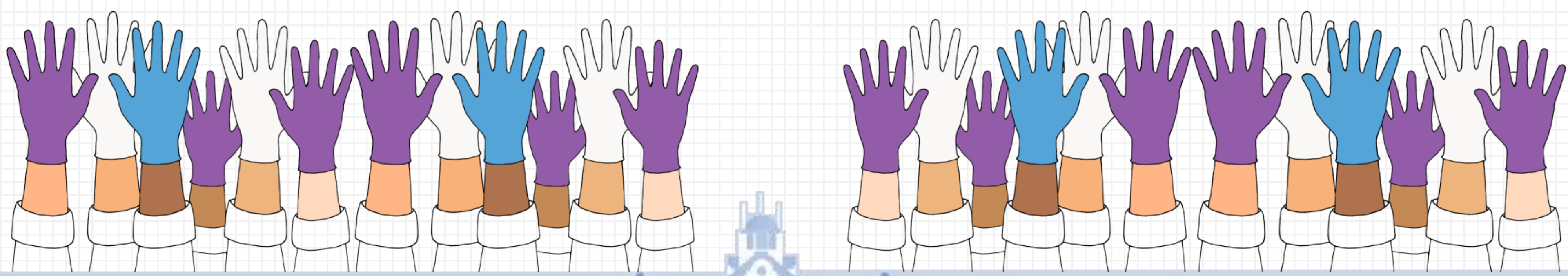
HYPOTHESIS

There will be no statistically significant difference in coherence change scores and neuropsych change scores between time groups.

In other words: 4 CH multivariate coherence training improves functioning, no matter how long one waits to seek treatment.

Sample Demographics

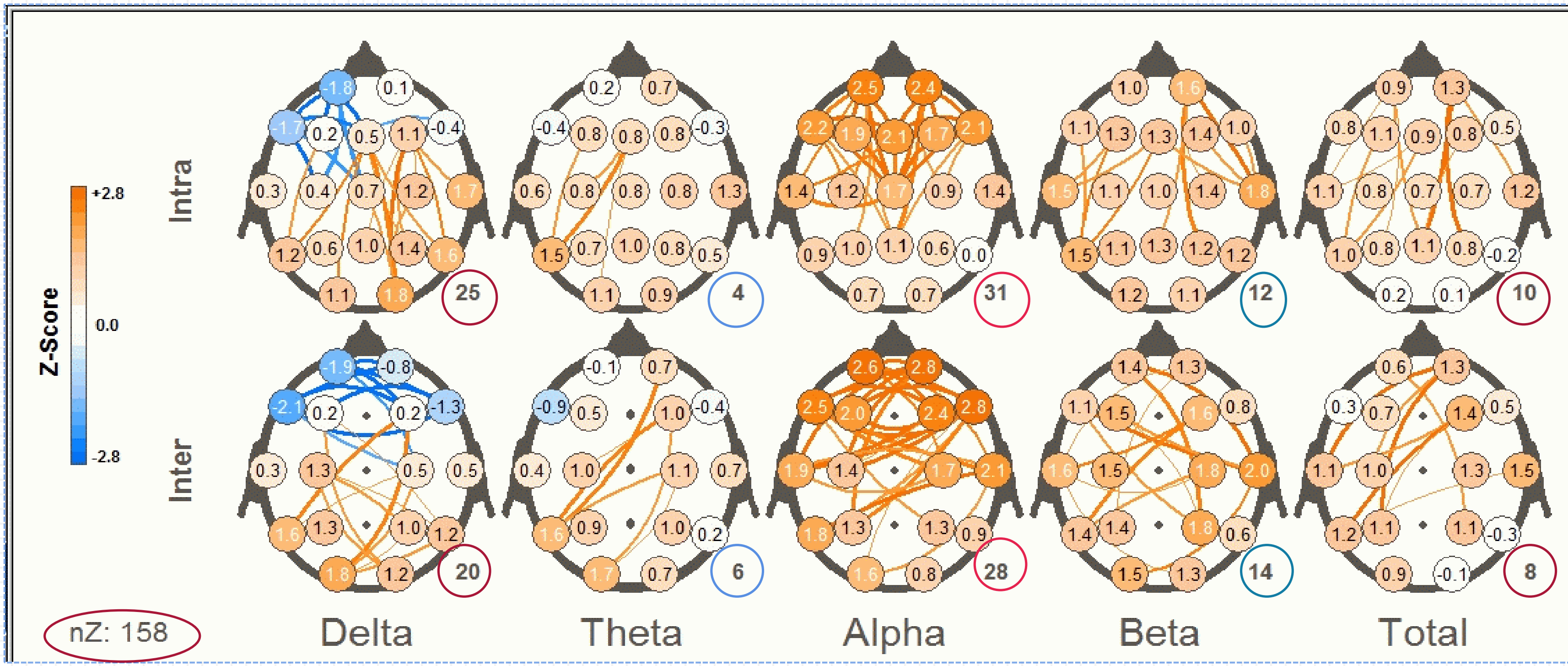
- N=20
- Female=13
- Male= 7
- Ages 18-65
- 100% Caucasian
- Treated for MTBI
- Received 4CH NFB
- Received Neuropsych testing



GROUP MAKEUP

	0-1 Years	1-5 Years	10+ Years	All Groups
Total N	8	8	4	20
Age Range	18-56	19-60	37-60	18-65
$\bar{X}$=	33	37	50	37
Gender	M=3, F=5	M=2, F=6	M=2, F=2	M=7, F=13
Head Injuries	1.6	1.25	2.25	1.6
Medications	~1	~2	~2	~2
$\bar{X}$ QEEG	2.87	3	2.5	2.85

COHERENCE CHANGE SCORES



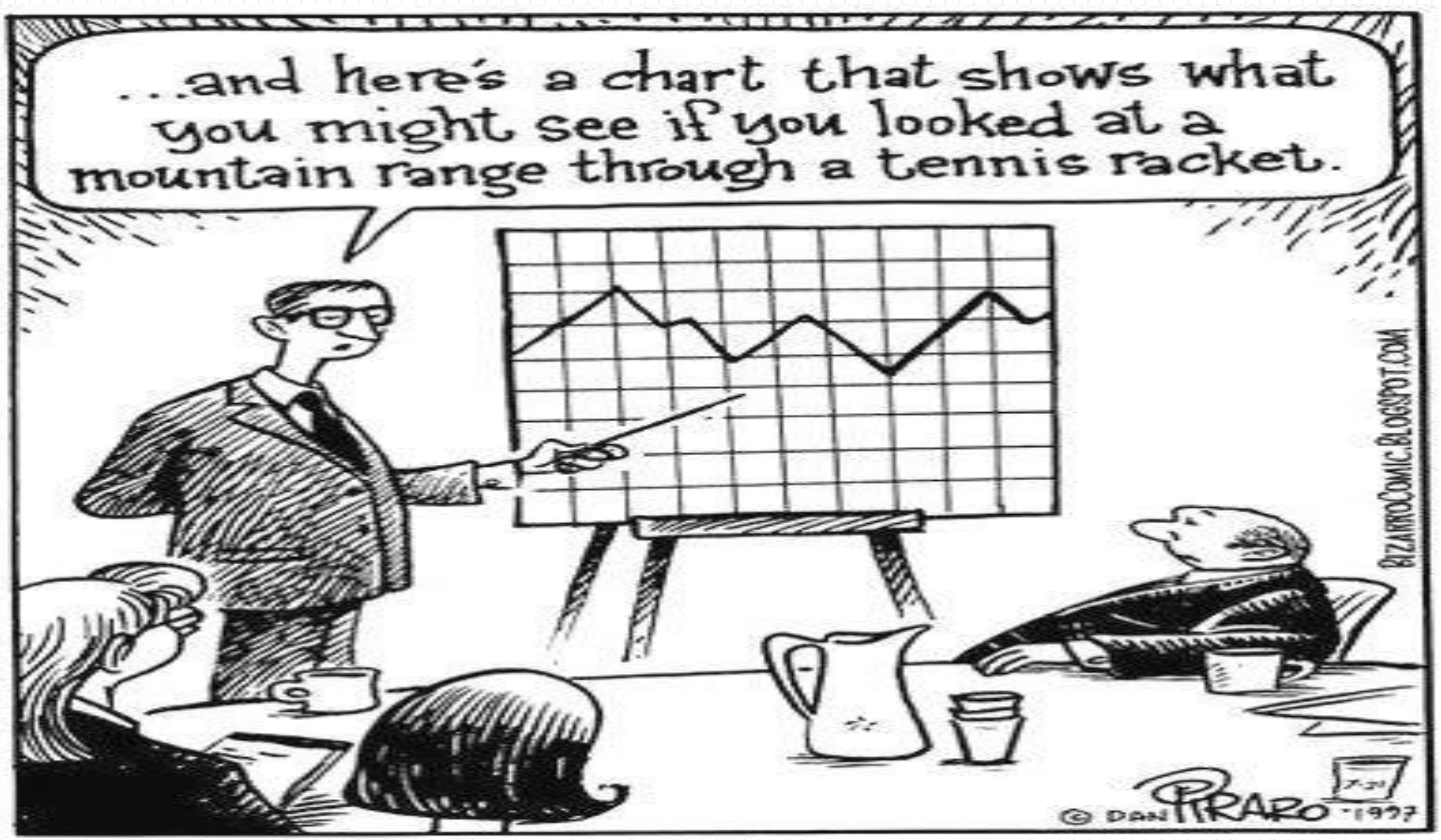
Global Z-score **Band Scores** **Total Scores**

PRE-POST=CHANGE SCORE

NEUROPSYCH COMPOSITE INDEX SCORES

Composite NeuroPsych Index (Pre/Post)	Self Report Index (Pre/Post)	The Math
- Includes: - Attention - Memory - Executive Functioning - Language processing - Sensory Perception - Verbal Reasoning	- Depression - Anxiety - Executive Fx	- The pre and post score represent the average of available scores - The change score represents the post score subtracted from the pre score

RESULTS


...and here's a chart that shows what you might see if you looked at a mountain range through a tennis racket.
BIZARROCOMIC.BLOGSPOT.COM
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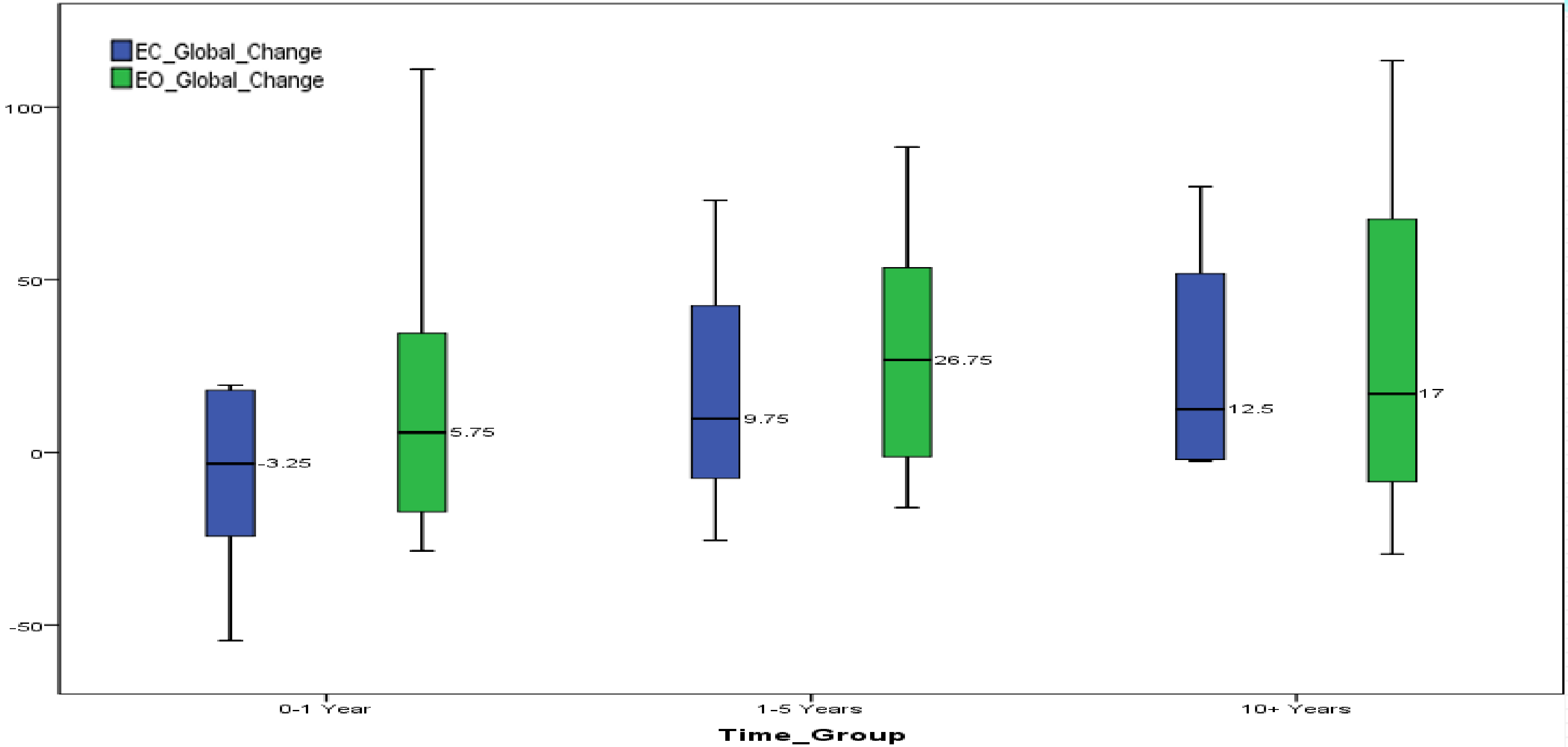
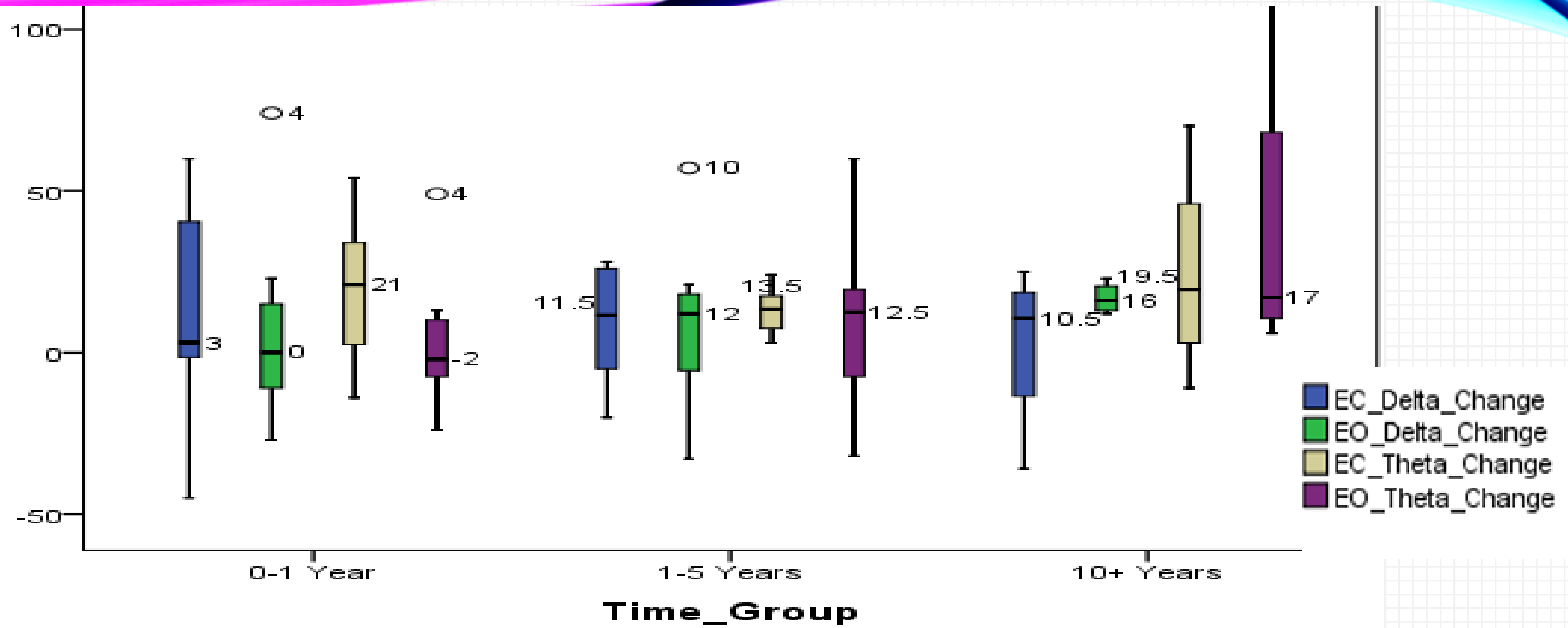


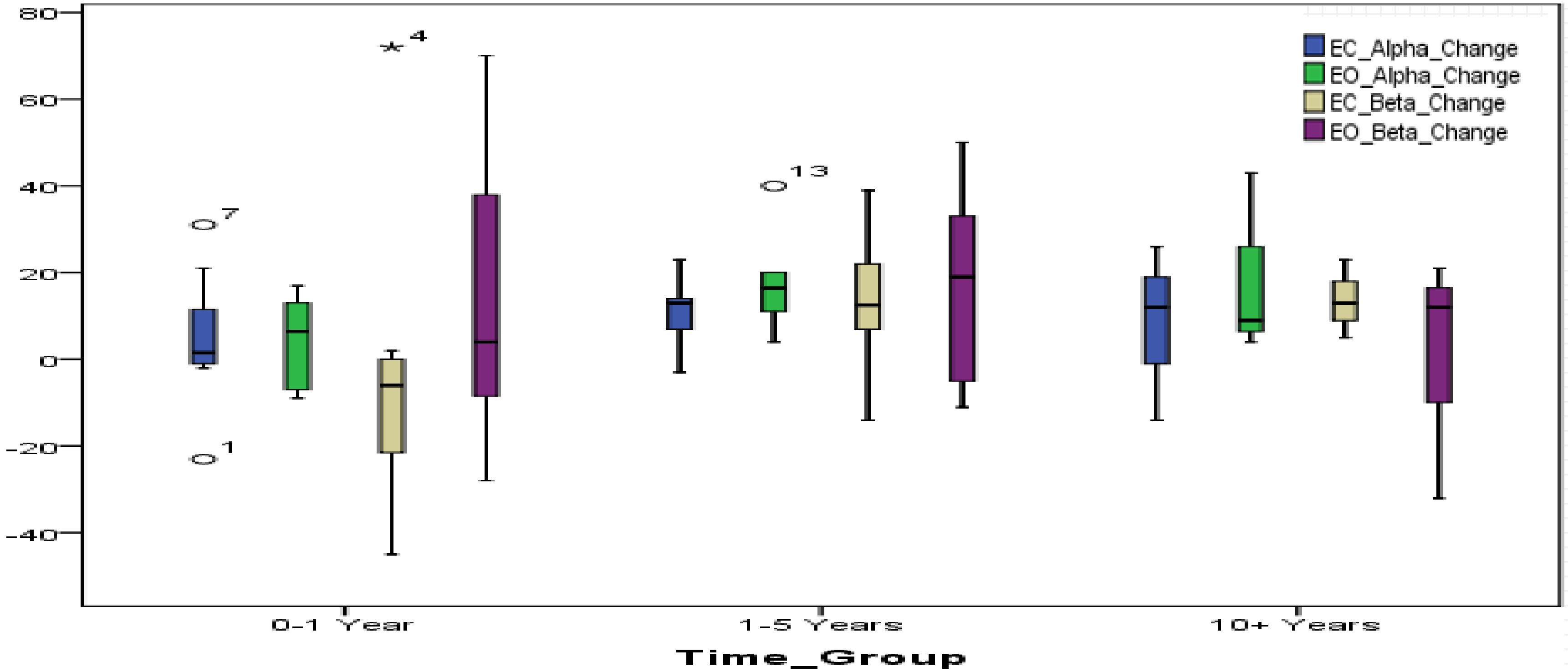
ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
EC_Global_Change	Between Groups	1087.019	2	543.509	.293	.750
	Within Groups	31537.031	17	1855.119		
	Total	32624.050	19			
EO_Global_Change	Between Groups	809.863	2	404.931	.196	.824
	Within Groups	35134.188	17	2066.717		
	Total	35944.050	19			
Combined_Global_Change	Between Groups	889.725	2	444.862	.245	.786
	Within Groups	30890.308	17	1817.077		
	Total	31780.032	19			



ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
EC_Delta_Change	Between Groups	321.328	2	160.664	.208	.815
	Within Groups	12375.304	16	773.456		
	Total	12696.632	18			
EO_Delta_Change	Between Groups	337.575	2	168.788	.239	.790
	Within Groups	12005.625	17	706.213		
	Total	12343.200	19			
EC_Theta_Change	Between Groups	383.675	2	191.838	.463	.637
	Within Groups	7050.875	17	414.757		
	Total	7434.550	19			
EO_Theta_Change	Between Groups	3349.575	2	1674.788	1.720	.209
	Within Groups	16554.625	17	973.801		
	Total	19904.200	19			

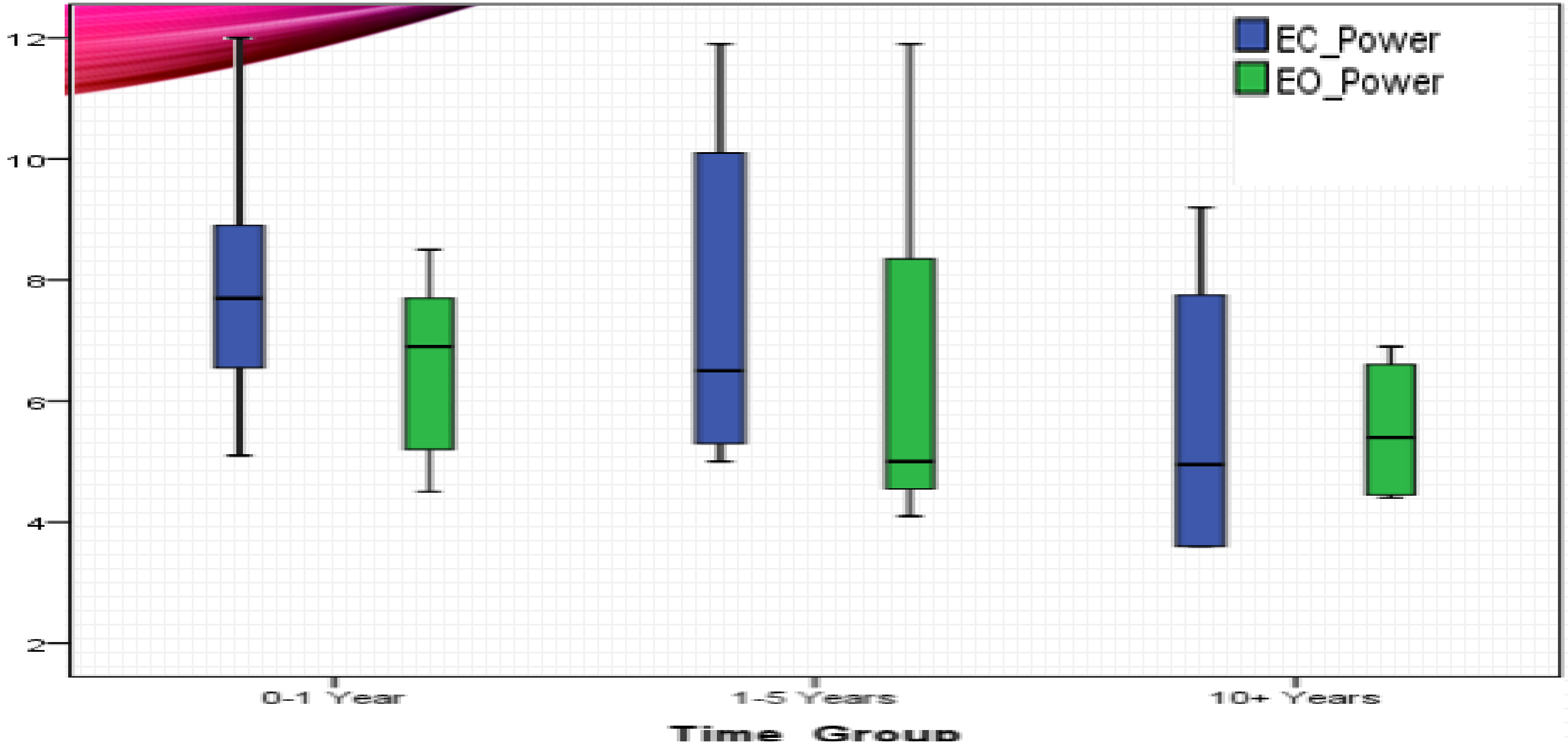


ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
EC_Alpha_Change	Between Groups	215.778	2	107.889	.497	.618
	Within Groups	3255.833	15	217.056		
	Total	3471.611	17			
EO_Alpha_Change	Between Groups	857.250	2	428.625	2.839	.086
	Within Groups	2566.750	17	150.985		
	Total	3424.000	19			
EC_Beta_Change	Between Groups	1511.406	2	755.703	1.210	.324
	Within Groups	9991.542	16	624.471		
	Total	11502.947	18			
EO_Beta_Change	Between Groups	253.575	2	126.788	.168	.847
	Within Groups	12850.625	17	755.919		
	Total	13104.200	19			

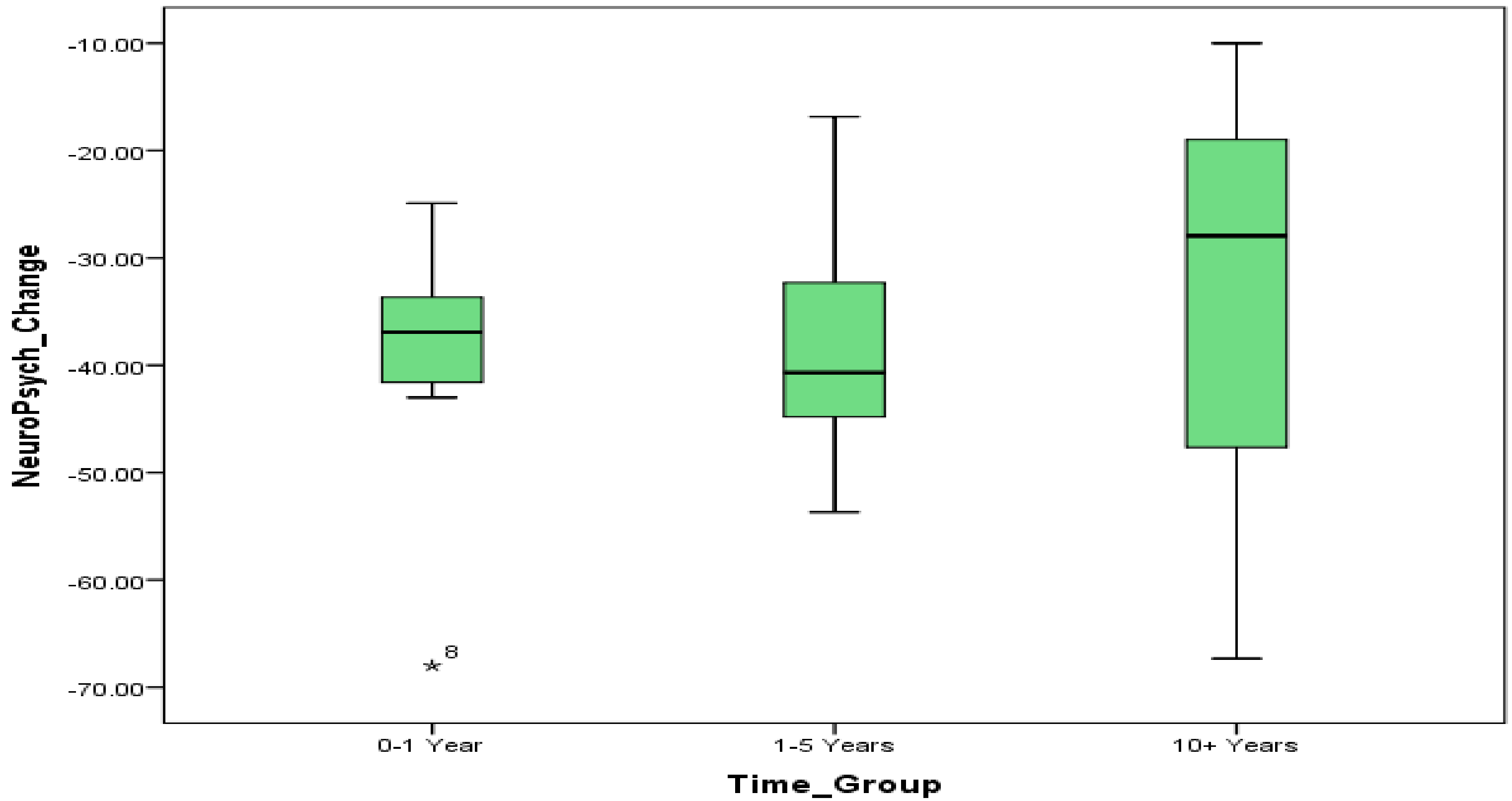
ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
EC_Combined_Change	Between Groups	343.575	2	171.788	.332	.722
	Within Groups	8786.625	17	516.860		
	Total	9130.200	19			
EO_Combined_Change	Between Groups	104347.050	2	52173.525	1.885	.182
	Within Groups	470539.500	17	27678.794		
	Total	574886.550	19			



ANOVA

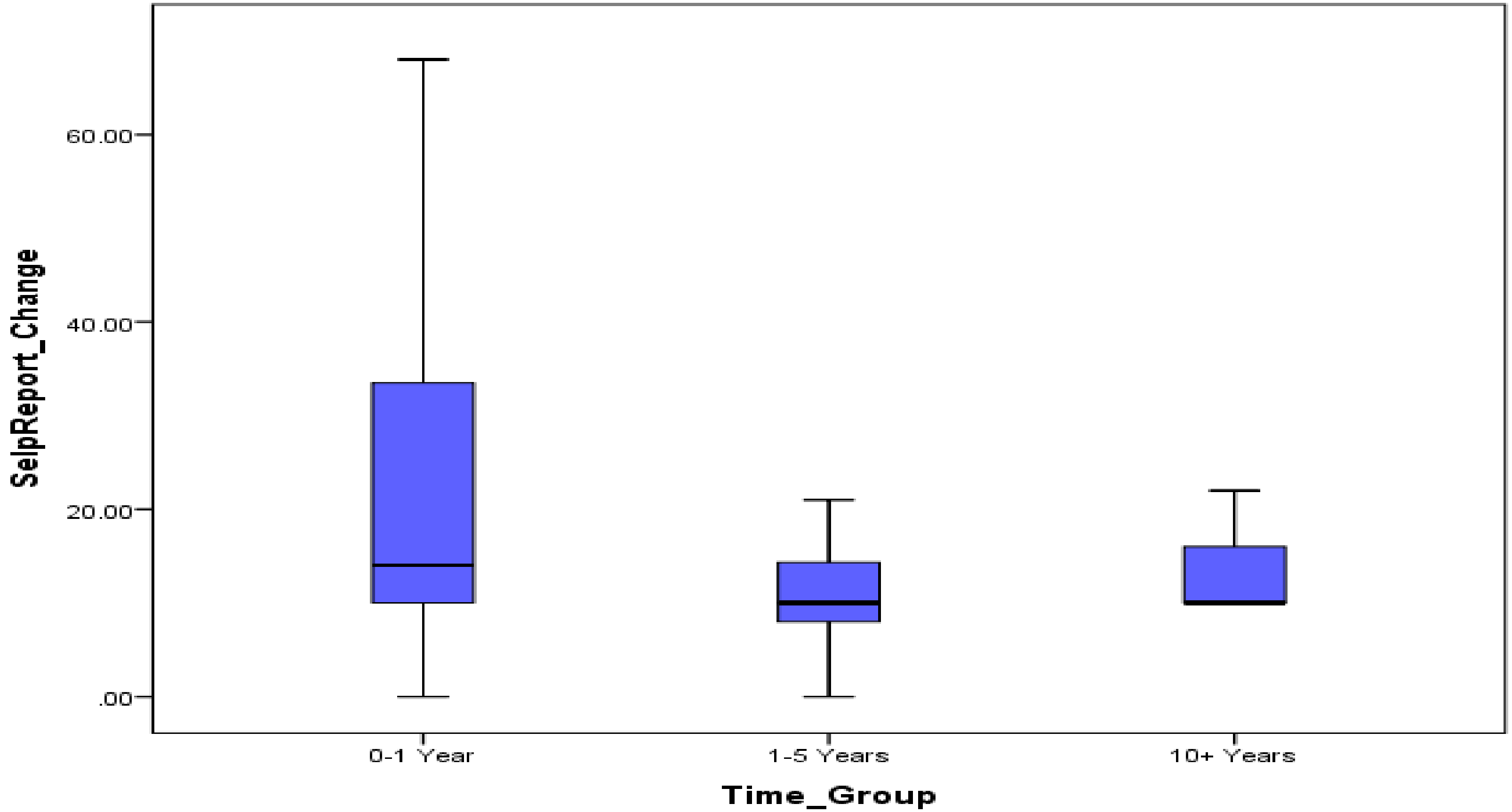
		Sum of Squares	df	Mean Square	F	Sig.
NeuroPsych_Composite_Pre	Between Groups	102.570	2	51.285	.332	.723
	Within Groups	2164.575	14	154.613		
	Total	2267.145	16			
NeuroPsych_Composite_Post	Between Groups	1133.458	2	566.729	.451	.644
	Within Groups	21364.371	17	1256.728		
	Total	22497.829	19			



ANOVA

NeuroPsych_Change

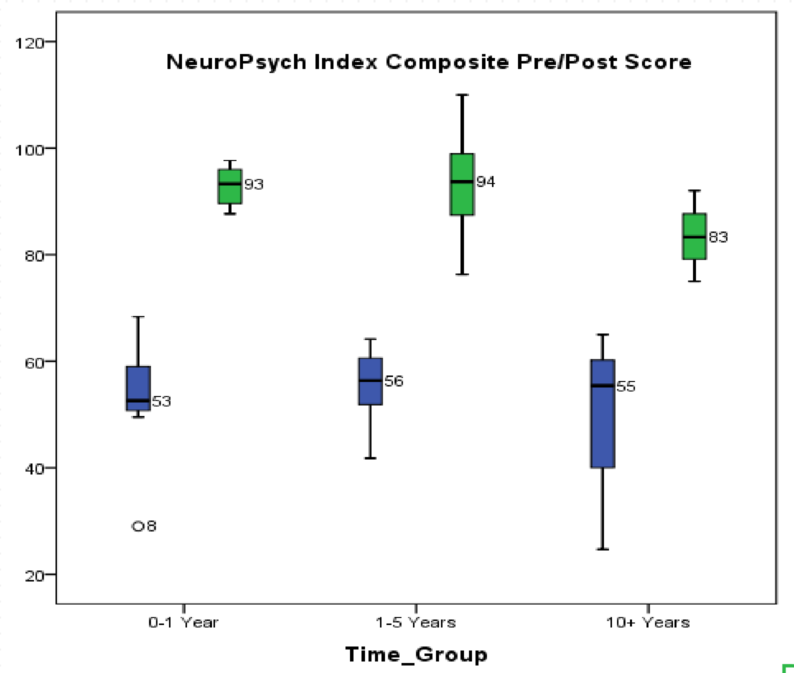
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	53.132	2	26.566	.100	.906
Within Groups	3724.649	14	266.046		
Total	3777.782	16			

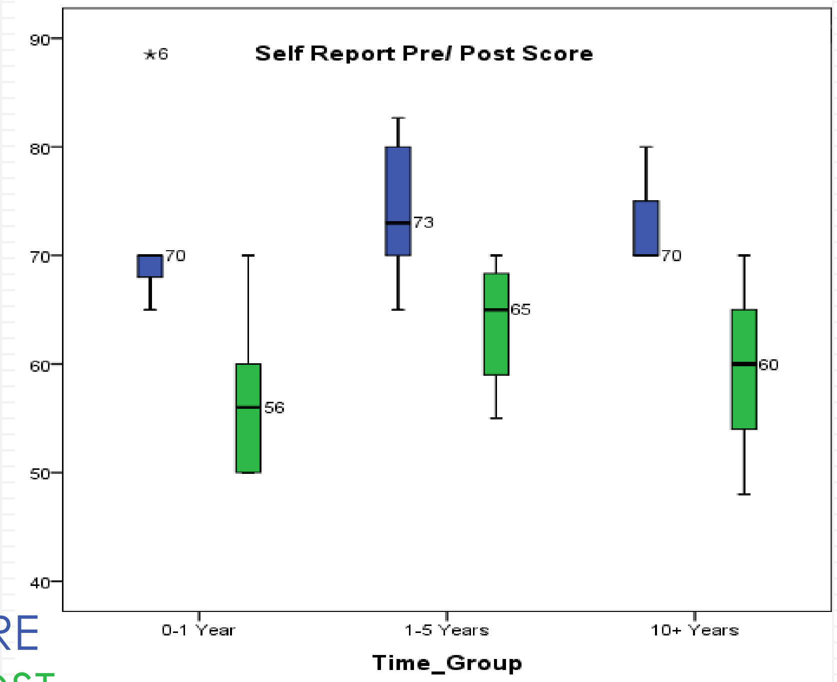


ANOVA

SelpReport_Change

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	461.214	2	230.607	.761	.490
Within Groups	3334.431	11	303.130		
Total	3795.645	13			





PRE
POST

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	NeuroPsych_Composite_Pre - NeuroPsych_Composite_Post	-38.29570	15.36592	3.72678	-46.19612	-30.39528	-10.276	16	.000
Pair 2	SelfReport_Composite_Pre - SelfReport_Composite_Post	16.77381	17.08721	4.56675	6.90795	26.63967	3.673	13	.003

- **Coherence Scores and Neuropsych Composite Scores Not * Predicted by:**
  - Time Group
  - Age
  - Gender
  - Handedness
  - Number of Head Injuries
  - Psychoactive Medication
  - Number of QEEG
  - Months elapsed between Initial eval/ Injury

*in most cases

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.532[a]	.284	-.238	46.09685

a. Predictors: (Constant), months elapsed between inital eval and head injury, Gender, Psychoactive_Medication, Number_Of_QEEG, Handedness, Number_Of_Head_Injury, Age, Time_Group

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	9249.932	8	1156.242	.544	.801[b]
	Residual	23374.118	11	2124.920		
	Total	32624.050	19			

a. Dependent Variable: EC_Global_Change

b. Predictors: (Constant), months elapsed between inital eval and head injury, Gender, Psychoactive_Medication, Number_Of_QEEG, Handedness, Number_Of_Head_Injury, Age, Time_Group

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	88.084	110.416		.798	.442
	Time_Group	-17.353	27.957	-.322	-.621	.547
	Age	-.395	.910	-.157	-.434	.673
	Gender	-11.708	25.540	-.138	-.458	.656
	Handedness	-2.231	63.565	-.012	-.035	.973
	Number_Of_Head_Injury	-22.297	14.639	-.459	-1.523	.156
	Psychoactive_Medication	13.904	8.954	.511	1.553	.149
	Number_Of_QEEG	-3.143	11.599	-.079	-.271	.791
	months elapsed between inital eval and head injury	.196	.168	.550	1.169	.267

a. Dependent Variable: EC_Global_Change

- **EXCEPT:**
  - QEEG predicted change in EO Delta Change Score
    - This could be due to the patient getting better at controlling eye movements artifact related to delta.
  - Gender predicts change in Self Report Composite Post Score and EC power
    - This could be reflective of the gender distribution of our sample group, however because of low sample size it’s hard to make solid assumptions about that.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.146[a]	.021	-.118	16.24996

a. Predictors: (Constant), Litigation, Personality_Profile

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	80.926	2	40.463	.153	.859[b]
	Residual	3696.856	14	264.061		
	Total	3777.782	16			

a. Dependent Variable: NeuroPsych_Change

b. Predictors: (Constant), Litigation, Personality_Profile

Coefficients[a]

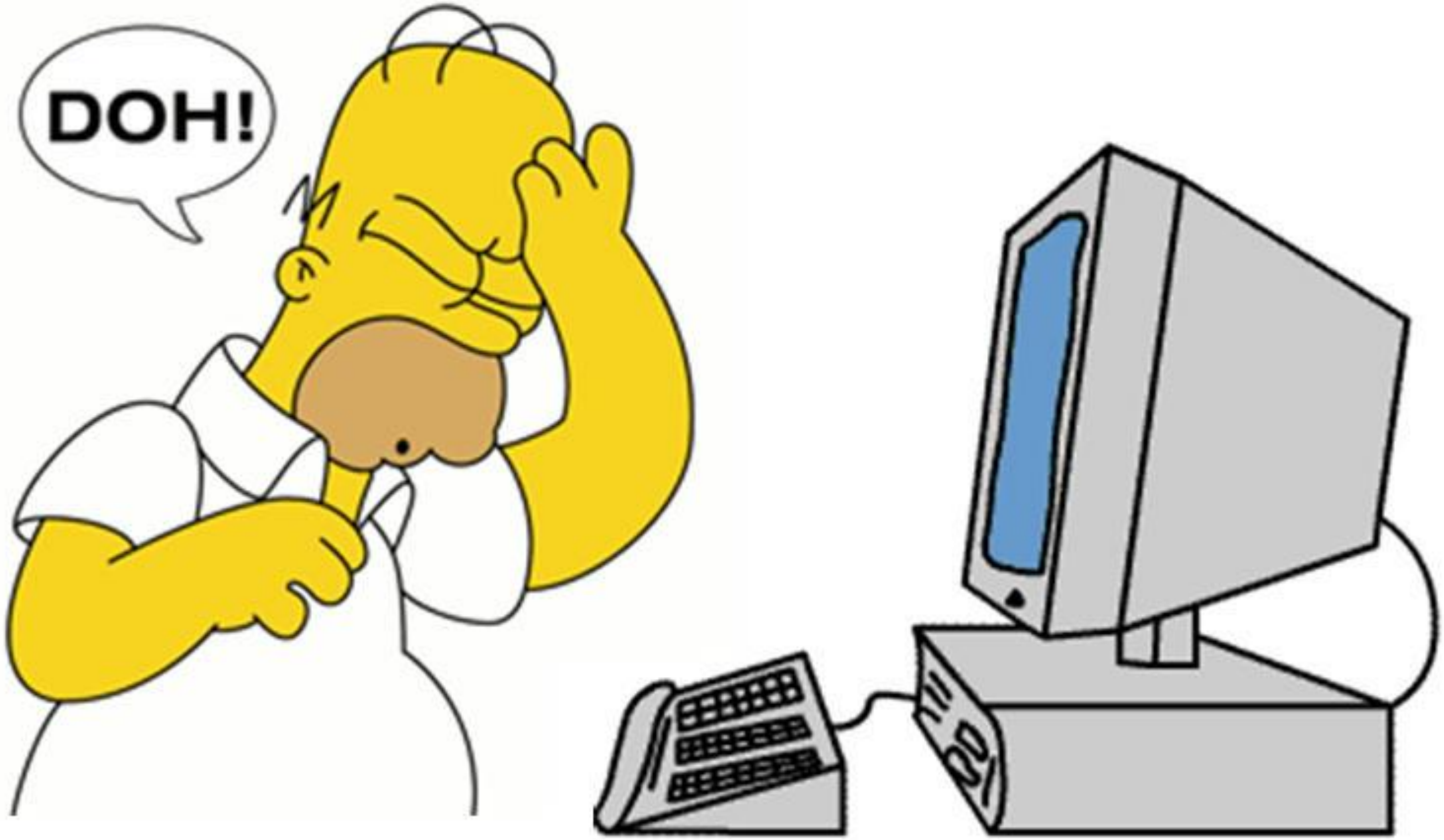
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-50.191	22.936		-2.188	.046
	Personality_Profile	.334	2.264	.041	.147	.885
	Litigation	6.017	10.882	.154	.553	.589

a. Dependent Variable: NeuroPsych_Change

Litigation and personality profiles were not predictors of NeuroPsych Score change.

This is important because many believe that….?

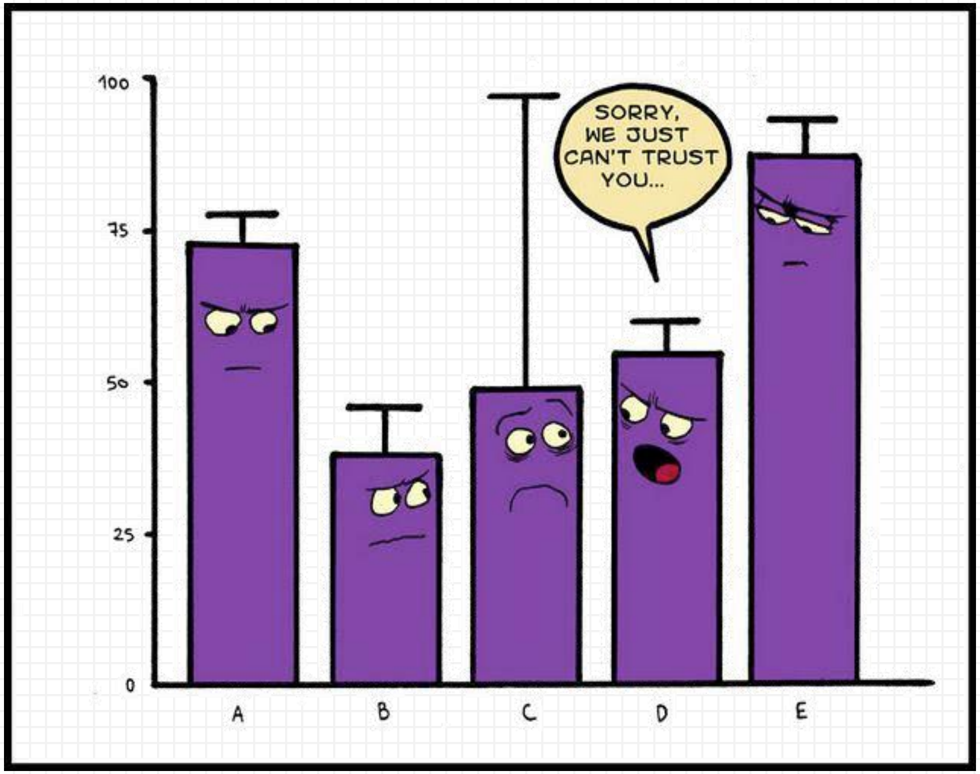
DISCUSSION



WHAT DOES IT MEAN?

- 4 channel multivariate coherence training can improve scores in coherence and neuropsych testing, even for those who wait to seek treatment.
- For each time group participants self reported less feelings of depression and anxiety.
- For each time group, participants scored higher on neuropsych testing, bringing them closer or into the normal functioning range.
- For each time group, participants saw a change in coherence scores that brought them closer to the norm.
- Factors such as litigation causing malingering or existing personality profiles were not predictors of neuropsych testing change.

LIMITATIONS



- Missing data
- Artifact
- Medications
- No information about treatments before initial eval.
- Increase N

Coherence score is based on average of averages, future studies could use ICA to look at source localization.

Could improve if a controlled study was used.

REFERENCES

- Centers for Disease Control and Prevention (CDC), National Center for Injury Prevention and Control. Report to Congress on mild traumatic brain injury in the United States: steps to prevent a serious public health problem. Atlanta (GA): Centers for Disease Control and Prevention; 2003.
- Coronado VG, Haileyesus T, Cheng TA, Bell JM, Haarbauer-Krupa J, Lionbarger MR, Flores-Herrera J, McGuire LC, Gilchrist J. Trends in sports- and recreation-related traumatic brain injuries treated in US emergency departments: The National Electronic Injury Surveillance System-All Injury Program (NEISS-AIP) 2001-2012. J Head Trauma Rehabil 2015; 30 (3): 185–197.
- Daneshvar, D. H., Nowinski, C. J., McKee, A., & Cantu, R. C. (2011). The Epidemiology of Sport-Related Concussion. *Clinics in Sports Medicine*, 30(1), 1–17. http://doi.org/10.1016/j.csm.2010.08.006
- Haneef, Z., Levin, H. S., Frost, J. D., & Mizrahi, E. M. (2013). Electroencephalography and Quantitative Electroencephalography in Mild Traumatic Brain Injury. Journal of Neurotrauma, 30(8), 653–656. http://doi.org/10.1089/neu.2012.2585
- King, D., Brughelli, M., Hume, P., Gissane, C. (2014). Assessment, Managements and Knowledge of Sport-related Concussion: systematic review. *Sports Medicine*, 44, 449-471. doi: 10.1007/s40279-013-0134-x
- Munivenkatappa, A., Rajeswaran, J., Devi, B. I., Bennet, N., & Upadhyay, N. (2014, January 01). EEG Neurofeedback therapy: Can it attenuate brain changes in TBI? Retrieved September 18, 2017, from http://content.iospress.com/articles/neurorehabilitation/nre1140
- Noble, J.M., Dale, C. (2013). Sports-related Concussions: A review of epidemiology, challenges in diagnosis, and potential risk factors. *Neuropsychology Review*, 23(4), 273-284. http://0dx.doi.org.library.uark.edu/10.1007/s11065-013-9239-0
- Taylor CA, Bell JM, Breiding MJ, Xu L. Traumatic Brain Injury–Related Emergency Department Visits, Hospitalizations, and Deaths — United States, 2007 and 2013. MMWR Surveill Summ 2017;66(No. SS-9):1–16. DOI: http://dx.doi.org/10.15585/mmwr.ss6609a1