TOWSON UNIVERSITY

OFFICE OF GRADUATE STUDIES

TRAINING THETA BRAIN WAVE ACTIVITY AFFECTS PERFORMANCE IN THE VIRTUAL WATER MAZE

By

Brianna Stinebaugh

A Thesis

Presented to the Faculty of

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In partial fulfillment

Of the requirements for the degree

Master of Arts

Department of Psychology

Towson University

Towson, Maryland 21252

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TOWSON UNIVERSITY

COLLEGE OF GRADUATE STUDIES AND RESEARCH

THESIS APPROVAL FORM

This is to certify that the thesis prepared by Brianna Stinebaugh entitled 'Training theta brain wave activity affects performance in the virtual water maze' has been approved by the thesis committee as satisfactorily completing the thesis requirements for the degree Master of Arts.

Frederick Parente, Ph.D.
Chair, Thesis Committee

5/5/14
Date

Mark Chachich, Ph.D.
Committee Member

5/5/14
Date

Bryan Devan, Ph.D.
Committee Member

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Janet V. DeLany, D.Ed.
Dean, College of Graduate Studies and Research

5-7-14
Date

Acknowledgements

I would not have been able to do this thesis project without the help and support from my advisor, Dr. Frederick Parente. I would not be where I am today and would not have been able to accomplish this thesis project without him. I received a lot of support, motivation, and encouragement from him that pushed me to accomplish many goals and dreams. I also want to thank Dr. Mark Chachich who not only supported me throughout this process but also has shown me how to believe in myself and to never give up even when things get tough. Both of these incredible individuals have been huge role models to me and always will be. I want to thank my family and friends who have been incredible support systems throughout this journey. I would not be where I am today without each and every one of them.

Abstract

Cortical theta activity is correlated with a person's use of spatial cues and landmarks to navigate through a virtual reality environment. This study used the Virtual Water Maze to study spatial navigation abilities in individuals after going through binaural pulse theta brain wave training or after listening to Mozart's Sonata for Two Pianos in D major, K. 448. The study design also included a control group that was not given any training or music to listen to. This group performed some basic math problems for the initial fifteen minutes of the study. All groups had their brain wave activity recorded through the use of a real time EEG head device. The current study hypothesized that if a theta state can be induced using binaural pulsing and if theta activity correlates with spatial navigation skill, then the participants in the binaural pulsing condition should show enhanced learning of the platform position in the Virtual Water Maze with faster latency scores relative to the no pre-training condition. The same was predicted for the Mozart condition; if Mozart's music creates a mental state of optimal learning, then the group that listens to Mozart should also experience enhanced spatial learning relative to the math condition which acted as this study's control condition receiving no theta pre-training before the Virtual Water Maze task. Results of the study showed there was no significant correlation between any of the EEG measures and the latency measure. When looking at the attention and meditation that were provided by the EEG program, the attention measure was slightly higher for the Mozart group compared to the other two groups.

Table of Content

Introduction

The brain consists of billions of neurons that communicate electrically with one another, a process that creates brain wave patterns. These electric waves give off different patterns that can be measured with electroencephalography (EEG). Each brainwave is distinguished by its frequency, number of repetitions of a wave per second, and of electrochemical impulses. An EEG device detects the different frequencies of the brain wave activity and measures the electrical potential from the scalp electrodes. There are five main brain wave patterns: gamma, alpha, beta, delta, and theta (Neurohealth Associates, 2004).

Theta Brain Waves

Theta brain waves are known to have a frequency of 3.5 to 7.5 Hz. Theta waves are relatively slow and usually occur during the in-between state of wakefulness and sleep. Neurohealth Associates (2004) theta brain wave activity is a characteristic of the subconscious mind and is associated with activity in the limbic system and hippocampus and its surrounding regions. Theta wave activity is correlated with performance on complex cognitive tasks (Neurohealth Associates, 2004). Theta waves are also related to memory performance (Klimesch, W., 1999); increases in memory load result in increases in theta oscillations (de Araujo, D. B., Baffa, Oswaldo, & Wakai, R. T., 2002).

Synchronization of theta brain waves is also correlated with encoding of novel information (Klimesch, W., 1999). For example, rats (McNaughton, Ruan, and Woodnorth, 2006) lose the ability to initially learn when their theta input from the hippocampus was blocked by injecting tectracaine into the medial septal area of the rats' brain before a series of trials in the Morris Water Maze. These results show that altering these rhythms can impair learning and memory in a spatial navigation task (McNaughton, N., et al., 2006).

Theta activity increases when performing a spatial navigation task (Ekstrom, A. D., Caplan, J. B., Ho, E., Shattuck, K., Fried, I., & Kahana, M. J., 2005). Cortical theta activity is coincident with a person's use of spatial cues and landmarks to navigate thru a virtual reality environment. Theta oscillations correlate with a person's ability to coordinate sensory information with the directed motor plan to help direct behavior to the aimed location (Kober, S. E. & Neuper, C., 2011). Compared to other brain wave frequencies, theta activity was the largest during goal directed navigation and has the highest correlation with performance in the Virtual Water Maze, specifically, during the encoding and retrieval of spatial information (Cornwell, B. R., Johnson, L. L., Holroyd, T., Carver, F. W., & Grillon, C., 2008).

Cornwell, et al. (2008) found that during spatial navigation, the hippocampus and parahippocampal cortices show theta brain wave activity. These theta oscillations are produced by movement in virtual maze settings. Because the environment in these settings gets more difficult, the oscillations increase. Theta oscillations in the hippocampus seem to be responsible for the formation of episodic memories and memories involved in spatial navigation tasks (Cornwell, et al., 2008). Therefore, behavioral changes affect hippocampal oscillations within the theta band. Theta oscillations also have an important role in the timing of action potentials throughout place learning. (Ekstrom, et al., 2005).

Training of Brain Waves

Zoefel, B., Huster, R. J., Herrmann, C. S. (2010) showed that it was possible to train a specific frequency band independent of other bands, specifically, the upper alpha frequency band. The training of this brain wave increased across sessions of their study. Each training experience built upon the previous training allowing an increase in the upper alpha band which correlated with performance on other cognitive tasks.

Binaural Pulsing is a method of training theta brain wave activity by using a series of tones and beats. Binaural tones are used to alter cognitive processes by targeting the physiology of brain waves. After being stimulated by binaural beats, research has shown that the frequency of beta and theta brain waves increase (Goodin, P., Ciorciari, J., Baker, K., Carrey, A., Harper, M., & Kaufman, J, 2012). Another study specifically showed that this protocol significantly increases anterior theta activity for five of the six participants that took part within the study (Brady, B. & Stevens, L., 2000).

Mozart

Terzin-Laub, N. & Ivanec, D., (2012) reported that listening to a piece of Mozart music improved spatial navigation. This finding, known as "the Mozart Effect", which lasts 10 to 15 minutes after being exposed to Mozart music, has been replicated in several studies. For example, Jones, M. H. & Estell, D. B. (2007) reported that participants within the Mozart condition performed better on spatial reasoning tasks after listening to the first movement of a Mozart piece entitled "Sonata for Two Pianos in D major, K. 448" for seven minutes and 28 seconds. The same improvement does not occur with other types of classical music that have been tested. Although there is no clear explanation for why Mozart pieces improve spatial reasoning, it presumably occurs because the musical structure of the Mozart Sonata activating or stimulating the requisite activity in the same areas of the brain that are activated when performing a spatial cognitive task, specifically, the right cerebral hemisphere areas of the parietal lobe are activated (Aheadi, A., Dixon, P., & Glover, S., 2010).

Memory and Spatial Learning

Memory and spatial learning has been a topic of study for many years and has been mostly studied using animals, mainly rats (Hamilton et al., 2001). Studying human memory and

spatial learning is usually done through case studies on specific individuals although these studies are rare due to the lack of availability of humans with brain damage and ethical issues. One way to study memory and learning that is still used today is through the use of the Morris Water Maze.

The Morris Water Maze has been used for testing navigation strategies and is widely used because of its ability to assess "hippocampal-dependent spatial learning and memory" (Dam, Lenders, & De Deyn, 2006, p. 164). The maze is a pool of water with a hidden escape platform submerged just beneath the opaque water surface (Dam et al., 2006). The pool is divided into four quadrants. The rats are placed in the pool from different starting locations around the edge of the pool and are timed to see how quickly they learn the platform location from each start point. Most studies consist of various acquisition and testing trials ending with a probe test. A probe test is a regular trial in the water maze except the platform is removed from the pool and the rats are observed to see which quadrant they spend most of their time searching. When the platform is removed from the pool, the rats will still search in the region where they learned the platform was located if the animals have succeeded in learning the task (Hamilton, Driscoll, & Sutherland, 2001).

The Virtual Water Maze is a human learning analogue to the Morris Water Maze. The Virtual Water Maze is a computer task that can be used to test spatial recognition and memory in humans using the competitive place task test. Participants start out in a round pool of water in a virtual room. Participants enter the pool at a different starting location on each trial. Participants navigate their way through a virtual pool of water by using the arrow keys on the keyboard and they learn to move around in the water by using distal visual cues (Hamilton et al., 2001).

The Morris Water Maze and the Virtual Water Maze allow comparisons of functions of brain structures involved with spatial learning and memory common to rats and humans (e.g., the hippocampus and basal ganglia; Hamilton et al., 2001). Various memory processes have been studied using the Virtual Water Maze which is similar to those observed in rats. The virtual version of the Morris Water Maze was developed to gain a better understanding of actual human learning and memory without having to rely on data obtained from rodents.

Overview of the Present Study

This study used the Virtual Water Maze to study spatial navigation abilities in individuals after going through binaural pulse theta brain wave training or after listening to Mozart's Sonata for Two Pianos in D major, K. 448. Participants either went through theta brain wave training for fifteen minutes by using a binaural pulsing system or was given the same type of head phones but listened to the Mozart Sonata for fifteen minutes. Both groups did not listen to the tone or music while they participated in several trials of the Virtual Water Maze. The study design also included a control group that was not given any training or music to listen to. This group performed some basic math problems for the initial fifteen minutes of the study. All groups had their brain wave activity recorded through the use of a real time EEG head device.

If theta wave training produces effects consistent with past studies that have reported increased theta wave activity during spatial navigation tasks and if listening to Mozart music improves navigation, then pre-training procedures that increase theta activity will improve performance in a Virtual Water Maze task (Ekstrom, et al., 2005; Kober, S. E. & Neuper, C., 2011; Cornwell, et al., 2008; Terzin-Laub, N. & Ivanec, D., 2012; Jones, M. H. & Estell, D. B., 2007; Aheadi, A., et al., 2010). Specifically, if virtual navigation correlates with theta activity and if theta activity is trainable using the binaural pulsing technique or listening to Mozart, then

pre-training using binaural pulsing may enhance later performance in the Virtual Water Maze relative to a no pre-training condition.

Method

Participants

A total of 24 Towson University undergraduate college students participated in this study. There were eight individuals in each of the three groups. All participants were required to be at least 18 years old and were recruited through the use of an introductory statistics course offered at the university. Students received extra credit for their statistics class in return for their participation. Participation was voluntary.

Procedure

Participants were given an informed consent form to sign and fill out before beginning the study. The instructions given on the informed consent form guided the participants through what was to be expected of them throughout the study. Students also received an identification code and a group code to save their Virtual Water Maze data to the computer. The coding system was designed to keep each student's data anonymous prior to the start of the study. The participants were then connected to the EEG headset software and a check was completed to confirm that the EEG monitoring device was recording correctly. Each student wore a headset that sits atop the head and measures the various EEG waveforms. In all of the conditions, the participants wore a set of "ear bud" phones through which they heard the pre-training materials. Participants in the no pre-training condition also wore the "ear buds" but nothing played through them. The study began with participants sitting quietly and listening to a binaural pulsing tone, a section of the Mozart music, or nothing through the ear phones for the initial 15 minutes of the total 30 minute time slot. Students were asked to sit initially for the fifteen minutes listening to

whatever is playing in their ear phones or if in the control group they were asked to complete some basic mathematical problems to ensure that they would not enter a theta like state. After the fifteen minutes of pre-training was complete, students were given a series of trials to complete in the Virtual Water Maze for the remainder of the study. Once completed, students received their credit for their participation.

All participants received the same amount of trials within the Virtual Water Maze lasting for a total of 15 minutes if the full 60 seconds for each trial was used. Participants finished before the half hour was complete if they found the hidden platform in less than the 60 seconds allotted for each trial. If the platform was not found in 60 seconds, the platform became visible and a message prompting the participant to swim to the platform appeared on the screen. In between each trial before the screen faded out to begin the next trial, participants sat on the visible platform for about two seconds. They completed a total of 10 trials with the platform hidden in the same location of the water maze. Following the hidden trials was a probe test where there was no platform in the pool of water. The series of trials ended with four visible trials where the platform was visible and participants were instructed to swim to the platform. These trials mimicked the standard water maze task by using half of the usual recommended trials for time restraint purposes.

The time that student's spent in the quadrant containing the platform was observed during the probe trial. This gave evidence that the participants remembered where the hidden platform was located. This software program has been widely used for several years and is known to be a reliable and valid way to measure spatial behavior, memory, and learning (Hamilton et al., 2001).

Results

Data from the series of trials were recorded into the Virtual Water Maze software computer program and then transferred to a data analysis spreadsheet to be analyzed. Data was entered into the Statistical Package for the Social Sciences (SPSS) after which a between-subjects factor independent group Univariate Analysis of Variance was used to analyze these data. The grouping variable was the type of pre-training the participant received (Binaural Pulsing, Mozart, or math problems). Dependent variables included the average time to reach the Virtual Water Maze platform, also known as the average latency, and the meditation and attention scores obtained through the pre-training on the EEG program analysis.

Analysis of variance computed on these measure did not reveal any significant differences among the various conditions, $F(2, 24) = .410$, $p > .05$. All groups performed similarly on the Virtual Water Maze task. When looking at the attention and meditation that were provided by the EEG program, the attention measure was slightly higher for the Mozart group, $M = 57.50$ compared to $M = 46.25$ for the meditation group and $M = 54.38$ for the no-training group. There was no significant correlation between any of the EEG measures and the latency measure.

Discussion

According to past research, cortical theta activity is correlated with a person's use of spatial cues and landmarks to navigate through a virtual reality environment. Therefore, theta brain wave training should increase the spatial navigational abilities. Two of the most well-known types of theta training include the use of binaural beats which stimulates a theta like state and Mozart music which has been found to be successful through the Mozart effect. Spatial

abilities are heightened for approximately 10 to 15 minutes after the exposure to the Mozart piece entitled, “Sonata for Two Pianos in D major, K. 448.”

The current study hypothesized that if a theta state can be induced using binaural pulsing and if theta activity correlates with spatial navigation skill, then the participants in the binaural pulsing condition should show enhanced learning of the platform position in the Virtual Water Maze with faster latency scores relative to the no pre-training condition. The same was predicted for the Mozart condition; if Mozart’s music creates a mental state of optimal learning, then the group that listens to Mozart should also experience enhanced spatial learning relative to the math condition which acted as this study’s control condition receiving no theta pre-training before the Virtual Water Maze task.

The results of this study however, showed no significant findings that supported this past research. There were no differences amongst the three groups in the average latency scores obtained in the spatial navigation task. The only difference observed was that the group who received Mozart music had higher attention levels during the pre-training condition compared to the other two groups used within this study.

There are several limitations found within this study that should be looked at for future research that may support why no results were found from this current study. Because there were a limited amount of students participating in this study, a larger sample size may have yielded significant results. Second, the sample used for this study was limited to only undergraduate Towson University students taking an introductory statistics class. It would be interesting to extend this sample to include other populations or age categories. A third possible limitation of this study was this was the first study to look at spatial navigation and theta training using the Virtual Water Maze. The Virtual Water Maze is known to be a valid measure of spatial

navigation abilities but it would be beneficial to run other studies with extended trail periods to see if more trials would show a larger effect of the theta training. This study used half of the standard amount of trials usually used in a water maze study. Usually, 20 hidden trails are used followed by one probe trail and then eight visible trials. For time restrictions, these trials were cut in half. With the full amount of trials, the expected results might have been obtained.

Appendices

TOWSON UNIVERSITY

APPROVAL NUMBER: 14-A063

To: Brianna Stinebaugh
1300 Terry Way
Fallston MD 21047

From: Institutional Review Board for the Proctection of Human Subjects Stacy Spaulding, Member

Date: Friday, February 07, 2014

RE: Application for Approval of Research Involving the Use of Human Participants

APPROVED
FEB – 7 2014
TOWSON IRB

Office of Sponsored Programs
Et Research

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Training theta brain wave activity affects performance in virtual water maze

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: R. Parente
File

TOWSON UNIVERSITY

Date: Friday, February 07, 2014

NOTICE OF APPROVAL

TO: Brianna Stinebaugh **DEPT:** PSYC

PROJECT TITLE: *Training theta brain wave activity affects performance in virtual water maze*

SPONSORING AGENCY:

APPROVAL NUMBER: 14-A063

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [ ] is [✓] is not required of each participant

This protocol was first approved on: 2014-02-07
This research will be reviewed every year from the date of first approval.

MPA (SOR)
Stacy Spaulding, Member
Towson University Institutional Review Board

INFORMED CONSENT FORM

PRINCIPAL INVESTIGATOR: Brianna Stinebaugh

PHONE: 410-937-2823

Purpose of Current Study:

This Virtual Water Maze study will be used to study spatial navigation abilities in individuals after going through theta brain wave training or after listening to Mozart music. Participants will either go through theta brain wave training for ten minutes by using a binaural pulsing system or will be given the same type of head phones but given Mozart music to listen to instead for ten minutes. The study design will also include a third group who will not be given any training or music to listen to. This group will simply be asked to perform a mathematical task for the ten minutes. All groups will have their brain wave activity recorded through the use of a real time EEG head device.

Procedure:

Participants will contact the experimenter and sign up for a 30 minute time slot. Participants will be given an informed consent form to sign and fill out before beginning the study. The instructions will guide the participants through what will be expected of them throughout the study. Students will also receive an identification code and a group code to save their Virtual Water Maze data to the computer. The coding system is designed to keep each student's data anonymous prior to the start of the study. The participants will then be connected to the software and a check will ensue to confirm that the EEG monitoring device is recording correctly. Each student will wear a headset that sits atop the head and measures the various EEG waveforms. In all of the conditions, the participants will wear a set of "ear bud" phones through which they will hear the pre-training materials. Participants in the no pre-training condition will also wear "ear buds" but nothing will play through them. The study will begin by participants sitting quietly and listening to a binaural pulsing tone, a section of Mozart music, or nothing through the ear phones and asked to perform mathematical problems for about 10 minutes of the total 30 minute time slot. Students will be asked to sit initially for ten minutes listening to

whatever is playing in their ear phones or if in the no pre-training group they will be asked to simply sit quietly and perform the mathematical problems. After the ten minutes of pre-training is complete, students will be given a series of trials in the maze. Once completed, students will receive their credit for their participation.

All participants will receive the same amount of trials within the Virtual Water Maze lasting for a total of a half hour if the full 60 seconds for each trial will be used. Participants may finish before the half hour is complete if they find the hidden platform in less than the 60 seconds allotted for each trial. If the platform is not found in 60 seconds, the platform will become visible and a message prompting the participant to swim to the platform will appear on the screen. In between each trial before the screen fades out to begin the next trial, participants will sit on the visible platform for about 5 seconds.

Participant Description:

Research participants will be undergraduate Towson University students recruited from an undergraduate Towson University Psychology Introduction to Statistics class. Participants must be signed up for the study through the website prior to the start of the study. The participants must be at least 18 years old.

Risk/Discomfort:

The risks to the research participant have been minimized by research design. Should the testing become distressing to you, it will be terminated immediately.

Alternatives to Participation:

Participation in this study is voluntary. Participants are free to withdraw or discontinue participation at any time. Withdrawing from this study will have no adverse effects on their standing as a student.

Confidentiality:

All information collected during the study will be kept strictly confidential. Your data will be identified through a code. No publications or reports from this study will include identifying information on any participant. If you agree to join this study, please sign your name below.

____ I have read and understood the information on this form.

____ I have had the information on this form explained to me.

_____

Participant's Signature Date

_____

Investigator Date

If you have any questions regarding this study please contact Brianna Stinebaugh at (410) 937 – 2823 or at bstine2@students.towson.edu. You can also contact the faculty advisor of this study at 410-704-3073.

This study has been reviewed by the Towson University Institutional Review Board for the Protection of Human Participants. If you have questions, you may also contact the Chair of the IRB, Dr. Debi Gartland, at (410) 704 – 2236.

References

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CURRICULUM VITA

Brianna Stinebaugh
[redacted]

EDUCATION

B.S. Psychology
Undergraduate Honors Thesis Research Program — Graduation: May 23, 2012

M.A. Experimental Psychology — Graduation: May 21, 2014

AWARDS

- Dean's List- Towson University 2008-2012
- Undergraduate Research Grant 2011
- Represented Towson University's Liberal Arts College at Open House 2011
- Undergraduate Teaching Assistant 2011-2012
- Presented Undergraduate Thesis at Towson University's Research Expo 2012
- Graduate Teaching Assistantship 2012-2014
- Presented research at the Maryland Psychological Association of Graduate Students 2013
- Presented graduate research at Towson University's Research Expo 2013
- Graduate Assistantship at Towson University 2013-2014

EXPERIENCE

Laboratory Skills

Experience in Animal Research: 2010-2012
Peritoneal Injections
Handling Rats
Running the Morris Water Maze
Creating TXP files
Husbandry/Chores
Nissl Tissue Staining
Histology
Analyzing data with SPSS

Experience in Human Research: 2010-2014
Virtual Water Maze software program
Mindwave EEG Headset devices
Analyzing data with VASSAR STAT
Analyzing data with SPSS

Laboratory of Comparative Neuroscience May 2010-May 2012

Research Assistant

- Assisted with research project investigating the effects of the cholinergic muscarinic receptor antagonist scopolamine and the dopamine D2/D1 receptor antagonist haloperidol on competitive place task performance in the water maze. The project is still underway, however our prediction is that cholinergic blockade will affect recent spatial working memory whereas dopaminergic antagonism will disrupt well learned (habit-like) remote place learning in the water maze.

National Institute of Health/NIA October 2010-October 2011

Special Volunteer with the National Institute of Aging

- Worked with cow, mice, rat, and monkey brains analyzing the effects aging has on the brain. Compared young verses aged animals in a behavioral task and preformed histology on the animal after learning the task and compared the brains to see where the differences were between ages.

Sheppard Pratt Health Systems January 2012-May 2012

Volunteer

- Working in the Adolescent and Children Day Hospital Unit.
- Running therapeutic groups with children and adolescents.

EMPLOYMENT

Towson University, Teaching Assistantship Towson, Maryland Fall 2012-Spring 2014

- Taught as a teaching assistant for a semester in Psychology 101
  - Ran study groups
  - Collected Attendance
  - Helped grade exams
  - Answered emails and questions that the students had
  - Held office hours several hours a week
  - Helped students when needed on an individual basis
- Taught as a teaching assistant for two semesters in Sensation and Perception, Psych 317
  - Ran study groups
  - Collected Attendance
  - Helped grade exams
  - Answered emails and questions that the students had
  - Held office hours several hours a week
  - Helped students when needed on an individual basis
  - Gave a lecture on color vision

Sheppard Pratt Health Systems Towson, Maryland May 2012-present

- Work on the Child and Adolescent Day Hospital Unit
- Work with patients that are diagnosed with various types of mental illness including depression, anxiety, bipolar disorder, mood disorder, borderline personality disorder, schizophrenia, psychosis, drug addiction, etc.
- Work with patients with behavioral issues including aggression and oppositional defiant disorder.
- Run therapeutic groups throughout the day with children and adolescents.