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Assessing the transfer of video game play versus attention training using 3D-Multiple Object Tracking

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Résumé

Durant la dernière décennie, la recherche sur les jeux vidéo et leur implication sur les habiletés perceptivo-cognitives a gagné en intérêt. Plusieurs études ont démontré que les jeux vidéo (particulièrement les jeux d'action) possèdent la capacité d'influencer et d'améliorer différentes aptitudes perceptives et cognitives telles que l'attention visuo-spatiale, la vitesse de traitement de l'information, la mémoire visuelle à court terme ainsi que la poursuite d'objets en mouvement. Cependant, plusieurs autres études n'ont pas réussi à reproduire les mêmes résultats. D'un autre côté, un nouveau type d'entraînement perceptivo-cognitif, nommé *3-Dimensional Multiple-Object Tracking* (3D-MOT), et qui consiste à traiter des scènes visuelles dynamiques dénuées de contexte, a démontré son implication sur différents types d'attention, la mémoire de travail ainsi que la vitesse de traitement de l'information. L'étude actuelle a examiné quatre groupes de joueurs inexpérimentés qui s'entrainaient durant 10 séances à l'aide d'un exercice perceptivo-cognitif (3D-MOT), ou d'un jeu de haut niveau visuel (jeu vidéo d'action : Call of Duty), de bas niveau visuel (Tetris) ou d'un jeu non-visuel (Sudoku). Des mesures d'électroencéphalographie quantitative et des tests neuropsychologiques effectués avant et après l'entraînement ont démontré que le 3D-MOT, par comparaison aux autres jeux testés, améliorait de façon plus efficace les fonctions reliées à l'attention, la mémoire de travail ainsi que la vitesse de traitement de l'information. Pour la première fois, cette étude démontre que l'entraînement non-contextuel de 3D-MOT améliore les habiletés perceptivo-cognitives plus efficacement que l'entraînement à des jeux de divertissement tels que les jeux vidéo.

Mots-clés: 3D-MOT, jeux videos, d'entraînement perceptivo-cognitif, qEEG

Abstract

In the past decade, research on video games and their implications on cognitive abilities have gained significant interest. Various studies suggest that video games (in particular action video games) have the inherent ability to influence and improve attentional abilities such as visual spatial attention, processing speed, visual short-term memory and multiple-object tracking. However, many other studies have been unable to replicate similar results. On the other hand, a recent cognitive enhancement tool that is visually dynamic and void of context called 3-Dimensional Multiple-Object tracking (3D-MOT), has demonstrated robust effects on cognitive-perceptual abilities such as divided, selective, and sustained attention as well as working memory and information processing speed. The current study examines four groups of non-video game players that train for 10 sessions on the cognitive enhancing technique (3D-MOT) or on one of three different visually stimulating games: highly visually stimulating game (Call of Duty), lowly visually stimulating game (Tetris), or non-visually stimulating puzzle (Sudoku). A battery of cognitive tests and quantitative electroencephalography preformed before and after training, demonstrated that training on 3D-MOT improved cognitive functions related to attention, working memory, and visual information processing compared to video games. For the first time, this study demonstrated that non-contextual training with 3D-MOT improves perceptual-cognitive abilities more efficiently than video game playing.

Keywords: 3D-MOT, video games, perceptual-cognitive training, qEEG

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ANOVA – Analysis of variance

AVG- Action Video Game

COD- Call of Duty

CERES - Comité d’éthique de la recherché en santé

EC- Eyes-Closed

EEG- Electroencephalograph

EO- Eyes-Open

ESA- Entertainment Software Association

fMRI- Functional Magnetic Resonance Imaging

FPS - First person shooter

Hz - Hertz

IVA+CPT – Integrated visual and auditory continuous performance task

LSD – Least Significant Difference

NT- NeuroTracker™

NVGP – Non-video game player

qEEG- Quantitative electroencephalogram

SD- Sudoku

SEM- Standard error mean

TT- Tetris

UFOV – Useful field of view

VGP - Video game player

WAIS-III – Weschler Adult Intelligence Scale Third Edition

3D- Three-dimensional

3D-MOT – Three-dimensional multiple object tracking

To everyone who has encouraged the scientist in me.

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Chapter 1 - Introduction

1. Overview

What kind of games do you play? Rarely will someone today answer this question by naming a classic board game like Monopoly or Scrabble. Instead, they might respond by retorting that the question is too broad and ask you to narrow down the selection to online, mobile, or console games all of which are electronic by nature. According to the Entertainment Software Association (ESA), approximately 59 % of Americans play video games and the average North American household consists of two gamers who own at least one dedicated gaming console, PC, or smartphone (ESA, 2015). Devices such as wireless tablets, a PlayStation®, laptop, and smart TVs, are now intricately woven into our home décors. As a result of the digital age of gaming, consumers spent over 22 billion dollars in the video game industry, including software, hardware and accessories in 2014 (ESA, 2015). To describe the strong impact this industry is making, when Grand Theft Auto V (Action-adventure game) was released in 2013, the game grossed a record one billion dollars worth of units in just under three days (ESA, 2015). It is clear that today's society loves to play video games, and lots of it.

How long have you been gaming? Those who grew up in Generation Y can recount the exact moment they experienced their first video game. Whether it was Nintendo's Super Mario Brothers (1985), Atari's Tetris (1988) or Sega's Sonic the Hedgehog (1991), these games are classics in the video game world. According to the ESA, the average video gamer is thirty-one years old and has been playing video games for 14 years (ESA, 2015). Contrary to popular belief, women make up 48% of video gamers and women aged 18 years and older represent 36% of the gaming population in comparison to boys aged 18 or younger who make up just 17% of the population (ESA, 2015).

It appears that with the growth of video game culture, more and more individuals are looking to uncover the hidden benefits and untapped potential of this unique form of entertainment. Its presence in popular media in recent years has highlighted certain cognitive benefits and the psychological disadvantages of playing video games. It is safe to say that video games are embedded into our day-to-day lives and the sheer number of individuals who are connecting with the gaming world is increasing at an ever-increasing rate. Common to all games is the aching curiosity of knowing whether playing video games can make you smarter. So can video games offer something more than just a means of entertainment? Can their popularity and entertainment value be harnessed as tools to help train our brain, to be faster, stronger, and more capable? Some researchers have suggested that video game playing might be an effective means to train the brain and highlight cognitive abilities that are triggered such as attention, working memory and spatial abilities while others suggest its transfer onto every day activities is very limited (Bavelier et al., 2011; Boot, Kramer, Simons, Fabiani, & Gratton, 2008). Perhaps video games aren't the root of the cognitive enhancement but rather an inherent ability by the individuals who enjoy playing video games. The ideas seem encouraging but the research is inconclusive.

Research has demonstrated quite evidently that the brain is capable of reorganizing itself based on experience, a phenomenon often termed as *neuroplasticity* (Draganski et al., 2004). This newly recognized characteristic of the brain has opened up the ever-expanding field of brain-training programs, which are often geared towards improving overall cognitive abilities. However, many of these programs lack scientific arguments to support such large claims (Jak, Seelye, & Jurick, 2013). The idea that the brain can be systematically exercised to function at a higher level has gained attention by cognitive neuroscientists worldwide. Considering the immense potential of the field, various digital brain-training programs have become widely available to anyone who owns a smartphone, PC or tablet, and for a few extra dollars, the expansion pack promises you cognitive enhancement within just a few tries. But these applications are supported by very little research and even fewer results. Effective marketing on major social media outlets has convinced consumers that beneficial effects on the brain can be achieved through training applications such as Lumosity™ (Lumos labs) or Brain Age™ (Nintendo®). In fact, Lumos labs have recently been scrutinized by the Federal Trade Commission for claims of false advertising and are expected to pay a settlement of two million dollars (FTC, 2016). Do these programs truly offer anything more than an empty pocket?

Despite the lack of research, one particular brain-training method has provided significant conclusions in cognitive enhancement in young adults, the elderly, and athletes. The training method utilizes 3-dimensional multiple-object tracking (3D-MOT) to improve perceptual cognition and is a technology licenced under NeuroTracker™ (by Cognisens Inc.). The object of the task is to follow multiple objects presented in 3D while ignoring the distractors. Critical mental abilities are isolated through four defining factors including 1) MOT 2) a large visual field 3) speed thresholds and 4) binocular 3D cues (Faubert, 2013). The technique is void of any content and aims to improve divided, sustained and selective attention.

The purpose of this thesis will be first to determine the effects of visual training using several types of modern video games compared to the 3D-MOT technology, and second, to subsequently compare the cognitive gains of each game by using a battery of neuropsychological tests and brain imaging to determine which provided the most significant cognitive gains. By reviewing the most current literature in the video game field, we hope to get an understanding of whether certain styles of video games can be harnessed as a tool to enhance cognitive function or if 3D-MOT may be a more effective tool to stimulate cognitive enhancement.

2. Cerebral Plasticity

The term plasticity refers to the ability the nervous system has to reorganize its connections functionally and structurally in response to experiences in their environment (Baroncelli et al., 2011). In other words, cerebral plasticity corresponds to the development and adaptability of neuronal circuits. Neuroplasticity can be divided into two types: functional plasticity (which allows the brain to relocate its abilities from a damaged area to an undamaged area) and structural plasticity (which is the brains capacity to change its physical structure as a result of learning).

Plasticity is the defining factor of memory and learning processes and at times, intervenes to compensate for effects created by intrinsic and extrinsic factors by organizing new neuronal networks. It is incredibly active during the first few stages in post-natal development, particularly in the brain regions that correspond to major behavioural functions (Berardi, Pizzorusso, & Maffei, 2000). However, the evidence over the years has shown that neuroplasticity can be induced well after the critical period has ended (Kramer, A. & Willis, 2003). This "*plastic*" potential of the brain persists throughout the lifespan and has also been observed in elderly persons (Mahncke et al., 2006). The human brain is capable of reorganizing neuronal tissue and networks when learning new abilities (Draganski & May, 2008). Besides its role during the acquisition of new experiences, synaptic plasticity plays a major role in the restoration of a function that is damaged after cerebral lesions (Ptito, Kupers, Lomber, & Pietrini, 2012; Sabel, Henrich-Noack, Fedorov, & Gall, 2011; Wiesel & Hubel, 1963). For example, brain-imaging studies have shown the ability of cross-modal plasticity, which permits the reorganization of neural networks when one sensory system is absent or inhibited (Kupers, Chebat, Madsen, Paulson, & Ptito, 2010). Additionally, neuroplasticity has been shown to persist well after the critical periods of development have passed. Early research conducted on individuals who have lost a limb show functional cortical reorganization in areas that are responsible for the output of movement (Merzenich, 1998) and others have found that newly generated cells in the hippocampus (a region in the brain that is responsible for learning and memory) can transform into functional neurons in an adult human brain (van Praag et al., 2002).

Plasticity can be observed in different levels within the visual system, in a healthy brain or in a damaged brain. Usually, it can be induced during perceptual learning that is influenced by a change in performance while training. Perceptual learning can be defined as the increased ability to extract information from the environment due to an experience or practice (Kellman & Garrigan, 2009). A noteworthy example of plasticity in the human brain and in other animal species is the effect of physical activity. In fact, physical activity plays an important role in neurogenesis, angiogenesis, and the production of growing factors important for memory and cognitive functions. There are a number of studies that show the beneficial effects of physical exercise as well as enriched environments on cognitive functions in animal models (Vaynman & Gomez-Pinilla, 2006; Vivar, Potter, & van Praag, 2013) and in humans (Kramer, A. F. & Erickson, 2007).

The idea that the brain can change based on learning and new experiences is well accepted in science. This understanding of neuroplasticity has led to an increase in curiosity in brain training techniques for a variety of purposes. Cognitive training can benefit older populations, training athletes, or cognitively impaired individuals. In addition, these training programs often grow with strength when *transfer* is observed. Researchers often describe the result of training to produce *near* or *far* transfer effects. Transfer can be described as the ability to extend a task learnt in one context onto a new context (Bransford, Brown, & Cocking, 1999). *Near-transfer* can be described as improvements in a task and similar tasks within the same context following training whereas *far-transfer* suggests transfer onto tasks outside of the trained context (Barnett & Ceci, 2002).

Due to the great amount of interest in brain research and its implications on every-day society, researchers have looked towards a common hobby that is highly prevalent among people: Video games. Some researchers believe that playing video games has a beneficial effect on cognition while others are not as convinced by its abilities to cause such change (Bavelier et al., 2011). In turn, cognitive enhancers such as 3D-MOT have similarly gained interest as a simplified method to increase cognitive perceptual abilities.

Throughout the subsequent chapters, understanding different types of video games and commercial brain-training programs will be pertinent to uncovering the plastic potential of the brain and whether 3D-MOT can offer a more efficient approach.

3.Types of Video Games

For a non-video gamer, it is easy to suggest that all video games are the same. Video games vary from content, audience, format and overall style. Some games can be fast paced racing games like *Need for Speed*, where the goal of the game is to compete in racing competitions and unlock levels to upgrade your racing car. Other games are slower and more strategic like *Civilization*, where the goal is to create your own empire and conquer the virtual enemy in hopes to achieve world domination. Each game offers a unique experience to the player, tailored to their preference and style. For the purpose of the research study, three types of games were explored due to their various levels of visual stimulation and attentional requirements expected. The tree categories included a high visual stimulus, a low visual stimulus, and a non-visually stimulating game. However, there is one type of video game that has received more attention than all the others when it comes to video games and cognitive enhancement: Action-video games (AVG).

3.1 Action Video Games

First person shooter (FPS) games often fall under the category of AVG's and are primarily centered on weapon-based combat through the experience of a protagonist. In other words, through a first person perspective, the main character is controlled by the gamer. This is unlike third-person shooter games, in which the player can usually see the character they are in control of. The story line in many of these action video games change, however the idea stays the same – navigate yourself through a series of dynamic visual scenes while you kill the enemy and avoid being killed. Often times, this requires players to memorize the detailed playing map, track their opponents and teammates, react quickly to visual stimuli, and take note of their resources all at the same time.

The first FPS game was developed in 1987 by Atari ST and was called MIDI Maze, similar to the game PacMan. However, the pioneer in FPS games were developed by id Software™ with the creation of Wolfenstein 3D in 1992. With the success of their game, id Software™ quickly released Doom in 1993, which paved the way for FPS games for years to come. Their popularity and success was attributed to the creation of a multiplayer setting where players could engage in competitive matches amongst each other. Over the subsequent years, FPS games gained increasing popularity with the addition of household PC, gaming consoles, and hand held devices.

Interestingly, this genre of gameplay has gained a lot of interest over the last few years as a tool for cognitive enhancement not for their graphic content but rather their visually stimulating scenes. The idea that spatial awareness, working memory, and attention are all cognitive abilities utilized when playing these games have sparked significant debate in the research world.

3.2 Casual Video Games

Although AVGs have dominated public interest, casual games have become increasingly popular due to mobile handheld devices such as tablets and cellular phones. The Casual Games Association (CGA) estimates approximately 103 billion US dollars in revenue for the casual game market encompassing Asia, Eastern Europe and Latin America alone in 2017 (CGA, 2014). Casual games are often catered to individuals who do not normally engage in video games and involve simple rules that allows for easy completion in a relatively short period of time. Common games such as *Solitaire* or *Minesweeper* are two games that many associate with their first PC. However, video games have come a long way since their simpler forms and a large number of games have been created on various platforms that can be easily accessed from the Internet and ultimately on a variety of devices. The boost in casual games is largely credited to the ease of game access. To illustrate this fact, the popular casual game *Candy Crush Saga* by King was downloaded approximately 268 million times in 2013 (Lototska, 2014) . Although 40% of all game revenue is generated on the computer screen it is estimated that the Personal Screen (i.e. cellular phone) and floating screen (i.e. tablet) will rise to a total of 36% of all game revenues by 2017 (CGA, 2014).

One casual game in particular has stood the test of time and has appealed to all age groups: Tetris™. Developed by Russian programmer Alexey Pajitnov in 1984, the developer combined the game of tetrominoes and his favourite sport tennis to create a worldwide game sensation. The game consists of four consistent shapes that fall continuously from the top of the screen. The goal of the game is to maximize the score by arranging the shapes to fill a completed row so that the pile of shapes decreases and points may be awarded (Lindstedt & Gray, 2015). As the number of lines cleared increases, the faster the shapes fall, until the player can no longer clear the rows and game over is inevitable. The game has continued to keep players entertained over the span of two decades and has recently gained interest in its influences on cognition.

3.3 Reasoning-puzzle game

Finally, there is another type of game that does not require any platform other than a pencil and paper: reasoning-puzzle games. Although this type of game is not considered a video game or visually dynamic in any way, their prevalence in newspapers and magazines has withstood the modern age of technology. Often, these reasoning-puzzle games require a logical approach in order to find the correct solution and encompass a wide variety of games such as crossword puzzles, word-search puzzles, number puzzles or logic puzzles. These are games that often require pattern recognition and inductive reasoning to solve and in turn increases in difficulty as the players advance and creates new strategies. Deduction skills are also another asset that are frequently used in reasoning-puzzle games.

Under the current definition, the widely popular game *Sudoku* can be incorporated into reasoning-puzzle games. Originally called Number Place, this logic-based puzzle was created in the late 1900's but gained popularity near the end of the 1980's. The objective of the game is to organize the digits 1 to 9 in a square grid (9 x 9) where each column, each row, and each sub-grid (3 x 3) contains all the digits. There are many variations of the game since its invention, including larger grids, the incorporation of letters and mathematics and even the Rubik's Cube.

What cognitive abilities seem to be trapped by game play? Where does the debate on transfer lye and does expertise have an influence on cognitive enhancement? By analyzing game training studies and various game playing studies in the field, we hope to reach a better understanding on these various types of games and their impact on our brains.

4. Video games in cognitive training

4.1 First person shooter – High visual stimulus

AVGs have become particularly popular as a genre of video game that promotes a number of broad perceptual and attentional abilities especially due to the intense speed of the game. These types of games contain fast moving objects that often move in and out of the visual field, a high motor load demand while manoeuvring the main character or characters, and draws on capabilities such as divided attention or peripheral processing when new or existing information is presented in one of the four corners of the screen, recreated in figure 1-1 (Spence & Feng, 2010).

Two researchers, Shawn Green and Daphne Bavelier, have largely contributed to the field of video games and science. In particular, their interest in AVGs have sparked discussions and gained significant interest from cognitive researchers and the general public. It was in their *letters to nature* in 2003 where they first suggested that playing AVGs have an effect on selective attention and that there seems to be a difference in cognition when comparing expert video game players (VGP) and non-video game players (NVGP) (Green & Bavelier, 2003). In their article, they predicted the results of two attentional tasks such as the flanker compatibility effect and the enumeration task, and correctly assumed that VGP's would outperform NVGP's (Green & Bavelier, 2003). In the same study, the researchers continued their experiments by conducting an adapted version of the Useful Field of View (UFOV) task to determine if video game playing would enhance processing abilities outside the training range (10°, 20° and 30° from fixation). They noted that VGPs appeared to substantially outperform NVGPs for all three ranges. They suggested that their results indicate an enhanced allocation of spatial attention over the visual field, including previously untrained locations (Green & Bavelier, 2003). The two researchers expanded their investigation on VGPs by reporting enhanced abilities in the number of objects that can be apprehended (in enumeration and multiple object tracking tasks [MOT]) and suggested that these enhancements are driven by changes in visual short-term memory (Green & Bavelier, 2006a).

Figure 1-1: An example of a highly visually stimulating AVG as seen in the game Call of Duty®: Ghosts – Level 5 Homecoming

Finally, Green and Bavelier (2007) go as far as suggesting that action video games can alter characteristics within the visual system, including changes in spatial resolution of visual processing by conducting a two part experiment. To do this, they found the spatial resolution of visual processing by calculating the smallest distance a distractor can be located from a target without compromising the ability to identify the target. This phenomenon is also referred to as "*crowding*" and suggests that the closer distractors are located to a target, the harder it is to identify the target object (Leat, Li, & Epp, 1999). The authors claimed that action VGPs could tolerate the affects of crowding better than NVGPs. In addition they claimed that similar effects were reflected in NVGPs who were trained on an AVG and thus arguing that AVG augmented spatial resolution (Green & Bavelier, 2007).

Visual short-term memory is another cognitive process that is suggested to be enhanced by video game play (Blacker & Curby, 2013; Green & Bavelier, 2006a). In their first experiment, Blacker and Curby (2013) demonstrate that action VGPs have an advantage over NVGPs when presented a brief coloured visual stimuli suggesting an enhancement of visual short-term memory. However, to increase task difficulty, their second experiment used complex shapes as the stimuli and found that both groups were less efficient when encoding and storing the complex shapes (Blacker & Curby, 2013). These results conflict with an existing study by Wilms and colleagues (2013) who suggested that action VGPs have a heightened ability when processing information into visual short-term memory.

Video game research has since expanded into a diverse field suggesting a number of cognitive advantages. Training studies have been an integral part in the research to help persuade the idea of a transfer effect, in particular in tasks that would benefit humans in their every day lives. However, there have been numerous replication failures, which often leave the public wondering, is there truly an advantageous effect to playing video games?

Although their conclusions sounds convincing and in many ways may justify the endless hours some people play action video games, other researchers have taken it upon themselves to question the validity of such strong claims. Boot and colleagues (2008) examined the perceptual-cognitive abilities apparently tapped by AVGs by conducting a two-part study. First they examined the possible transfer of cognitive tasks between VGPs and NVGPs and then they sought to train NVGPs in one of three video games (AVG, puzzle game, or real time strategy game) for a duration of twenty-one hours (Boot et al., 2008). In the first scenario, VGPs and NVGPs were given twelve neuropsychological tests that examined attention, memory and executive control. Interestingly, VGPs did not differ significantly to NVGPs on expected tests such as the UFOV task, enumeration, Corsi block-tapping task, attentional blink, or the Tower of London tasks (Boot et al., 2008). Experts were however more capable in MOT, task switching and mental object rotation (Boot et al., 2008). More interestingly, NVGPs that were trained extensively on a video game did not improve on most cognitive tasks and slightly improved on mental rotation performance (Boot et al., 2008).

Similarly, Irons and colleagues (2011) were also curious about the effects of action video game playing and attempted to replicate previous findings related to attentional capacity. Their study compared VGPs and NVGPs on a flanker compatibility task and determined that VGPs do not exhibit a greater capacity to filter out distractors (Irons et al., 2011). The authors were unable to replicate the results of Green and Bavelier's flanker compatibility task a few years earlier (Green & Bavelier, 2006b). In addition, the researchers conducted an Eriksen flanker task (Eriksen & Eriksen, 1974) to test differences in VGPs and NVGPs when processing irrelevant peripheral stimuli (Irons et al., 2011). Although VGPs had a faster reaction time than NVGPs, this difference in speed did not yield significance. The researchers were unable to reproduce previous findings that suggested that video game playing leads to an increase in attentional capacity (Green & Bavelier, 2006b) but were surprised to find other researchers had the same difficulty in replicating video game play studies that improved attention (Boot et al., 2008; Murphy & Spencer, 2009).

Interestingly, a recent study examined the effects of action video games versus strategy video games and the influence of game expertise on two cognitive tasks: the flanker task and the change detection task (Gobet et al., 2014). The aim of the study was to replicate previous studies on video game transfer and to uncover the influence of expertise in either Call of Duty: Modern Warfare 3 (AVG) or StarCraft 2: Wings of Liberty (strategy video game). The researchers found no significant correlation between the expert video gamers' skill level and the two cognitive tasks. Remarkably, action players failed to outperform the strategy players on the flanker task and there was no effect of expertise on the change detection task, suggesting that there was no interaction between the type of game played and the image type

(Gobet et al., 2014). This last detail was particularly interesting considering that near-transfer did not occur even though images from the players' game expertise were used.

Video games are often packed with high intensity moments where multitasking skills are utilized and practiced. However, Donohue et al. (2012) conducted a study to test whether VGPs are immune to dual-task costs by preforming three experimental paradigms with and without a simultaneous distracting task: videogame-based driving task, MOT, and a non-computer-based image search task (Donohue, James, Eslick, & Mitroff, 2012). The distractor task consisted of oral questions from the game Trivial Pursuit™ (Genus II and Pop Culture editions). A total of sixty participants were included in the study and were divided into FPS video game experts and non-video game experts. Subjects then conducted each paradigm in a single-task and dual-task phase. The researchers observed that performance deteriorated for all participants during the dual-task phase and noticed no differences between VGPs and NVGPs, suggesting that costs can be observed in situations of high attentional demand across modalities despite the level of video game expertise (Donohue et al., 2012). The research surrounding AVGs has yielded confounding results and more research is needed to understand the effect of video games and its influence on cognitive perceptual abilities.

4.2 Casual games – Low visual stimulus

Casual games are simple games that players often play without dedicating an extended period of time to completing the game and contain very simple rules. These are types of games that individuals can play on the bus during their commute to work or while they wait in the line at the grocery store to pass the time. As pictured in figure 1-2, with the increase in mobile devices and relative ease of access to the Internet, these casual games are often just a fingertip away and have become the most popular types of games played online or on mobile smartphones (ESA, 2015). But can these casual games offer more than just a means of short-term entertainment? Are there any cognitive advantages that can be tapped through these simple games?

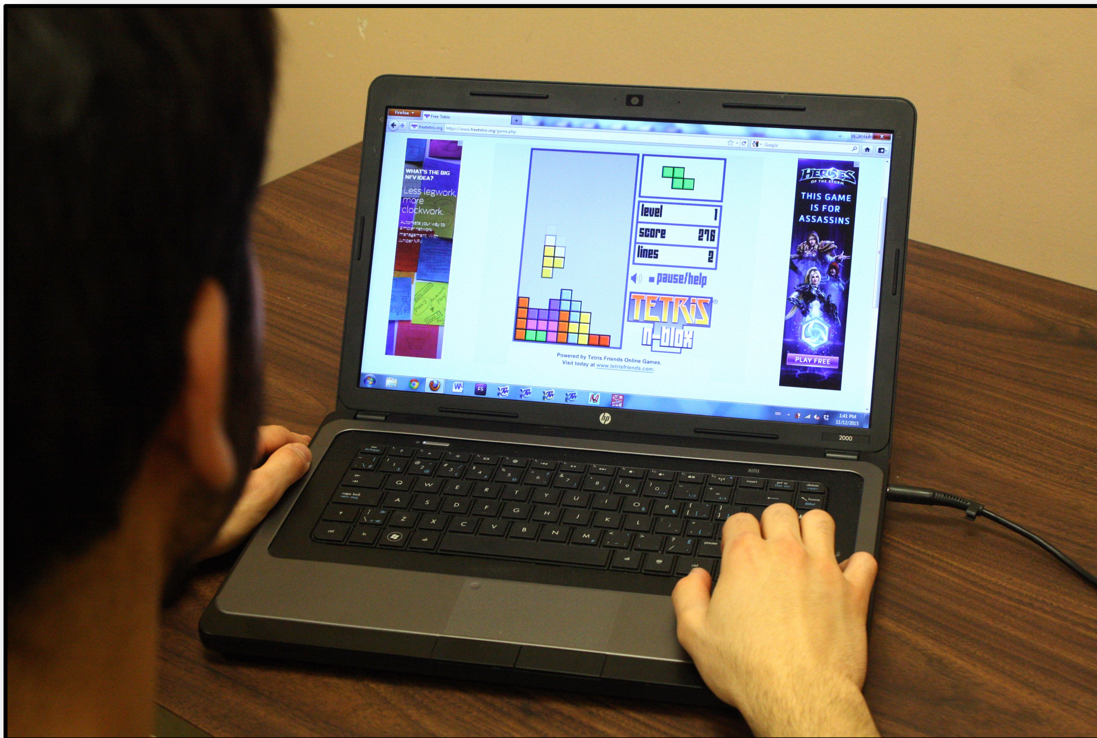


Figure 1-2: An illustration of a participant playing the low-visual stimulus casual video game, Tetris®

One casual game in particular has gained the interest of researchers since the mid 90's. An early training study took participants with no prior Tetris experience and subjected them to a 6-hour training regimen in two separate experiments (Okagaki & Frensch, 1994). After preforming pre and post session computerized measures of mental rotation and visualization skills, the researchers found that practicing Tetris was efficient enough to improve mental rotation time and spatial visualization (Okagaki & Frensch, 1994).

In another experiment, skilled Tetris players were compared to non-Tetris players and revealed that experts in Tetris were superior in mental rotation of shapes similar to Tetris pieces or identical but not on other various tests of spatial ability (Sims & Mayer, 2002). Interestingly, the same researchers trained a group of non-Tetris players for 12 hours, over a span of four weeks, and compared their pre and post gains with a control to find that the results did not differ between groups (Sims & Mayer, 2002). In fact, the expert-Tetris players used an alternative method when dealing with Tetris shapes compared to non-experts. This suggests that spatial expertise is highly domain specific and does not transfer onto other domains (Sims & Mayer, 2002). However, Terlecki et al. (2008) tested video game transfer with Tetris and found that training on the game was able to transfer onto other spatial tasks and was persistent several months after training.

Green and Bavelier (2003) have also used Tetris as a control group for their research on video games. In their initial study, they trained a group of NVGPs on an AVG called *Medal of Honor*, for one hour per day for 10 consecutive days. They also trained a separate group of participants on the casual game Tetris, for the same amount of time. They suggested that Tetris contained a stimulating visuo-motor component but that AVGs, on the other hand, challenges distributed and selective attention (Green & Bavelier, 2003). They even suggested that Tetris would be an ideal control task due to the fact that attention is focused on one object at a time therefore there would be no changes in visual attention the way an AVG would continuously stimulate the subject with new visual information (Green & Bavelier, 2003). Their results showed perceptual-cognitive improvements in their AVG group and not in the control Tetris group.

Another study compared the effects of Tetris Nintendo® and a commercial brain training game called Brain Age Nintendo® (Nouchi et al., 2013). Here, 32 participants were divided into a brain-training group and an active control in which the subjects were given an extended battery of neuropsychological tests to assess perceptual-cognitive abilities. The participants were then trained for a minimum of 5 days a week for 15 minutes. Although the researchers found significant improvements in measures of executive function, working memory, and processing speed in the Brain Age group compared to the active control group, the Tetris group showed improvements on measures of attention and visuo-spatial ability (Nouchi et al., 2013).

Finally, a study by Haier and colleagues (2009) took structural and functional images using Magnetic Resonance Imaging (fMRI) of adolescent girls before and after training on Tetris (Haier, Karama, Leyba, & Jung, 2009). The subjects were asked to practice Tetris for three months for an average of 1.5 hours a week whereas the control group was asked not to play Tetris for the duration of the study. At the end of the study, post images found that the Tetris trained group showed thicker cortical regions but that brain activity was reduced primarily in the frontal area (Haier et al., 2009). Interestingly, the blood oxygen level dependent changes observed did not overlap with the changes in cortical thickness. The researchers suggested that playing the visual-spatial problem solving game Tetris for a period of 3 months structurally changed an area of the brain but not consequently create a functional change in the same area (Haier et al., 2009). Although the idea that a simple casual game will provide cognitive benefits is enticing, the research at the moment is limited and lacking in scientific strength to be considered as an efficient brain-training exercise due to weak far-transfer effects observed (Baniqued et al., 2014).

4.3 Reasoning Puzzle Games - No visual stimulus

It is a common conception that Sudoku helps exercise the brains capacity, but is that truly a fact or a myth? Although this idea is widespread, there is little evidence to prove its veracity. Well-known magazines and media outlets with bold article headings suggest that Sudoku practice, as observed in figure 1-3, is proven to workout the brain and cognitive

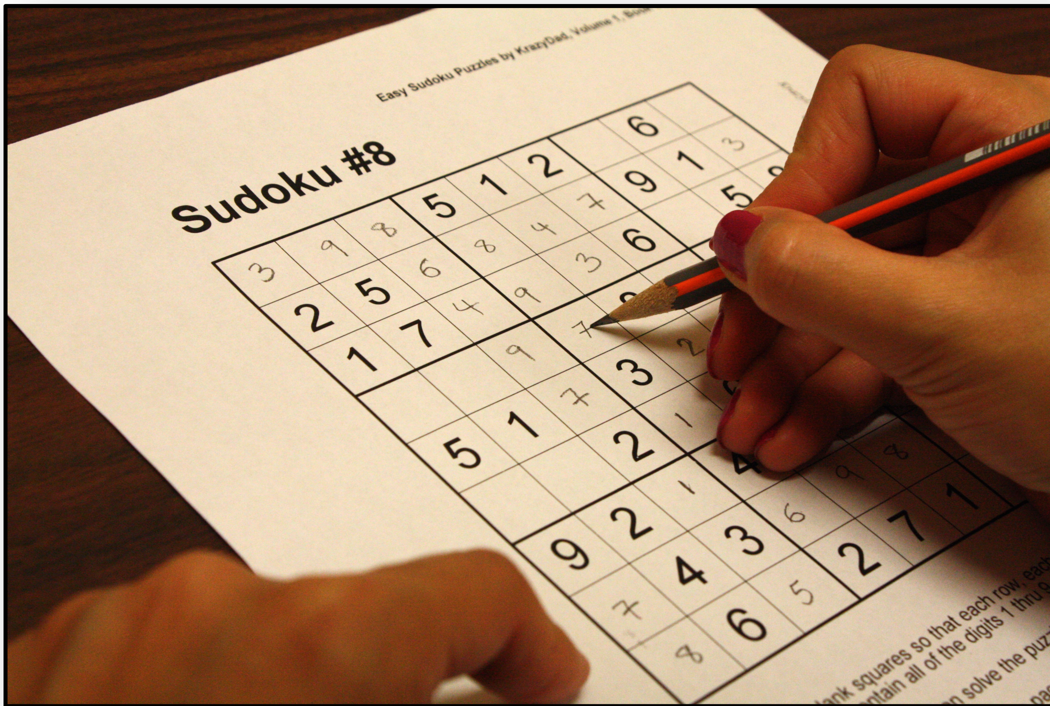


Figure 1-3: An illustration of a participant solving the non-visually stimulating puzzle game, Sudoku

training games like Brain Age™ Nintendo® have incorporated Sudoku in their training programs. However, the scientific literature is very limited, leaving these seemingly convincing claims without any support.

There are few published articles on the effects of Sudoku and cognitive function; however, a study by Grabbe (2011) examined the popular game and its influence on working memory. Grabbe suggested that Sudoku performance and performance on working-memory tests would have a significant relationship. Forty-seven participants were recruited for the study (28 young adults and 19 older adults) for a single session of ninety minutes. Participants were asked to perform eight cognitive tasks that particularly measured working-memory such as backward digit span, letter-memory, Stroop task, before they continued onto the timed Sudoku tests. The results showed that three of the working-memory tasks were correlated to Sudoku performance (Grabbe, 2011). Although Grabbe found a correlation in three out of eight working memory tests, the idea that Sudoku puzzles offer cognitive benefits lacks scientific weight.

Since the research on various types of games has proven to be unclear in regards to their influence on cognitive perceptual abilities, then perhaps techniques directed to cognitive enhancement may offer more significant results.

5. Cognitive brain-training techniques

Cognitive enhancement or "brain training" can be defined as any increase of core information processing systems in the brain, which includes the mechanisms that are responsible for perception, attention, conceptualization, memory, reasoning and motor performance (Sandberg & Bostrom, 2006). In addition, brain training can also be defined as the engagement of a program or activity whose intention is to improve a cognitive skill or ability through repetition over a limited amount of time (Rabipour & Raz, 2012).

Training can range over a variety of different facets. Some therapies have explored the natural affects of exercise and nutrition, suggesting that the collaboration of these non-invasive therapies can stimulate synaptic activity and repair damaged neurons (Gomez-Pinilla, 2011). Recently, brain-enhancing drugs called "nootropics" have gained the interest of students looking for a competitive advantage over their peers. These smart drugs known otherwise as methylphenidate, modafinil, and piracetam influence the brains alertness, promote oxygenation of neurons, increase blood flow and heighten overall stimulation of brain activity (Piracetam, 2015). Another brain enhancing therapy popular within research is neuro-stimulation. Transcranial magnetic stimulation (TMS) is an invasive technique that uses brief high intensity magnetic fields to induce currents so that neurons may be depolarized in small regions of the cortex (Luber & Lisanby, 2014). Studies show that specific frequencies have induced cortical enhancement. Five Hz of cortical stimulation has specifically shown to affect executive function (Boroojerdi et al., 2001; Cooper, Humphreys, Hulleman, Praamstra, & Georgeson, 2004; Kohler, Paus, Buckner, & Milner, 2004; Luber et al., 2007; Romei, Driver, Schyns, & Thut, 2011; Yamanaka, Yamagata, Tomioka, Kawasaki, & Mimura, 2010).

However, in this modern age, a quick and simple subconscious practice, where one can attain improvement without perceiving the work behind it as a chore, intrigues the average consumer more than actively exercising or undergoing treatment.

6. Commercial brain training games

Over the last few years, brain training companies have developed into a multibillion dollar industry and their revenue is expected to surpass 6 billion by 2020 (SharpBrains, 2013). An increasing number of brain training programs have guaranteed that their techniques enhance or rehabilitate behaviour and brain function. Lumosity™, Brain Age: Nintendo® DS, and Brain Metrix™ are just a few of the many companies that have optimized on the market of products, each promising that their programs lead to enhanced cognition. Lumosity™ has recently reached 50 million subscribers and members have spent nearly 39 million hours on brain training activities (Zhang, 2014). These statistics illustrate the consumers' curiosity and belief that such training programs have a significant affect on their cognition. The prospect of these changes appeals to a variety of consumers – from the healthy and ambitious to the concerned and cognitively impaired, there is no shortage of consumer interest in the field of cognitive neuroscience. These companies primarily target younger children and elderly persons whose cognitive abilities are in the process of developing or have declined with age.

The programs also offer a simple platform through the Internet medium where consumers can access training from the comfort of their own living rooms.

The idea behind most of the commercial brain-training programs is that practicing one or more tasks may lead to an improvement in performance on previously untrained tasks (Boot & Kramer, 2014). But does it truly work? Most of these programs present individuals with a variety of simple games that involve tracking multiple moving objects, recognizing complex patterns, rapidly detecting objects presented in the visual periphery, or remembering properties in rapidly presented pictures (Boot & Kramer, 2014). Over time and with continuous practice, players are able to preform the tasks faster and more accurately. However, this objective would prove useless if there was no transfer onto other real-world scenarios. The real advantage of brain-training programs is to extend the training and practice gained while playing onto general perceptual and cognitive improvements that can benefit ones life in a meaningful and productive way.

There is an abundance of research that shows that brain-training protocols can improve visual attention, inhibition or conflict related attention, working memory and reasoning related to the trained task but these improvements seem to rarely expand further to influence broader abilities (Ackerman, Kanfer, & Calderwood, 2010; Ball et al., 2002; Boot et al., 2010; Boot et al., 2008; Lee et al., 2012; Owen et al., 2010; Willis et al., 2006).

In a massive experiment conducted by Owen and colleagues (2010) in collaboration with the BBC program ‘Bang Goes The Theory’, 11,430 individuals participated in a six-week online brain training study in which participants were trained on tasks that would improve reasoning, memory, planning, visuospatial skills and attention. Participants were divided into two testing groups; experimental group one was trained on tasks that emphasized reasoning, planning and problem solving whereas experimental group two was trained on tests that entailed short-term memory, attention, visuospatial processing and mathematics. As the participants improved on the said tasks, the tasks similarly became increasingly challenging. The control group was not trained in anyway and was asked to answer random questions with the use of online resources. All three groups were administered a set of four benchmark tests that observed reasoning, verbal short-term memory, spatial working memory and pairedassociates learning. Interestingly, after six-weeks of training, all three groups exhibited similar improvements across all four cognitive-perceptual tests (Owen et al., 2010). This suggests that the training program for the two experimental groups was not affective enough to create a significant enhancement in cognitive function when compared to the control group (Owen et al., 2010). The researchers consider that the lack of generalized effects of training was due to the types of cognitive tests but indicate the unlikeliness of this event due to the sheer variety of cognitive tasks that were used.

Interestingly, a study by Lee and colleagues (2012) attempted to understand directed training and the transfer of training onto untrained tasks. Their participants learned how to play a cognitive video game called *Space Fortress* (Donchin, 1989) over a period of 30 hours (Lee et al., 2012). Subjects were divided into two specified training regimens called Hybrid Variable-Priority Training or Full Emphasis Training. Subjects in the hybrid variable-priority group focused on improving specific skills while managing task priority whereas full emphasis training subjects played the game simply to achieve a high score. Groups were then compared based on their game performance, retention of training gains, and transfer of training to untrained tasks as a direct result of training. Their results showed that the hybrid variable-priority group was able to advance further in the game than the full emphasis group and was particularly helpful to individuals who had little video game experience (Lee et al., 2012). However, contrary to their initial expectations, both groups did not show any transfer onto untrained cognitive tasks that measured memory, attention, visual processing, motor control, reasoning ability, and dual-task ability (Lee et al., 2012). Their study is one of many that suggest that practice can influence improvement in a specific task but that these training regimens offer little transfer onto untrained task.

Researchers Nouchi et al. (2012) performed a randomized control trial on the brain training game Brain Age™ on the elderly. Thirty-two participants were randomly assigned to either the Brain Age group or the Tetris control group. The participants were then trained for a minimum of 5 days a week for 15 minutes per training session. The training session took about 20 days and multiple cognitive tests were administered before and after the study. The results showed that Brain Age was more effective than Tetris in all their measures of executive functions and to two measures of processing speed. However, the researchers found no significant differences in all measures of attention and global cognitive statuses between the Brain Age group and the Tetris group (Nouchi et al., 2012).

The rise in commercial brain-training games has peaked the awareness of consumers and in turn, researchers are working quickly to identify the benefits and/or faults of these so-called cognitive enhancing games. The research is still relatively new, however understanding the programs and developing more effective and efficient technologies is imperative if we wish to unlock and exercise the hidden capacities of the brain.

7. 3-Dimensional Multiple Object Tracking (3D-MOT)

The 3D-MOT model, also known under the commercial name as NeuroTracker™ (by Cognisens Inc.), was developed at the Université de Montréal. It is a program that trains cognitive-perception over dynamically complex visual scenes devoid of any athletic context or motor demand (Faubert & Sidebottom, 2012). The standard NeuroTracker™ program, titled "CORE", entails following four spheres (balls) in random motion within a virtual cube while four other identical balls serve as distractors. The balls are able to bounce off the virtual walls of the cube and collide with other balls as well. The stereoscopy of the virtual space is created with the help of 3D-glasses.

The 3D-MOT technique is represented in figure 1-4. During the test, the subject may fixate on a green dot, located in the centre of the virtual cube. To start, eight yellow spheres are stationary and uniform for 1 second (Figure 1-4 a). Four spheres of interest become red within a 2 second time frame so that the subject may identify the target spheres in an adequate amount of time (Figure 1-4 b) before they turn back to yellow. The eight spheres then begin to move in a randomized order for 6 seconds (Figure 1-4 c) until they simultaneously stop. At this moment, the subject is asked to identify the four target spheres. Once the selection is confirmed, the four correct spheres are revealed (Figure 1-4 e). Following 20 trials, the threshold is estimated by calculating the speed of the four last inversions. Each measure of threshold (20 trials) takes approximately 8 minutes. The speed of each trial increases after a

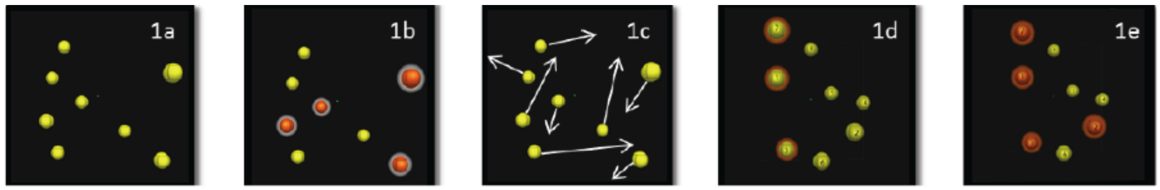


Figure 1-4: Illustration of the different phases of the 3D-MOT or NeuroTracker^{TM} during "Core" mode

correct response and decreases after an incorrect response, following a psychophysical staircase method (Levitt, 1971).

The 3D-MOT technique is a high-level cognitive task that stimulates a number of important neuronal networks that work simultaneously during the exercise. The task solicits networks implicated in the integration of the complex movement, distributed, sustained and dynamic attention including working memory (Faubert & Sidebottom, 2012). To achieve optimal training conditions and to maximize the effects of transferability, the technique is based on four critical components.

Firstly, 3D-MOT involves the distribution of attention on the targets of interest while ignoring the distractors (refer to figure 1-4). The idea behind the MOT is that it is a task that requires a divided attentional pursuit, which evaluates the visual systems ability to follow the position of all targets amongst the distractors. During the MOT task, performance is commonly measured as a function of the number of objects tracked successfully (Pylyshyn & Storm, 1988). It is possible to follow a maximum of four objects at the same time but only if the spatial index is limited to two indexes per visual hemisphere (Alvarez & Cavanagh, 2005). The limited resource model, also known as FINST, created by Pylyshyn (1989) tries to explain the way an individual is able to follow objects. Based on primitive mechanisms of vision, the visual system assigns attentional cues to each element that needs to be followed. Interestingly, each of these elements function independently (Pylyshyn, 1994). Another model suggests that the targets are grouped into a single element that demands a single attentional mechanism. The grouping continues during movement and helps to facilitate the pursuit (Yantis, 1992). Additionally, a more recent model suggests that the visual system deploys an attentional multifocal mechanism that allows for the pursuit of multiple moving objects (Alvarez & Cavanagh, 2005). Video games offer visually stimulating scenes that often require the player to track multiple objects and elements simultaneously. Figure 1-1 provides an example of an average visual scene in Call of Duty®: Ghosts where the first person shooter is introduced to a high level of visual information.

A study by Green and Bavelier (2006a) compared NVGPs and VGPs performance on 2-dimensional MOT and suggested that VGPs successfully tracked approximately two items more than NVGPs. In addition, non-video gamers who were trained on an AVG showed an enhanced performance on the MOT task suggesting that the effect is likely mediated by changes in visual short-term memory skills (Green & Bavelier, 2006a).

Furthermore, the addition of stereoscopy to the MOT paradigm is important. Many of the studies found in the literature consist of the MOT task in 2D, projected on a standard sized computer screen (Green & Bavelier, 2006a; Pylyshyn & Storm, 1988; Trick, Perl, & Sethi, 2005). In fact, with the application of 3-Dimension (stereoscopic vision), following the targets proves to be more superior as it helps disambiguate the obstructions that could be presented in dynamic visual scenes like in 3D-MOT (Faubert & Allard, 2013). Additionally, 3D-MOT uses a measurement of average speed thresholds as a dependent variable, which is important in performance since it requires more attentional resources to track targets at higher speeds (Feria, 2012).

7.1 Perceptual-cognitive training with 3D-MOT

Recent studies have revealed the effectiveness of this new type of perceptual-cognitive training based on a general cognitive approach (Faubert, 2013; Faubert & Sidebottom, 2012; Legault, Allard, & Faubert, 2013; Legault & Faubert, 2012; Parsons et al., 2014; Romeas, Guldner, & Faubert, 2016). Young adults, elderly people and even professional athletes that are trained with 3D-MOT have shown an increase in their threshold speed and ultimately their ability to attend to the targets (Faubert & Sidebottom, 2012; Parsons et al., 2014; Romeas et al., 2016). By training 308 participants on the 3D-MOT task for a total of 15 sessions (approximately 90 minutes per session), Faubert (2013) demonstrated that the processing of dynamic and complex visual scenes that are void of sport context is sensitive to athletic performance. In fact, the speed of visual trailing and the learning capacity of professional athletes were superior to elite amateurs (university level athletes) and were superior to novices (Faubert, 2013). Similarly, a study showed that younger and older adults trained on 3D-MOT over a period of 5 weeks showed similar gains and their training significantly improved their speed thresholds (Legault et al., 2013). According to the authors, younger adults exhibited greater performance than the older adults while tracking three or four targets.

In another study, researchers reached the same conclusions as the former experiment, however they suggested that the young adults who habitually played video games preformed significantly better at their MOT task (Sekuler, McLaughlin, & Yotsumoto, 2008).

Interestingly, children who play video games have shown to preform better at the MOT task than children who do not play video games (Trick, Jaspers-Fayer, & Sethi, 2005). Trick et al. (2005) modified the MOT task and asked participants to track one of four moving targets that were disguised to blend in a crowd of 10 other similar looking distractors. Tracking accuracy was measured in five age groups between 6 to 19 years of age. The conclusion was that tracking performance was significantly better in young participants who played AVGs, and slightly better in those who played action-sports games as opposed to those who did not play video games at all (Trick, Jaspers-Fayer, et al., 2005).

Taking into account the effect of video game playing influences on MOT throughout age groups, Sekuler et al. (2008) divided participants into three groups: one older group of adults, and two younger groups of adults (subdivided into habitual video gamers and non-habitual video gamers). They suggested that had they not subdivided the youth group into NVGP and VGP's the age-related effects would have been overly exaggerated however the effect of video game playing substantially affected MOT performance (Sekuler et al., 2008).
Legault et al. (2013) considered video game play to have an affect on their participants' results, however a video game habit survey was unable to explain the difference between younger and older adults. In fact, most participants did not play video games more than once a week except for one expert gamer and yet his MOT speed threshold did not seem to be substantially superior than the others (Legault et al., 2013)
Recently, neurological techniques have allowed researchers to explore the effects of 3D-MOT on cognitive functions and attention (Parsons et al., 2014). Parsons and colleagues (2014) trained one group of ten young adults (on 10 sessions of 3D-MOT while another group of young adults (n=10) were not trained. Participants completed a battery of neuropsychological tests before and after testing, along with a quantitative electroencephalogram (qEEG). This technique allowed the researchers to identify the electrical activity of the brain pre and post 3D-MOT training. The results revealed that 3D-MOT training had a positive affect on attention, speed of information processing, and working memory. Interestingly, those who were trained with 3D-MOT exhibited changes in cerebral activity that corresponded to frequencies associated with attention (represented by theta and beta waves at 4-8 Hz and 13-30 Hz respectively) and visual processing speed (represented by gamma waves at 30-50 Hz) (Parsons et al., 2014). QEEG studies have shown that delta, theta and alpha brainwaves (slow

frequency waves) are often associated with inattention, lack of focus, and dissociative states whereas beta brainwaves (high frequency waves) are often associated to cognitive activity and cortical activation (Monastra et al., 2005; Thompson & Thompson, 2003). Other studies have shown that individuals with attentional deficits exhibit high amplitudes of slow wave activity (1-11 Hz) and relative deficits in high amplitude beta activity (12-20 Hz) (Arns, Heinrich, & Strehl, 2014; Lubar, 1991; Sterman, 2000). Parsons et al. (2014) suggest that the benefits that are observed as a result of 3D-MOT training have a transferable capacity onto our everyday activities

In addition, the 3D-MOT technique has revealed promising effects on transferability onto socially relevant tasks. A study by Legault and Faubert (2012) trained older observes on the 3D-MOT task for 5-weeks and submitted them to a simple biological motion task consisting of two components: walker and mask. The study included two control groups that were either subjected to a visual perceptual task (once every week for a duration of 5 weeks) or a single session of 3D-MOT and biological motion testing. The researchers found that training on 3D-MOT had a significant effect at 4 meters on the biological motion walker task, whereas the control groups showed no transferable effects (Legault & Faubert, 2012). Training on 3D-MOT also had an impact when participants were asked to discriminate the walker amid noise and revealed greater tolerance for the masked task than untrained participants (Legault & Faubert, 2012).

Another example of 3D-MOT transferability was revealed in a recent study by Romeas, Guldner and Faubert (2016). Varsity soccer players from the University of Montreal were recruited and divided into one experimental and two control groups. The experimental group was trained on the 3D-MOT task, while the active control group was asked to watch 3D soccer videos and the passive control were given no particular instructions (Romeas et al., 2016). The researchers revealed that those trained on 3D-MOT showed improvements in decision-making accuracy while passing the ball when compared to the two control groups (Romeas et al., 2016). The authors suggest the study is the first of its kind to demonstrate non-contextual perceptual-cognitive training to have an effect from the laboratory setting onto the field (Romeas et al., 2016).

One of the major goals in our study was to evaluate the impact of various visually stimulating video games onto 3D-MOT thresholds, before and after training. If video game researchers suggest that certain video games have positive effects on cognitive perceptual abilities and specifically MOT (Dye, Green, & Bavelier, 2009; Green & Bavelier, 2006a; Green, Pouget, & Bavelier, 2010; Trick, Jaspers-Fayer, et al., 2005), then we would anticipate the same results across our participants. AVGs often stimulate the gamer to make fast decisions at any given moment. However, 3D-MOT helps actively train dynamic visual information, which is a crucial part of decision-making (Romeas et al., 2016). The technique applies the networks implicated in the integration of complex movements, distributed, sustained and selective attention which are all crucial elements in precise decision making.

It is difficult to predict the future of perceptual-cognitive training and to what extent the training methods will show transferability. Measurable tools such as neuropsychological tests and qEEG will provide insight on the benefit of 3D-MOT training compared to individuals who train on a variety of visually stimulating video games. If the purpose of brain training is to efficiently and effectively enhance the brain, then unbiased participants who are NVGPs are essential in measuring the effect of each training method. The study will contribute to the understanding of 3D-MOT and video games in a field that has only lightly been exploited.

8. Objectives and hypothesis

Given the existing evidence for the perceptual-cognitive effects of video games (in particular AVGs) and the promising effects of 3D-MOT training, we wanted to compare these methods of cognitive training using empirical data consisting of neuropsychological tests and a qEEG. These techniques would allow us to observe changes on a qualitative and quantitative level. In short, our aim was to compare the groups trained on various visually stimulating video games to a separate group trained on the 3D-MOT program and identify whether playing video games or training on 3D-MOT is a more reliable and effective means to enhance perceptual-cognitive abilities.

Hypothesis 1: Improvement in 3D-MOT with training.

Perhaps most obviously, we expected to see improvements in the 3D-MOT task across all participants in the 3D-MOT training group. Preliminary data have already shown that the capacity for MOT can be enhanced using the NeuroTracker^{TM} technology (Faubert & Sidebottom, 2012). This experiment should replicate the documented evidence.

Hypothesis 2: Positive attentional changes in qEEG

We expected the most significant changes to occur in the 3D-MOT group. These changes were expected to occur in the frontal and parietal attentional areas of the brain. Specifically, we expected to see decreases in delta, theta and alpha brainwaves (slow frequency brainwaves) in the group undergoing 3D-MOT training. Furthermore, we expect to see an increase in beta power (high frequency brainwaves) in the 3D-MOT group.

Hypothesis 3: Improvements in Neuropsychological Attentional Assessments

It stands to reason that improvements in the 3D-MOT task, which relies heavily on attention and visual processing, should correlate with improvements in scores on standardized neuropsychological test batteries. We expected the individuals trained on the 3D-MOT task would preform better on all of the cognitive tests compared to the other three groups.

Chapter 2: Materials and Methods

The research project was approved by the ethics board (Comité d'éthique de la recherché en santé; CERES) of the Université de Montréal on July 29th 2014.

1. Subject recruitment

Participants for the study were recruited from the Montreal area. Individuals who were interested in participating were initially screened by email correspondence and were asked two critical questions. Firstly, potential participants were asked how many hours of video games they play approximately in 1 week and if so, then what type of games. Secondly, participants were asked if they were in any way considered a professional athlete and was part of a competitive sports team. Due to the nature of the training-effect in the study, it was crucial that participants were inexperienced players with little to no video game playing experience on a PC or consol. Subjects who played less than one hour of video games a week over the last 12 months were admitted to the study. Most participants admitted to little to no exposure to video games and overall disinterest in video games. Additionally, professional to highly experienced athletes, were also rejected from the study due to their superior capabilities in 3D-MOT. Individuals who were interested in participating but admitted to playing on a competitive high to intermediate level sports teams for an extended period of time in their childhood were also rejected from the study.

A total of 47 participants were recruited for the project after passing the initial screening phase. Five participants were excluded due to failure to pass the Integrated Visual and Auditory Continuous Performance Task (IVA+CPT). These participants scored between 0 to 59 on either one, or both, their auditory or visual quotient scores (suggesting major deficiencies in attention). Two participants concluded the study but upon analysis, were excluded based on IVA+CPT post scores (exhibiting major deficits). One of these participants seemed to be unaware of his attentional deficit and the other admitted going through psychologically stressful times in her life and was not functionally stable. In total, 40 participants were divided into four separate training groups of ten: NeuroTracker™ - NT, Call of Duty - COD, Tetris - TT, and Sudoku - SD.

Participants were accepted into the study once they confirmed they spent less than one hour a week on playing video games and that their athletic standing was less than highly experienced. Other restrictions included age (constrained between 18-35), visual acuity (6/6 Snellen chart), stereoscopic acuity (minimum 40 sec of arc) which were evaluated during the first session. Psychological capacity (stable and no known psychological deficits; including attention deficit/hyperactivity disorder, epilepsy, or depression) was also a restriction determined in the initial questionnaire.

An initial questionnaire was also sent to determine level of education, current medical conditions, and caffeine, alcohol and nicotine habits.

2. Consent, Compensation and Adverse Effects

Participants were sent an electronic copy of the consent form, along with the initial questionnaire and subject guidelines. The guidelines were intended to ensure that participants arrived to the sessions in an adequate cognitive ability and were not influenced by physical exercise, caffeine, or nicotine.

During the initial testing session, participants were free to ask any questions about the study. A hard copy of the consent form was signed and the training group assigned to them was revealed.

Participants were compensated for their participation in the study at a rate of 15 dollars per session. Initial testing took approximately 2.5 hours. Training sessions were 30 minutes per session for a total of 5 hours. Additionally, the fifth session (half-way mark) took approximately one hour because it included a training session followed by a qEEG. The final session took approximately 2 hours for an overall total of 10 hours. All subjects received a total of 150 dollars for their participation in the study.

Participants in all groups were aware of the nature of the study. They understood that each group was being trained using a game that required different levels of visual stimulation and that the effects of training were analyzed pre and post for each group. Each group assumed the group in question was the one they were assigned to.

In terms of expected adverse effects, participants were cautioned that the MOT exercise in 3D may induce sore eyes, headache, fatigue, and mild-nausea. None of the participants in any of the training groups admitted to such adverse effects.

Participants included in experimental the COD group were cautioned that training on the AVG Call of Duty ® may provoke heightened levels of anxiety or acute aggressive behaviour. Participants in this group were told to discontinue game play should they feel uncomfortable or anxious at any time during the testing session. None of the participants in the group experienced such adverse effects.

3. Initial assessment

All participants met with the researcher for an initial (pre) testing session. They were advised of the duration of the pre session in advance to avoid time constraints. In this session, three types of assessment tools were used in order to evaluate the effects of video game training. First, standardized neuropsychological tests were used to measure attention, short-term and working memory, and information processing speed. Second, a functional measure of brain activity using a qEEG was used to assess resting state brain function. Finally, a baseline 3D-MOT session was also performed to observe threshold scores before and after training.

4. Baseline neuropsychological evaluation

Eight separate neuropsychological tests were used to measure a variety of cognitive abilities, including attention, working memory, visual information processing speed and spatial perception. To replicate a previous study done in the lab by a fellow colleague, a similar battery of tests were used with the exclusion of the Delis-Kaplan Executive Functions System Color-Word Interference Tests. The Delis-Kaplan Executive Functions System Color-Word Interference Test was not included in this study because of the large ceiling effects observed in the Parsons et al. (2015) study. The tests are defined and explained below according to the cognitive function they measure.

Attention

4.1 Integrated Visual and Auditory Continuous Performance Task

The Integrated Visual and Auditory Continuous Preformance Task (IVA+Plus®) is a neuropsychological test administered on the computer that analyzes different types of visual and auditory attention and yields information regarding these two modalities (Arble, Kuentzel, & Barnett, 2014). The test is particularly useful in the diagnoses of attention deficit disorders, however its use in research is well recognized (Sanford & Turner, 2009). The test is divided into three sections, including a 2-minute warm-up, 15-minute test, and 2-minute cool-down. In total the test lasts approximately 20 minutes. Each participant was instructed to click the right mouse button when a visual and auditory stimulus of the "number-1" is presented and to inhibit this motor action when an alternate stimulus of the "number-2" is shown. The test is categorized into 'response control' and 'attention'. To consider all the various elements of attention, both categories are then further subdivided into 6 different scales: Prudence, consistency, stamina, vigilance, focus and speed. The IVA+Plus® has the added benefit of comparing an individual's raw scores to normalized test scores based on the participant's age. However, due to the nature of the continuous performance tests, the IVA+Plus® test is prone to ceiling effects in high-preforming populations (Tinius, 2003).

4.2 The d2 Test of Attention

The d2 test is administered to measure information processing speed and attention. The task proves simple, but selective attention and speed is key to the success of the task. Participants were shown three examples of various types of the letter 'd'. The first is a lower case 'd' with two dashes at the top, another lower case 'd' with two dashes on the bottom, and finally a lower case 'd' with one dash at the top and one dash at the bottom. Following the example, a line with 47 different configurations of 'd's and 'p's were presented with randomly alternating dashes. The distractors were presented as the letter 'd' or 'p' with a maximum of four dashes and were hidden amongst the targets. The participant was asked to cross out as many targets as quickly and as accurately as they could while ignoring the distractors. Each subject was given a 20-second time limit for each line and a total of 14 lines to complete (Brickenkamp & Zillmer, 1998). Errors of omission (failure to cross out a target) and errors of commission (failure to cross out the right target) were added together for the total number of errors. The final score was calculated by counting the total number of items identified, minus the number of total errors (Brickenkamp & Zillmer, 1998).

Short-term and Working Memory

4.3 Digit Span (WAIS-III)

To test for short-term memory and working memory, specifically in the auditory domain, the digit span task was administered. The instructions for the task were fairly simple. For the first trial, subjects are read a series of numbers (in English or in French- depending on their preference) and were asked to repeat them back in the same order. The second trial was similar but subjects were asked to repeat the numbers in reverse order. Each trial contains a new series of numbers and increases in length after each second trial. In other words, trials 1 & 2 contain two digits, trials 3 & 4 are three digits and so on. One point was given for the success of each trial and the task was stopped once the subject was unable to successfully repeat the sequence twice in a row (Wechsler, 1997).

4.4 Letter-Number Sequencing (WAIS-III)

To test for working memory in the auditory domain the Letter Number Sequencing task was administered. In this task, a sequence of letters and numbers were read out loud to the subject (in English or in French, depending on their preference). The subject then had to reorganize the sequence and repeat the letters in alphabetical order and then the numbers in ascending order. Just like in the digit span task, each sequence gets harder with the addition of a number or a letter following every third trial. One point was given for the success of each trial and the task was stopped once the subject was unable to successfully complete the trial three times in a row (Wechsler, 1997).

4.5 Spatial Span (WAIS-III)

The Spatial Span task was administered to test visuo-spatial working memory and is an adaptation of a task developed by Corsi (Kessels, Van Zandvoort, Postma, Kappelle, & De Haan, 2000). Similar in some ways to the digit span task, subjects were shown a sequence of taps, which are tapped onto a board containing 10 mounted cubes. The test is administered in two parts: Forward tapping and reverse tapping. In the first part, subjects were shown a sequence of taps and are asked to repeat the sequence in the same order. The second part was similar to the first, but this time subjects were asked to repeat the taps in reverse. One point was given only if the entire sequence was correctly repeated. After every second trial, the task becomes more difficult with the addition of an extra cube. In other words, trials 1 & 2 include two cube taps, trials 3 & 4 include three cube taps and so on. Testing ends once the subject failed to correctly repeat the sequence demonstrated (Kessels et al., 2000).

Information Processing Speed

4.6 Block Design (WAIS-III)

To test spatial perception, problem solving and visual abstract processing, the Block Design task was administered. Subjects were initially given a set of 4 blocks. Two faces of the block are entirely red, two are entirely white, and the other two sides are half-white and half-red (dissected on the diagonal). Subjects were shown an image taken from the WAIS-III stimulus booklet and were asked to reconstruct the image using all four of the blocks as quickly as they could. For the first set of tests, subjects had a time limit of 60 seconds. The amount of time taken to execute the task is noted and points are given according to their time. Subjects were then given an additional five blocks, for a total of nine red-white faced blocks. In this part of the task, subjects had 120 seconds to correctly reconstruct the image. If the subject was unable to recreate the model, the timer was stopped and the stimulus was removed (Wechsler, 1997).

4.7 Symbol Search (WAIS-III)

To test visual information processing speed, the Symbol Search task was administered. Subjects were shown two target symbols and a series of five symbols that followed. Subjects were asked to cross off the box ‘yes’ or ‘no’ when one of the two targets were present in the sequence of distractors. Each trial had to be completed in order, for a total of 60 trials. The subject was given 120 seconds to complete as many trials and as accurately as possible. One point was given for each correct trial (Wechsler, 1997).

4.8 Code (WAIS-III)

Another way to test visual information processing speed was the Coding task. In this task, subjects were shown a diagram with the numbers 1 to 9, where each number was associated to a symbol. Underneath the diagram was a grid in which the numbers 1 to 9 were randomly assigned to each empty square. The subject must then fill each empty square with the appropriate paired symbol in successive order. The subject was given 120 seconds to correctly fill in as many boxes as possible and one point was given for each correctly filled box (Wechsler, 1997).

5. Resting state qEEG

The first subject to participate in the study was tested using a 64-channel BioSemi system before the 32-channel Mitsar system (Model 202, Mitsar Medical) was available for the remainder of the experiment. Neuroelectric activity was recorded from 32 individual channels. This included a pair of linked ear references (A1/A2), a ground electrode (AFz) and 31 active electrodes. The active electrodes were attached to the Mitsar cap and were placed according to the 10-20 system (represented in figure 2-1).

The subjects' forehead and ears were cleaned using NuPrep and rubbing alcohol to ensure proper impedance. A properly fitted Electro Cap was gently placed on the subjects' head according to a circumferential measurement of their head (medium: 54-58 cm large: 58-62 cm). Electro-Gel (Electro-Cap International, Inc.), a medium viscous conducting gel, was inserted into each electrode-hole in the cap through a blunted needle attached to a syringe. The blunted needle was used to push apart any hair or remove scalp residue to ensure good impedance throughout all the electrodes of below 5kOhms.

The subjects were tested in an eyes-open and eyes-closed condition. Five minutes of data was collected for each condition. During the eyes-open condition, participants were told to fixate on a red-dot on the wall, located at eye level. To avoid contaminating the data through natural eye movements known as ocular artifacts, subjects were asked to avoid excessive blinking, inhibit shifting their gaze, and to control blurring their vision. The data were coded by the main author and given to a colleague to remove any anomalies due to

Figure 2-1: Augmented 10-20 system of the Mitsar cap placed on a participant

ocular artifacts and facial muscle tension as well as to ensure the cleaned data were unbiased by the main author. The colleague was unaware of the condition (pre or post) or training group (NT, COD, TT, SD) assigned and from these data extracted 60 seconds of qEEG recording. The mid-testing qEEG was left to review and analyze once preliminary conclusions were investigated. All the EEG recordings were analyzed using Neuroguide (version 2.7, Applied Neuroscience, Inc), which is software that contains a normative database and various tools for statistical data analysis.

6. 3D-MOT session

The 3D-MOT sessions were performed in the laboratory on a 60-inch screen Panasonic television as observed in figure 2-2. Subjects were asked to sit in a chair approximately 58 inches away from the surface of the screen. The length between the subject and the screen was calculated using the field of view formula, because the 3D-MOT task utilises a visual field of approximately 45 degrees. The subjects used a set of Panasonic stereoscopic glasses, which are active shutter lenses that are synchronized to 120 Hz.

The 3D-MOT task was divided into five different phases and is outlined below. Each series of 3D-MOT was comprised of 20 trials and yields a cumulative threshold. Each session consisted of three trials and an average session score was calculated. Subjects in all four groups performed the 3D-MOT task at the initial and final testing sessions as a final measure of cognitive-perceptual changes.

There were five phases to each trial:

1. *Presentation*: the eight yellow spheres appeared and remained still for two seconds.

2. *Indexation*: the four spheres turned red (*targets*) and were lined with a white halo for two seconds. The four target spheres turned back to yellow and the spheres appeared as they had in the original phase. The phase lasted one second.

3. *Movement*: all eight spheres moved along a linear path in the virtual 3-D cube. When two

Figure 2-2: An illustration of a participant performing the 3D-MOT task

spheres came into contact with one another or when it hit the wall, it bounced off and continued its trajectory. This phase continued for six seconds. During tracking, the cross in the middle of the cube served as a fixation point so that subjects could focus more efficiently and track the spheres using their peripheral vision. Subjects were not told the benefit of the fixation point but were merely suggested the application could be useful.

4. *Stoppage and identification*: all eight spheres stopped movement and were labeled with numbers (1 to 8). Subjects verbally stated which spheres they tracked and were inputted using a keyboard by the researcher. Each selected target was identified with a white halo. Saying the answers verbally helped the subject focus on the task at hand and not feel overwhelmed to switch their attention off the screen. When other distractors masked the targets, the subject would ask the researcher to rotate the cube so that they could identify the number of the target. Once the four spheres were selected, the researcher asked for a confirmation before validating the responses. There were no time limitations during this phase.

5. *Feedback*: the target spheres were revealed and illuminated. When all four spheres were correctly identified the system made a bell sound and a star appeared on the right side of the screen. When one or more of the targets were incorrectly identified, the system made a *swoosh* sound and identified the incorrect spheres. This phase lasted two seconds.

If the subject was able to correctly identify all four-target spheres, the speed of movement of the spheres increased in the subsequent trial. Similarly, if the subject was unable to correctly identify the spheres and made one or more mistakes, the speed of movement decreased on the subsequent trial. This method followed an adaptive staircase in which large changes were observed in initial trials when the spheres were correctly identified and smaller changes were observed in later trials, to maintain a zone where the participant could optimize their improvement.

At the end of 20 trials, a cumulative threshold for the speed of the spheres was measured and displayed on a graph that the subject can see. This number was recorded and the task was repeated for a total of three times.

7. Training

This section describes a typical training session for all four groups. Each participant visited the lab a total of ten times, including their pre and post testing session. The entire procedure took approximately three to four weeks, depending on the participants' availability. Furthermore, due to the training effect of the study, it was pertinent that participants scheduled sessions no longer than four days apart and were never scheduled for two training sessions in one day. This choice was made to help facilitate the effects of training and transfer onto the cognitive tasks within a limited amount of time.

Each group consisted of 10 subjects that were assigned randomly into one of four groups. The only factor taken into account was the distribution by sex within each group. Upon arrival at each training session, subjects were given a session questionnaire to measure their current level of fatigue, number of hours of sleep, last caffeinated/alcoholic beverage, last cigarette, and whether they had taken part in any kind of high-intensity physical activity within the last six hours. Although these data were not included in the final analysis, these variables were important in order to indicate possible reasons that may have influenced cognitive awareness during the testing session.

7.1 Experimental Group 1: 3D-MOT – NeuroTracker™ (NT)

Each training session consisted of three series of 20 trials (as described in the text above). It required approximately thirty minutes to complete the training session. Depending on the participants' availability, sessions were scheduled between two to four times per week.

7.2 Experimental Group 2: High visual stimulus- Call of Duty (COD)

Each training session restricted participants to 30 minutes of game play of a AVG called Call of Duty – Ghosts®. Participants played started the campaign on "*recruit mode"* due to their inexperienced level. Level one – *Ghost Stories* was mainly a practice level where subjects learnt how to run, aim, shoot, and operate other important controls required for completion of the game. Their main goal for each session was to reach each level checkpoint and ultimately defeat the level to continue onto the next series. When the level was deemed too difficult, participants were verbally instructed what to do. The training game was played on a PlayStation 4® approximately 95 inches away from the Panasonic television. The volume was turned on so that players can hear the verbal instructions in the game.

7.3 Experimental Group 3: Low visual stimulus – Tetris (TT)

Each training session required 30 minutes of game play of a classic video game called Tetris® on www.freetetris.org. Participants played on a 15 inch LG laptop and controlled the Tetris blocks using the arrow keys on the laptop keypad. Participants were given a score sheet to record their progress throughout the duration of the training session. The score sheet analyzed the improvement in level, total score, and the number of lines completed within each session.

7.4 Experimental Group 4: No visual stimulus – Sudoku (SD)

Each training session required 30 minutes of Sudoku puzzles printed on paper from www.krazydad.com/sudoku. Participants started the training session with an *easy level* puzzle. As they began to accurately complete the puzzles at a faster rate, participants were given more advanced puzzles to solve. The speed at which the subject completed the puzzle was timed and each test was corrected. Participants were encouraged to complete as many puzzles as possible within a given training session. Puzzles that were left unfinished at the end of a session were resumed at the following visit.

8. Final assessment

The post session took approximately 2 hours to complete and was comprised of the same neuropsychological tests and qEEG assessments as the pre session. Depending on the availability of the participant, the post session took place approximately 3 to 4 weeks after the initial assessment.

9. Statistical analysis

The statistical analysis for neuropsychological assessments and 3D-MOT measures were preformed using IBM SPSS statistics version 19. Parametric tests were used when the homogeneity of variances (Levene's test) was non-significant. A mix-design analysis of variance (ANOVA) with repeated measures and a Greenhouse-Geisser correction where the between-subject factor was by group (NT, COD, TT, and SD) and the within-subject factor (session) was used to compare the 3D-MOT speed thresholds between each training group.

A one-way ANOVA using delta values where the between-subject factor was by group (NT, COD, TT, and SD) and the within-subject factor by session (pre and post) was used to show significant differences between groups on neuropsychological tests. A repeated measure one-way ANOVA was used to compare each group to the NT group individually, where the between-subject factor was pre and post session. Finally pre and post- training t-tests were used to demonstrate significant changes within-groups on their neuropsychological test scores. In addition, effect size using Cohen's d was calculated to determine the magnitude of change for each test.

All the EEG recordings were analyzed using NeuroGuide (version 2.7, Applied Neuroscience, Inc), which is software that contains a normative database and various tools for statistical data analysis. Test-retest and split-half reliability measures were restrained at 0.90 or higher. On minute of artefact-free pre and post EEG data was extracted from a colleague who was masked to the test condition and group.

Chapter 3: Results

1. 3D-MOT

The results of the one-way ANOVA indicated that there was a significant difference among the four groups (F [3,36]=14.205, $p<0.001$, $\eta^2=0.542$). An LSD test revealed that NT group thresholds were significant compared to COD, TT, and SD ($p<0.001$, respectively), which showed that there was a significant improvement in the NT group. As represented in Figure 3-1, the thresholds for the 3D-MOT increased with every trial and produced significant results from the initial testing session to the final testing session ($p<0.001$).

Figure 3-1 displays the average 3D-MOT threshold scores for the 10 sessions of training and the pre and post sessions of those trained in groups 2, 3, and 4 with one standard error of the mean (SEM) and a logarithmic trend line representing the rate of change for the NT group. The final session scores for groups 2, 3 and 4 were improved by an average of approximately 0.3 on their threshold scores whereas group 1 improved by approximately 1.0 by the final session.

2. Cognitive measures

A Levene's test of homogeneity yielded no differences among groups ($p > 0.01$). The subsequent tables provide statistical data on the battery of neuropsychological tests preformed including pre-post 3D-MOT thresholds.

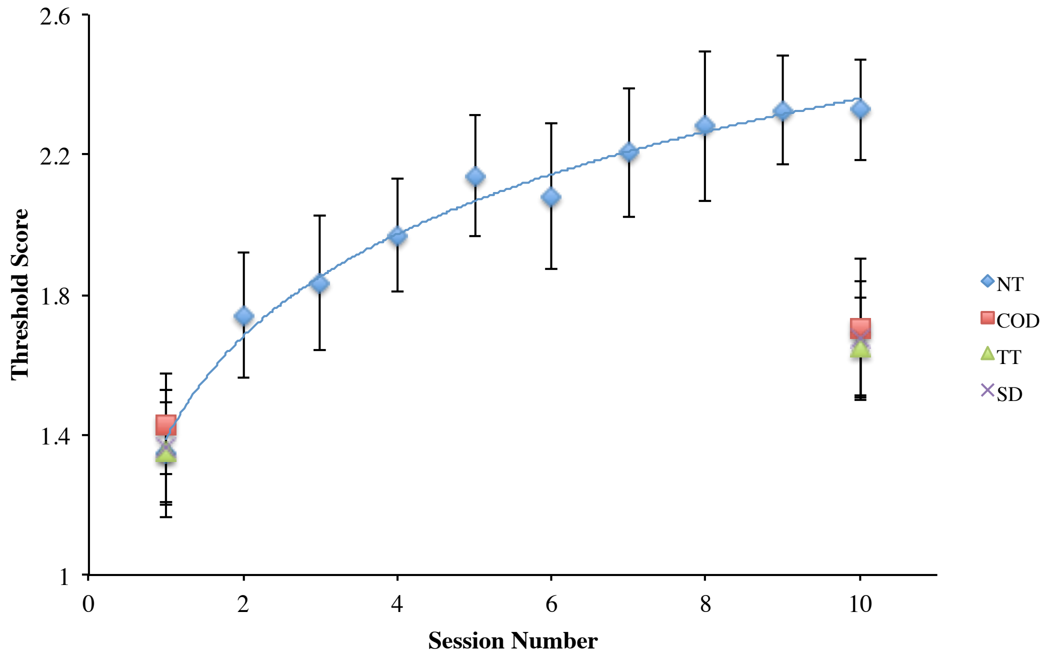


Figure 3-1: Average pre and post speed threshold scores on 3D-MOT for the NT, COD, TT, and SD group. A logarithmic trend line represents the NT GROUP session averages

Table 1. Neuropsychological Test Results: mean values of Pre-Post Within-Group *t*-Tests and effect sizes

	NT Group (n=10)					COD Group (n=10)				
Measure	Pre	Post	Delta	Significance	effect size	Pre	Post	Delta	Significance	effect size
IVA+Plus Auditory	120.8	126.2	5.4	0.190	0.427	118.9	112.4	-6.5	0.173	0.442
IVA+Plus Visual	102.6	102.2	-0.4	0.869	0.218	97.58	99.35	1.77	0.582	0.279
WAIS-Symbol Search	45.9	51.9	6	0.013*	0.719	38.3	46.4	8.1	0.000*	0.906
WAIS-Code	89.3	103.7	14.4	0.001*	0.851	85.5	91.9	6.4	0.018*	0.693
WAIS-Block Design	52.9	56.8	3.9	0.072~*	0.562	49.5	53.2	3.7	0.069~*	0.567
WAIS-Number Sequence	20.3	22.1	1.8	0.212	0.408	20.7	20.6	-0.1	0.893	0.046
WAIS-Letter-Number Sequence	11	12.8	1.8	0.035*	0.636	11	11.6	0.6	0.239	0.387
WAIS-Spatial Span	16.8	18.2	1.4	0.034*	0.638	15.6	15.1	-0.5	0.637	0.160
d2 Test of Attention	461.8	538.8	77	0.000*	0.942	425	478.9	53.9	0.001*	0.863
	TT Group (n=10)					SD Group (n=10)				
Measure	Pre	Post	Delta	Significance	effect size	Pre	Post	Delta	Significance	effect size
IVA+Plus Auditory	105.5	102.4	-3.1	0.725	0.119	107.6	103.7	-3.9	0.381	0.313
IVA+Plus Visual	100.9	101.9	1	0.754	0.170	95.93	95.73	-0.2	0.946	0.138
WAIS-Symbol Search	46.5	52.5	6	0.000*	0.880	49.3	52	2.7	0.093	0.530
WAIS-Code	90.9	95.1	4.2	0.050*	0.602	94.3	100.6	6.3	0.027*	0.660
WAIS-Block Design	51.1	53.8	2.7	0.289	0.351	59.2	61.1	1.9	0.082	0.546
WAIS-Number Sequence	21	21.2	0.2	0.751	0.108	20.3	21.3	1	0.244	0.383
WAIS-Letter-Number Sequence	12.4	12.9	0.5	0.399	0.282	12.2	12.6	0.4	0.443	0.258
WAIS-Spatial Span	16.5	17.4	0.9	0.108	0.511	17.6	17.1	-0.5	0.601	0.177
d2 Test of Attention	441.9	517.9	76	0.000*	0.902	466.8	545.2	78.4	0.000*	0.928

* Significant result
~* Trending toward significance
Abbreviations: IVA: Integrated Visual and Auditory Continuous Performance Test; WAIS, Wechsler Adult Intelligence Scale

Table 1 shows the NT group achieving significance on five out of nine of the t-tests and a sixth t-test trending towards significance, whereas COD and TT achieved significance for only three of the tests and SD achieved significance for only two tests. WAIS-Letter-Number-Sequence (p=0.035) and WAIS-Spatial Span (p=0.034) improvements were distinct to the NT group. WAIS-Block design trended towards significance for both the NT group (p=0.072) and COD group (p=0.069). All subjects improved on WAIS-Code and d2 test of attention, consequently exhibiting a ceiling effect. Additionally, the NT group preformed at an average score of 120 on the Sustained Auditory Attention Quotient, which is 2 standard deviations above the standard norm (100 ± 10). Cohen's *d*, is used to describe effect sizes which are defined as 'small' (*d*=0.2), 'medium' (*d*=0.5) and 'large' (*d*=0.8). The table above interestingly shows 6 standards of medium to large effect sizes for the NT group in comparison to 4 standards of medium to large effect for the COD, TT, and SD group.

Table 2. One-way analysis of variance (ANOVA) using delta neuropsychological test results

	Delta Anova		
Measure	**F(3,36)**	**p**	**η2**
IVA+Plus Auditory	1.240	0.310	0.094
IVA+Plus Visual	0.125	0.945	0.010
WAIS-Symbol Search	2.331	0.091	0.163
WAIS-Code	3.554	0.024*	0.228
WAIS-Block Design	0.255	0.857	0.021
WAIS-Number Sequence	0.875	0.463	0.068
WAIS-Letter-Number Sequence	1.500	0.231	0.111
WAIS-Spatial Span	1.537	0.222	0.114
d2 Test of Attention	1.228	0.314	0.093

* Significant result towards NT
Abbreviations: IVA: Integrated Visual and Auditory Continuous Performance Test; WAIS, Wechsler Adult Intelligence Scale

Table 2 displays the mean delta values between groups in a one-way ANOVA to determine if there were significant differences among each other. The WAIS-Code test showed a significant value where (F [3,36]=3.554, p<0.024, η^2=0.228). Also a mixed ANOVA (pre and post WAIS-Code results; NT, COD, TT, and SD) showed the NT group to be significantly different compared to COD (p=0.023), TT (p=0.005) and SD (p=0.022).

Table 3. Pre-Post ANOVA comparing the NT group to COD, TT, and SD on neuropsychological tests

	Pre-Post Anova (NT vs COD)			Pre-Post Anova (NT vs TT)			Pre-Post Anova (NT vs SD)		
Measure	**F**	**p**	**η2**	**F**	**p**	**η2**	**F**	**p**	**η2**
IVA+Plus Auditory	4.188	0.056 ~*	0.189	0.824	0.376	0.044	2.670	0.120	0.129
IVA+Plus Visual	0.141	0.712	0.008	0.059	0.811	0.003	0.904	0.354	0.048
WAIS-Symbol Search	0.829	0.375	0.044	0.000	1.000	0.000	1.877	0.187	0.094
WAIS-Code	4.688	0.044*	0.207	8.543	0.009*	0.322	4.547	0.047*	0.202
WAIS-Block Design	0.006	0.940	0.000	0.153	0.700	0.008	0.870	0.363	0.046
WAIS-Number Sequence	1.558	0.228	0.080	1.180	0.292	0.062	0.262	0.615	0.014
WAIS-Letter-Number Sequence	1.906	0.184	0.096	2.673	0.119	0.129	2.520	0.130	0.123
WAIS-Spatial Span	2.644	0.121	0.128	0.439	0.516	0.024	3.097	0.095	0.147
d2 Test of Attention	2.806	0.111	0.135	0.004	0.948	0.000	0.010	0.921	0.001
3D-MOT threshold	31.448	0.000*	0.636	35.623	0.000*	0.664	36.053	0.000*	0.667

* Significant result
~* Trending toward significance
Abbreviations: IVA: Integrated Visual and Auditory Continuous Performance Test; WAIS, Wechsler Adult Intelligence Scale

Table 3 analyses pre and post neuropsychological test results for each group relative to the NT group in a one-way ANOVA.The WAIS-Code test showed significant results across all groups in favour of the NT group. In addition, the 3D-MOT thresholds were significant (p<0.01) across the board. Interestingly, IVA+Plus Auditory demonstrated a statistical trend in the NT versus COD group (p=0.056). This result is displayed in figure 3-2.

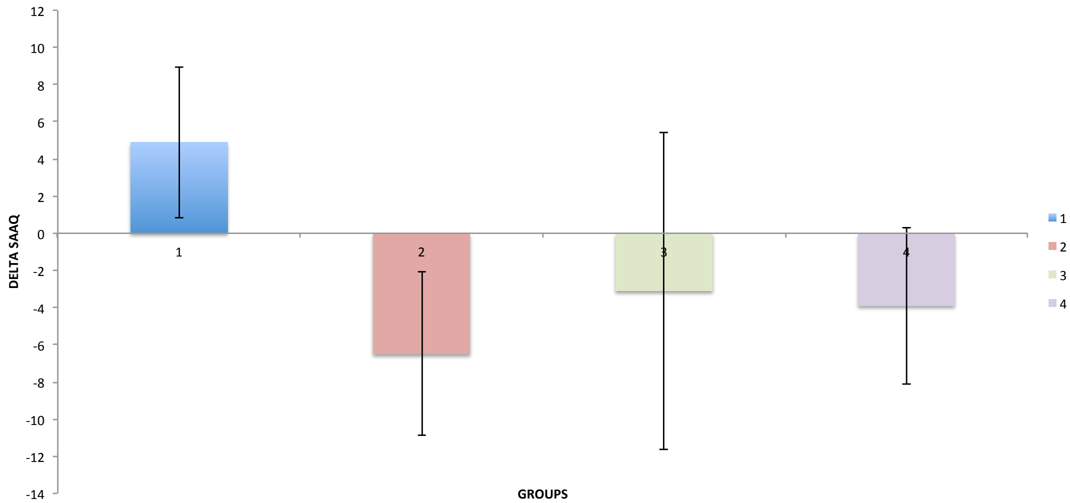


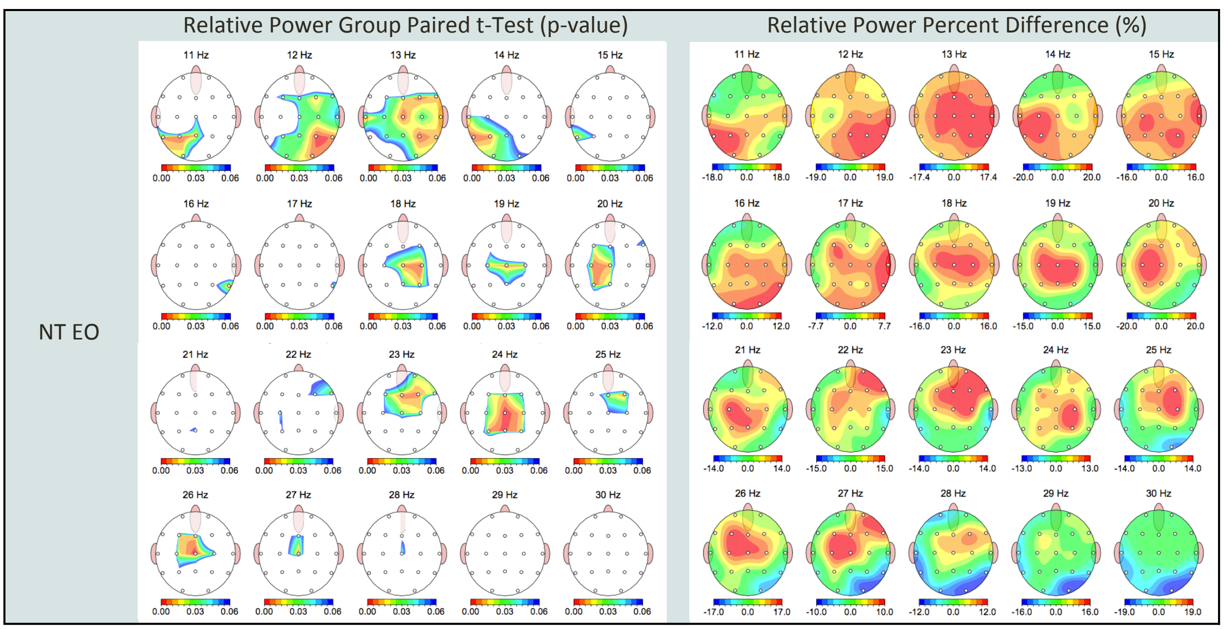
Figure 3-2. Delta IVA+CPT Auditory results for NT, COD, TT, and SD

3. QEEG:

Complete qEEG maps are provided in Annex 1. For the purpose of this study, only beta frequencies during eyes-open and eyes-closed conditions are represented in the tables below but a condensed analysis is provided under each table. An overview of the relevant significant results is provided in Table 12. Relative power group paired t-tests are presented on the left and provide a p-value scale from 0.00 (red) to 0.06 (blue). For strength and clarity, statistical results are considered highly significant where the p-value is between 0.00 (red) and 0.02 (yellow) and slightly significant where the p-value is between 0.03 (green) and 0.06 (blue). Relative power percent differences on the right show increases (red) or decreases (blue) in a cortical region. Frequency bands are defined in the NeuroGuide database as delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (13-30 Hz), and gamma (30-50 Hz).

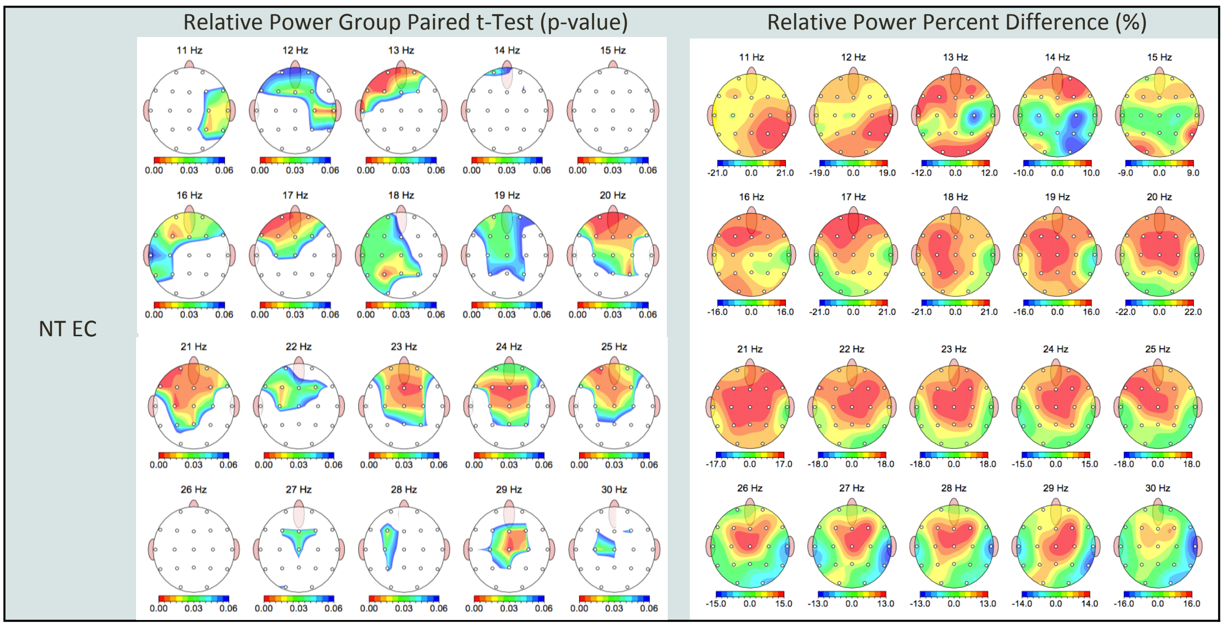
3.1 Beta frequency maps

Table 4. NT group qEEG results for relative power group paired t-test: Eyes-Open condition observing beta amplitude (13-30 Hz)



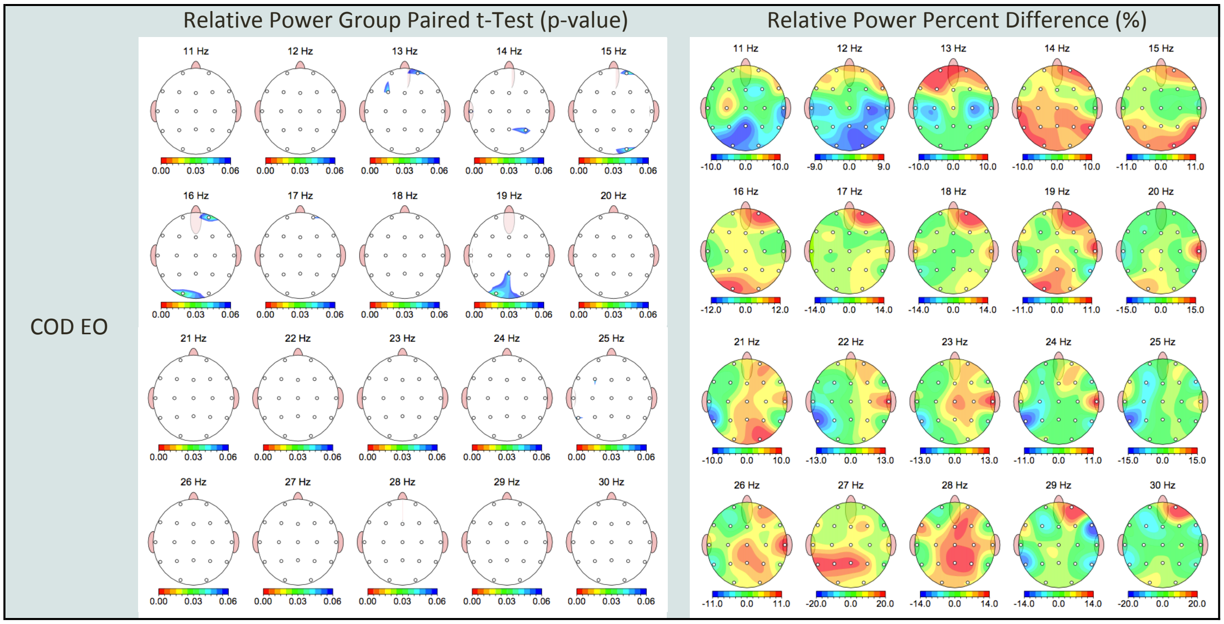
In the NT group eyes-open condition, absolute power group paired t-tests showed delta and theta frequencies decreased in activity in the mid-parietal, left temporal, and occipital regions. Absolute beta and gamma power decreased in the mid-left temporal lobe. Relative power group t-tests showed no significant changes in delta, theta, and gamma frequencies. Alpha frequency increased in the left and right posterior parietal regions and beta power significantly increased in the mid parietal region.

Table 5. NT group qEEG results for relative power group paired t-test: Eyes-Closed condition observing beta amplitude (13-30 Hz)



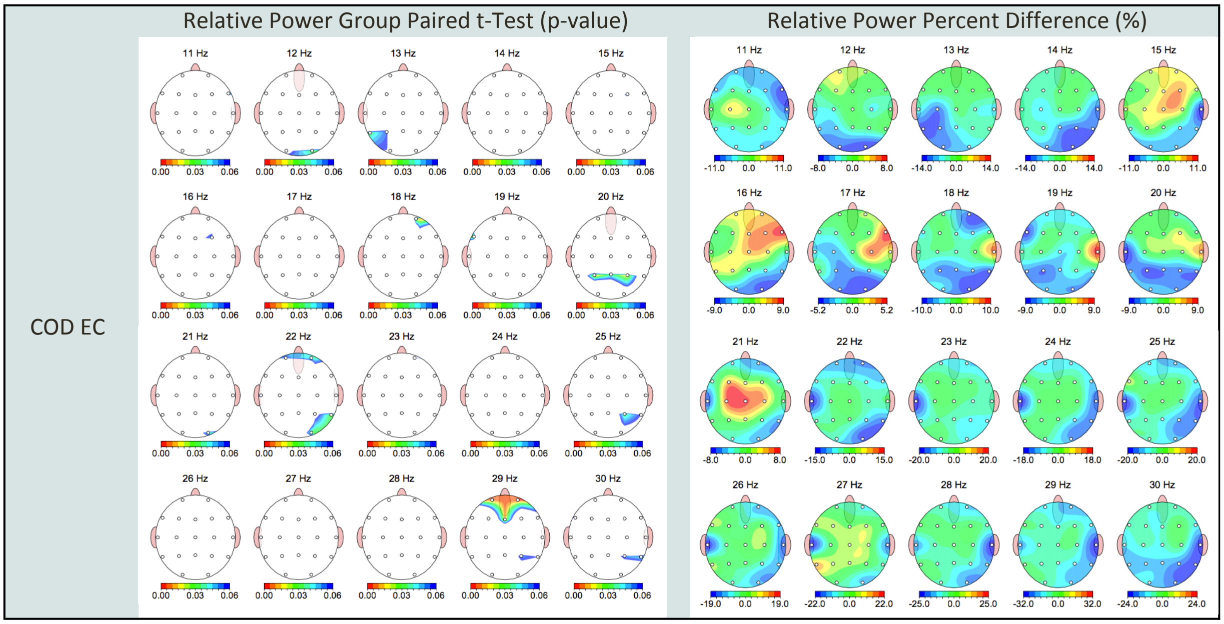
In the NT group eyes closed condition, absolute power group paired t-test showed delta, theta and gamma frequencies decreased in activity in the pre-frontal and mid-parietal areas. Relative power group t-tests showed no significant changes in delta, theta, and gamma frequencies. Alpha frequency increased in the right temporal region and beta power significantly increased in the pre-frontal and mid-frontal areas.

Table 6. COD group qEEG results for relative power group paired t-test: Eyes-Open condition observing beta amplitude (13-30 Hz)



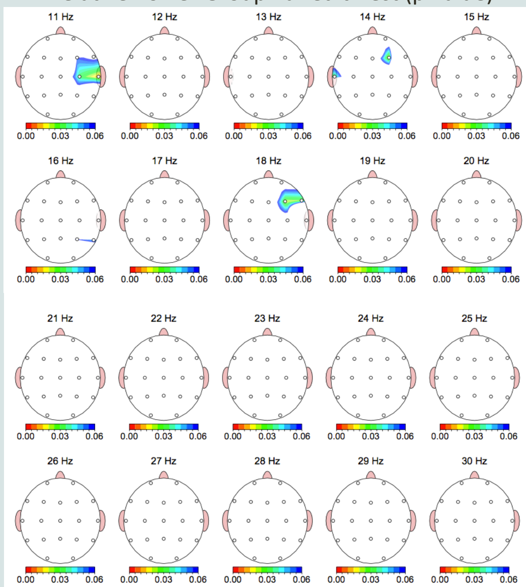
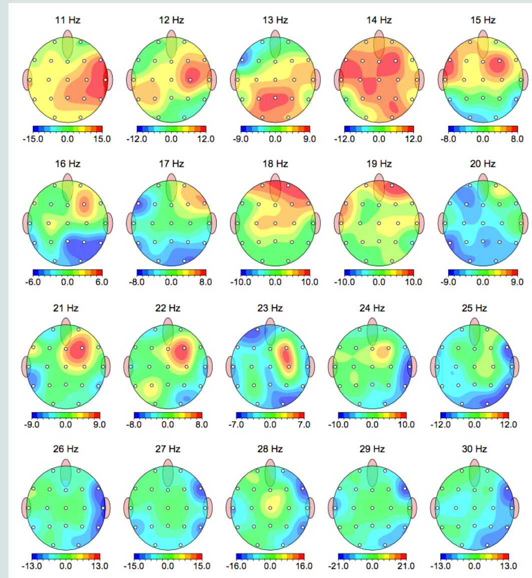
In the COD group eyes open condition, absolute power group paired t-tests showed no significant changes for any bandwidth. Similarly, the relative Power group Paired t-test showed no significant changes for any bandwidth.

Table 7. COD group qEEG results for relative power group paired t-test: Eyes-Closed condition observing beta amplitude (13-30 Hz)



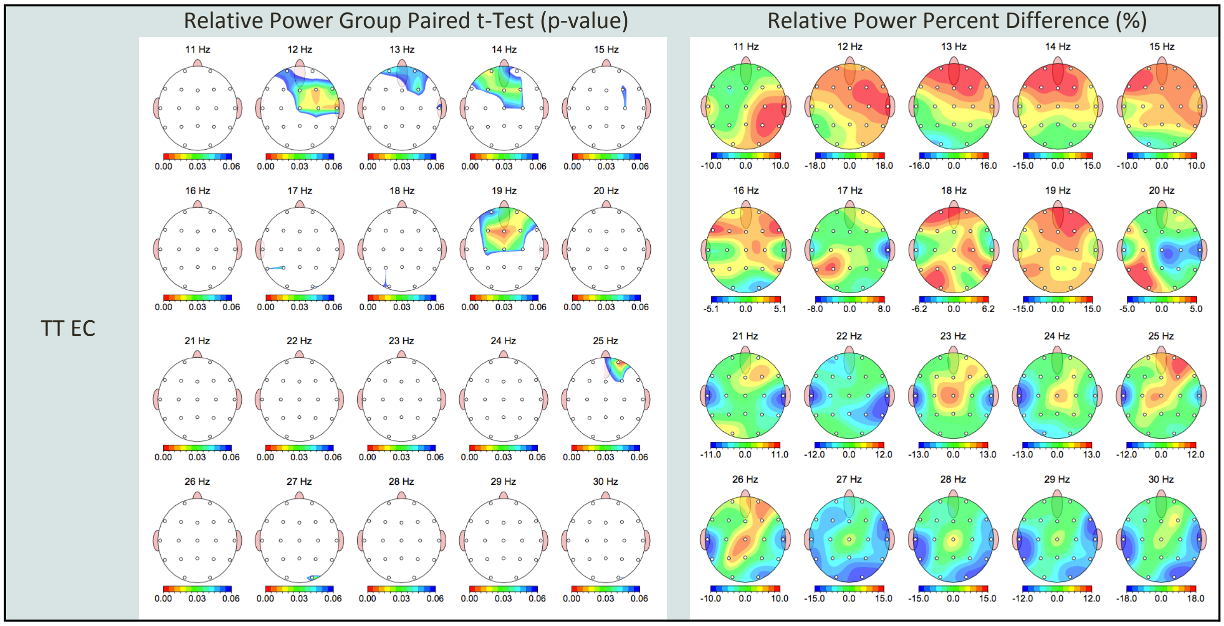
In the COD group eyes closed condition, absolute power group paired t-test showed a significant increase in theta at 7 Hz and 8 Hz in the frontal region and right posterior temporal region. In addition, a single significant increase in delta was observed at 3 Hz and at gamma 50 Hz in the left occipital area. Relative power group paired t-test shows a single significant increase in alpha/theta 8 Hz in the frontal region, a significant decrease of Beta at 29 Hz in the frontal region, and finally a significant decrease in gamma at 35 Hz in the frontal region.

Table 8. TT group qEEG results for relative power group paired t-test: Eyes-Open condition observing beta amplitude (13-30 Hz)

	Relative Power Group Paired t-Test (p-value)	Relative Power Percent Difference (%)
TT EO		

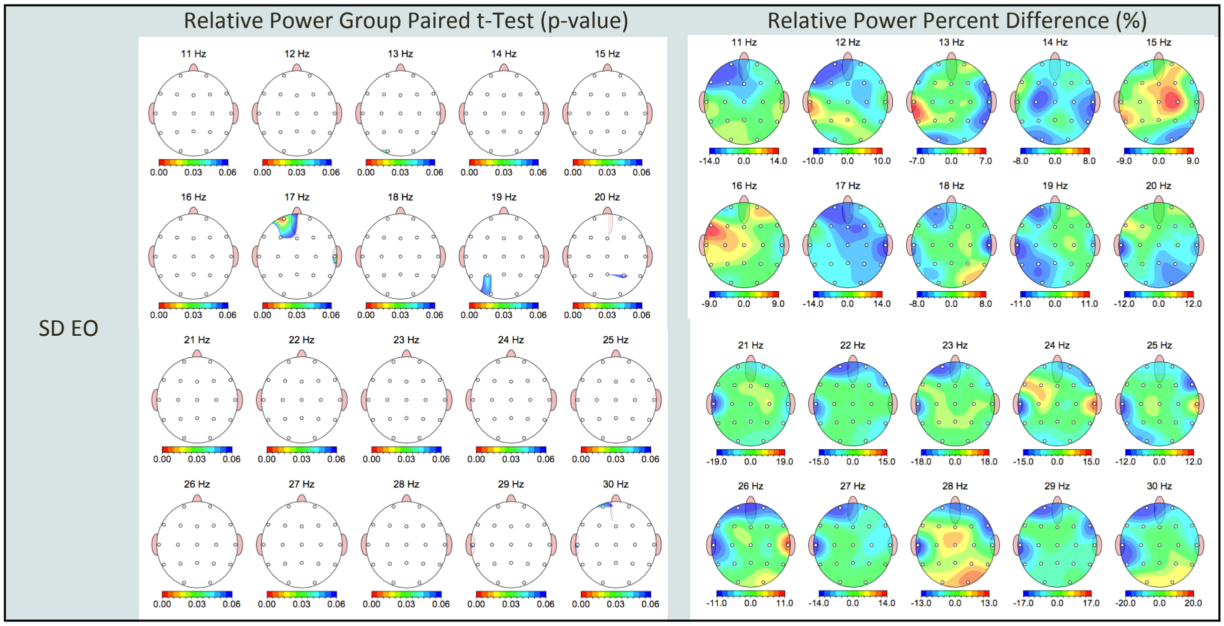
In the TT group eyes-open condition, absolute power group paired t-test showed a slight significant decrease of theta in the left-mid parietal region. Beta frequency increased in the mid-parietal area at 13 and 14 Hz only. Relative power group paired t-tests showed a slight decrease in theta at 6 Hz, slight increase in alpha at 11 Hz, slight increase in beta at 18 Hz, and slight decrease in gamma at 33 and 35 Hz.

Table 9. TT group qEEG results for relative power group paired t-test: Eyes-Closed condition observing beta amplitude (13-30 Hz)



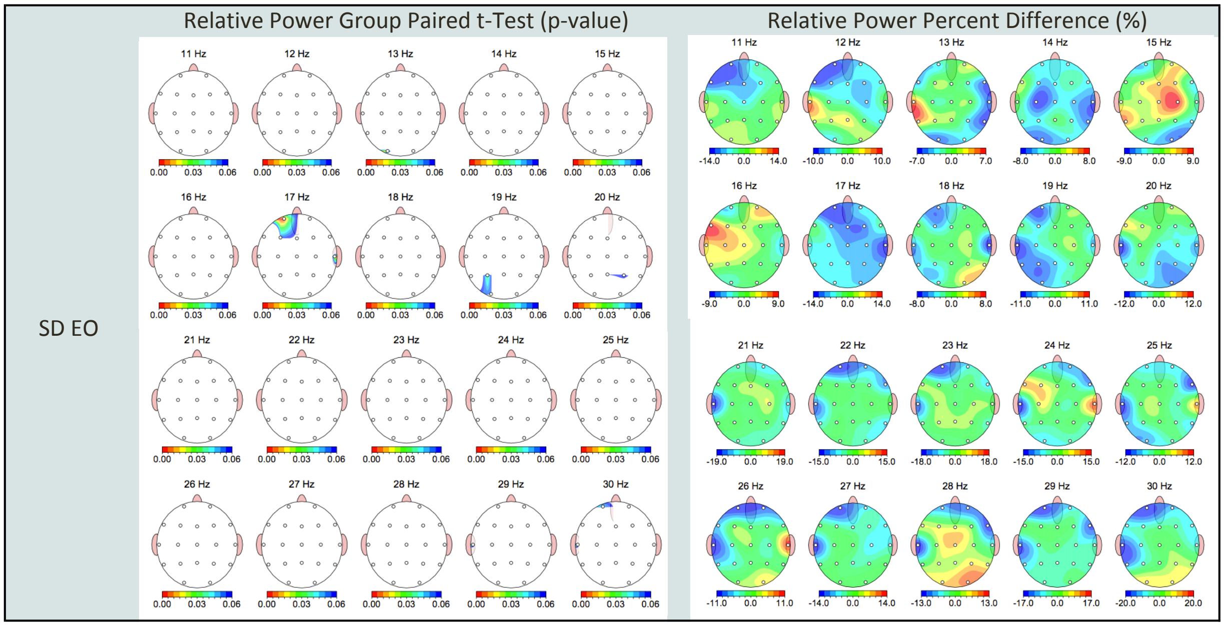
In the TT group eyes-closed condition, absolute power group paired t-test showed a slight decrease of theta in the frontal region at 6 Hz and a significant decrease in gamma frequency in both left and right temporal regions and mid-parietal region. Relative group paired t-test showed an increase in alpha frequency in the right-parietal region at 12 Hz. Beta frequency in the left-frontal and mid-parietal region also slightly increased at 13, 14 and 19, and 25 Hz. Gamma frequency significantly decreased in the right temporal region.

Table 10. SD group qEEG results for relative power group paired t-test: Eyes-Open condition observing beta amplitude (13-30 Hz)



In the SD group eyes-open condition, absolute power group paired t-test showed slight increases in delta in the mid-frontal region at 1 Hz. In addition, there was a slight increase in theta left temporally at 5 Hz and frontally at 8 Hz. A slight increase in absolute beta was observed in the mid-parietal region at 13 Hz and 15 Hz. No significant changes were observed in the relative power group paired t-test.

Table 11. SD group qEEG results for relative power group paired t-test: Eyes-Open condition observing beta amplitude (13-30 Hz)



In the SD group eyes-closed condition, absolute power group paired t-test showed an increase in delta in the frontal region and right occipital region. Theta was significantly high in the frontal and mid parietal region at 6 to 8 Hz. In addition, beta frequency increased mid-parietal to left frontal region at 14 to 18 Hz. Relative power group paired t-test showed an increase in delta in the occipital region. Theta frequency significantly increased in the left frontal region and occipital region as well as left and right mid parietal regions. A slight decrease in alpha was observed at 10 Hz in the mid-parietal area. Decrease in beta and gamma frequency is observed in the mid-parietal region.

Table 12. Overview of significantly relevant changes in eyes-open and eyes-closed conditions for NT, COD, TT, and SD

Wave	Condition	FTT Absolute Power Group Paired t-Test	FTT Relative Power Group Paired t-Test	Condition	FTT Absolute Power Group Paired t-Test	FTT Relative Power Group Paired t-Test
Delta		↓ in mid-parietal to occipital region	No change		No change	No change
Theta		↓ in mid-parietal to occipital region	No change		↓ in left mid-parietal region	↓ in mid-parietal region
Alpha	NT EO	No change	↑ in left + right posterior parietal region	TT EO	No change	No change
Beta		↓ in left temporal region	↑ in mid-parietal region		Slight ↑ in mid-parietal 13-14 Hz	No change
Gamma		↓ in left temporal to mid-parietal region	No change		No change	No change
Delta		↓ in left mid-parietal region	No change		No change	No change
Theta		↓ in left + pre-frontal and mid-parietal region	No change		Slight ↓ in right to pre-frontal region	No change
Alpha	NT EC	No change	↑ in right temporal region	TT EC	No change	↑ in right mid to left temporal region 12 Hz
Beta		No change	↑ in frontal + mid-parietal region		No change	Slight ↑ in mid-frontal 19 Hz
Gamma		↓ in frontal + left temporal region	No change		↓ in right + left temporal region	↓ right to left posterior temporal region
Wave	**Condition**	**FTT Absolute Power Group Paired t-Test**	**FTT Relative Power Group Paired t-Test**	**Condition**	**FTT Absolute Power Group Paired t-Test**	**FTT Relative Power Group Paired t-Test**
Delta		No change	No change		No change	No change
Theta		No change	No change		No change	No change
Alpha	CD EO	No change	No change	SD EO	No change	No change
Beta		No change	No change		No change	No change
Gamma		No change	No change		No change	No change
Delta		↑ in occipital region	No change		↑ in pre-frontal + right posterior region	↑ in right occipital region
Theta		↑ in frontal + right temporal region	↑ in pre-frontal region		↑ in frontal to occipital + mid-parietal region	↑ in frontal to occipital + left mid-parietal region
Alpha	CD EC	No change	No change	SD EC	No change	No change
Beta		No change	↓ in frontal region 29 Hz		↑ in mid-parietal to frontal region 14 + 16 Hz	Slight ↓ in mid-parietal to left-parietal region
Gamma		No change	Slight ↓ in right posterior + left frontal region		No change	↓ in mid-parietal region

The results from the qEEG data obtained are subject to interpretation and absolute power must be referred to when interpreting relative power.

Chapter 4: Discussion

The primary goal of this study was to compare the perceptual cognitive changes between participants trained on video games versus a high-level 3D-MOT cognitive technique. According to our neuropsychological tests and qEEG results, individuals trained on 3D-MOT revealed improved scores on neuropsychological assessments and increased in beta power compared to the other three groups trained on various video games. Most interestingly, subjects trained on the AVG showed no significant changes in beta power whereas 3D-MOT participants had significant gains in beta power and significant decreases in delta, theta and gamma power. The results suggest that training on 3D-MOT, for the same duration as playing a video game, can provide greater cognitive enhancement.

4.1. 3D-MOT

As expected, 3D-MOT speed thresholds improved with training. The group trained on 3D-MOT exhibited similar trends as pervious training studies on the elderly, athletes, and young adults (Faubert, 2013; Faubert & Sidebottom, 2012; Legault et al., 2013; Parsons et al., 2014; Romeas et al., 2016). A 3D-MOT session takes approximately 25 minutes to complete and each individual trial requires 7 seconds of sustained attention in order to accurately track the four spheres. During the trial, the individual must equally exercise their selective attention onto the four target spheres all the while dividing their attention to follow each sphere separately. The complexity of the perceptual-cognitive task collectively engages complex motion integration, sustained and distributed attention, and working memory. The 3D-MOT task has recently shown to enhance cognitive function by improving attention, visual information processing speed and working memory in young adults (Parsons et al., 2014). In addition, varsity soccer players trained on the task, improving attentional processes involved in decision-making accuracy on the field, indicating that the technique has a transferable effect onto untrained tasks (Romeas et al., 2016). The researchers also saw transferable effects onto a biological-motion perception task in an older population in a laboratory setting (Legault & Faubert, 2012). The group trained on the 3D-MOT task in this study demonstrated similar improvements in attentional processes evaluated through neuropsychological assessments and qEEG activity. This consistent trend in 3D-MOT improvement with training stands to reason that training on this task exercises and enhances these fundamental attentional features found within 3D-MOT.

4.2. QEEG

The most interesting result was the data provided by the qEEG for the NT group and the COD group. The NT group that trained on 3D-MOT showed significant increases in absolute and relative beta frequencies in the frontal, mid-parietal, and left occipital regions and significant decreases in absolute slow amplitude frequencies in the frontal, mid-parietal and occipital regions whereas the COD group that trained on the high-visual stimulus video game showed no overall significant changes at any bandwidth. According to these results, 3D-MOT training appears to increase attention associated with high amplitude waves and decrease inattention associated with low amplitude waves. To better interpret the data, the brain can be considered like an orchestra, in which the absolute power can be represented as each individual member of the orchestra and the relative power represents the orchestra playing as a whole. In the NT group, it appears that the absolute delta, theta, and gamma waves decreased, thus allowing for overall beta activity to be more representative. Beta activity has been associated with attentional cognitive processes (Ogrim, Kropotov, & Hestad, 2012; Ray & Cole, 1985). High beta activity coupled with low alpha activity at rest correlated with attentional investment, while low alpha activity and high theta activity at rest correlated with drowsiness and low attentional investment (MacLean, Arnell, & Cote, 2012). High theta activity to low beta activity ratios have been found to be characteristic of individuals with attention deficit hyperactive disorder (Barry et al., 2010; Barry, Clarke, & Johnstone, 2003; Monastra et al., 1999; Ogrim et al., 2012; Snyder & Hall, 2006). Our finding is consistent with a previous study by Parsons and colleagues (2014) who suggested that attention was improved on the group trained on the 3D-MOT task. According to their results, the group trained on 3D-MOT also revealed significant relative power increases in beta bandwidth and significant decreases in theta and alpha bandwidth (Parsons et al., 2014). Additionally, the increase in relative and absolute beta frequency in the 3D-MOT group associated with attentional cognitive processes may be indicative of the improvements observed in nearly 6 out of the 9 neuropsychological tests.

The cortical regions where increased beta activity was observed were particularly interesting. Several fMRI imaging studies using the MOT task have reported activations along the dorsal fronto-parietal cortex, intraparietal sulcus and superior parietal lobule (Alnaes et al., 2015). In particular, a study by Culham and colleagues (2001) observed the functional role of these areas during attentive tracking and suggested that these areas play a large part in the MOT task performance due to added control of attentional mechanisms or increased visual information selected by attention. The study observed load-dependent functions in the parietal and frontal cortex and in particular the intraparietal sulcus suggesting that this area is directly involved in the cognitive components required to preform a tracking task, including spatial attention and working memory (Culham et al., 2001). Bearing in mind that the brain images conducted in this study were obtained using a qEEG, it is relevant to note that fMRI and qEEG data can be examined in congruence with one another due to the strong link between electrophysiological and fMRI markers of neuronal activity (Huster, Debener, Eichele, & Herrmann, 2012; Logothetis & Pfeuffer, 2004). Also, fMRI signals at a specific region contain information about the local dipole activity and as such neuroelectric EEG signals may instigate a metabolic response (Wibral, Bledowski, & Turi, 2010). Remarkably, the 3D-MOT group eyes-closed condition revealed relative beta power increases in the dorsal frontoparietal cortex, intraparietal and superior parietal area and are highlighted in figure 4-1. In addition the 3D-MOT eyes-open condition revealed relative beta power increases in the areas containing the intraparietal sulcus and superior parietal lobule. These findings suggest that the areas of the brain known to have an active role in attention and visual information may be exercised with 3D-MOT training. Although video games offer a high load of visual information and in many ways involve selective, sustained and divided attention, the 3D-MOT task appears to be a more effective technique to enhance perceptual cognitive abilities. The overall minimal nature of the task provides a content free medium coupled with unpredictable and endless variations of possible trajectories, which ultimately enhances the effectiveness of the technique. Perhaps the over-stimulation that can be observed in many AVGs does not offer the same level of fine-tuned training when compared to 3D-MOT. In other words, the visual simplicity of the 3D-MOT task, that is content free, creates a more favourable exercise to strengthen complex cognitive perceptual skills.

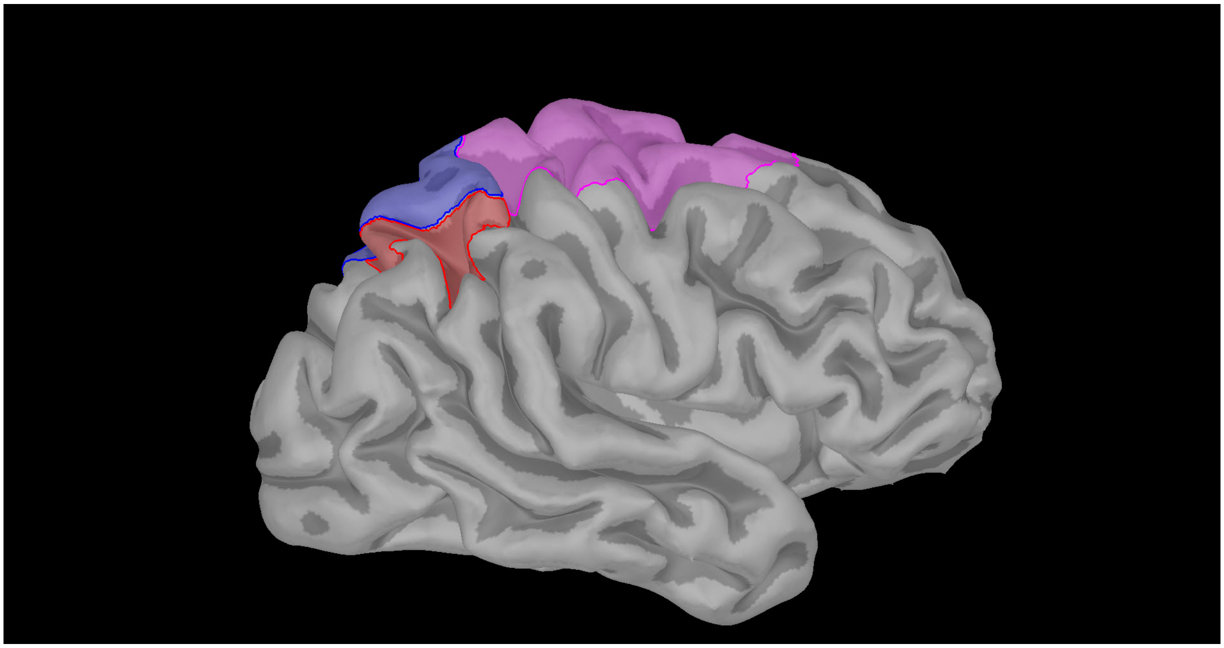


Figure 4-1: An fMRI image highlighting the dorsal fronto-parietal cortex (pink) , intraparietal sulcus (red) and the superior parietal lobule (purple) which represent areas of the brain where beta activity was observed in the NT group.

Several video game training studies have also used EEG to observe executive functions related to alpha and theta frequencies. The EEG data, however, were recorded in a non-resting state while the participant played the AVG video game in question. Maclin et al. (2011) and Mathewson et al. (2012) observed modest increases in frontal alpha power after 20 hours of training on the video game *Space Fortress* (Maclin et al., 2011; Mathewson et al., 2012). A study by Anguera et al. (2013) trained participants on a custom made 3D video game called *NeuroRacer* and observed increased midline frontal theta power after training. The researchers suggest that these changes in frequencies predict improvements in learning and sustained attention (Anguera et al., 2013; Maclin et al., 2011; Mathewson et al., 2012). The assumptions were made based on research indicating that increases in frontal theta power affects focused attention (Ishii et al., 1999) and increases memory load (Jensen & Tesche, 2002). However, research on increased frontal theta activity observed during resting-state EEG on subjects with attention deficit and hyperactive disorder has been linked to a decrease in attention (Hermens et al., 2005; Mann, Lubar, Zimmerman, Miller, & Muenchen, 1992) and decreases in theta activity has been associated with encoding new information (Klimesch, 1999). The COD group, eyes-closed condition revealed increased absolute and relative frontal theta activity at 8 Hz and no significant changes in the eyes-open condition. The frequency band at 8 Hz is partial to interpretation considering it sits on a boundary between theta (4-8 Hz) and alpha (8-12 Hz) frequency. The COD groups' neuropsychological tests revealed improvements in WAIS-Code, WAIS-Symbol search, and d2 test of attention and can be indicative of improved selective attention. Similarly, the SD group revealed eyes-closed absolute power increase in the frontal and mid-parietal theta activity at 6-7 Hz and relative power increases in occipital theta activity at 6 Hz. However, the SD group only improved on WAIS-Code and the d2 test of attention and lingered on trending towards significance for the block design task. The neuropsychological results do not offer a tangible explanation for the increase in frontal theta activity. Although the data regarding theta activity is rather conflicting it can also be proposed that the theta increase in eyes-closed condition is a result of the *default mode network*: The human brains basal neural activity (Raichle et al., 2001; Raichle & Snyder, 2007). Recent studies have identified regions of the brain (including the medial prefrontal cortex) that are activated under passive conditions such as daydreaming, reminiscing about the past or thinking about the future, and other varieties of spontaneous cognition (Buckner, Andrews-

Hanna, & Schacter, 2008). A study by Chen et al. (2007) observed changes in eyes-open and eyes-closed conditions to understand the features of the default mode network and found a greater fronto-central theta activity in the eyes-closed condition and theta reductions in the eyes-open condition (Chen, Feng, Zhao, Yin, & Wang, 2008). Inversely, Scheeringa et al. (2008) suggested that frontal theta activity is negatively correlated to the default mode network (Scheeringa et al., 2008). Considering the location of the theta activity (medial prefrontal cortex), the inconclusive neuropsychological test, and the observations made in the eyes-closed condition, the data suggest that the increases in frontal theta in both the COD and SD group could be a result of the default mode network in which participants were engaging in spontaneous cognition.

Another result that warrants further examination was observed in gamma frequency decreases in the eyes-closed condition for the NT, TT, and SD groups. Typically, gamma activity has been associated with auditory and visual attention as well as visual short-term memory tasks (Gruber, Muller, & Keil, 2002; Gruber, Muller, Keil, & Elbert, 1999; Jensen, Kaiser, & Lachaux, 2007; Tiitinen et al., 1993). Gamma band activity has also been linked to the coordination of cortical areas involved in a given task (Jensen et al., 2007). The expectation would then likely be to observe increases in gamma power, however here the opposite change was observed. The TT group saw decreases in absolute gamma in the left and right temporal regions and relative decreases in the right temporal region. These cortical areas are considered a part of the visual ventral stream, responsible for visual identification and object/face recognition with strong connections in the medial temporal regions (Desimone & Duncan, 1995). With regard to the neuropsychological assessments, the TT group demonstrated improvements in the WAIS-Symbol Search, WAIS-Code, and the d2 Test of Attention, three tasks measuring information processing speed that rely heavily on rapid object recognition.

How, then, would these functional changes in brain activity be interpreted? A decrease in gamma activity corroborates the neuropsychological tests in supporting the idea that visual identification and object recognition are exercised through Tetris training, leading to less overall activation of the visual ventral stream. Essentially, since less cortical areas were being solicited and task performance improved, this change appeared to reflect the brain to work more efficiently. These changes appeared to be symptomatic of specialization. Further observed decreases in frontal absolute gamma for the NT group in the eyes-closed condition and left-temporally in the eyes-open condition can be interpreted as a result of an enhancement of the involved cortical networks. In other words, the brain can decrease amount of cortical areas involved in these tasks (demonstrated by decreased gamma) while increasing the relative load on these areas (as demonstrated by increased beta activity).

4.3. Neuropsychological assessments

As hypothesized, the NT group improved significantly on five out of nine neuropsychological tests and a statistical trend was apparent on a sixth test. The COD and TT group improved on three tests while the SD group only improved on two. In view of the demanding attentional resources solicited by the 3D-MOT task, improvements on these cognitive tests were observed after 10 sessions. Perceptual-cognitive functions such as attention (sustained, selective and divided), working memory, and visual information processing speed were exercised and improved with 3D-MOT training. This finding corresponds to the EEG beta activity observed in the areas of the brain that are involved in attentional mechanisms. Interestingly the WAIS-Letter-Number sequence and WAIS-Spatial Span were the two tests in which the NT group uniquely reached significance, suggesting that visuo-spatial working memory, attention, and concentration may be inherently improved with 3D-MOT training. The EEG changes in the areas involved in the frontal-parietal network, responsible for cognitive control, complement this result. During the 3D-MOT task, short-term memory and working memory function collectively to increase threshold scores. The four target spheres must be temporarily stored within short-term memory while working memory is exercised to retain each individual target moving at random. The COD, TT and SD group did not show significant improvements on the same cognitive tests. It is unclear whether spatial and working memory can be improved with video game play and research studies have offered inconsistent results (Boot et al., 2008; Oei & Patterson, 2013). It was especially surprising to see the TT group gain no apparent spatial or working memory benefits from the training. The Tetris game required participants to strategically place different shapes while taking into consideration of each subsequent falling shape and the spaces that need to be filled, therefore involving a spatial memory component to the game. However, the qEEG data showed no major changes in any frequency that could justify this result. The idea that the relatively simple task would exercise spatial memory was rejected. Most researchers in video game training studies use cognitive tasks such as the UFOV, enumeration, attentional blink test, and MOT to evaluate attention. An extensive video game training study by Boot et al. (2008) used the aforementioned tests as well as the Corsi-Block tapping test. After training NVGPs for 20 hours on a FPS shooter game called *Allied Assault* or on *Tetris*, neither group showed any significant improved effect on the spatial processing and spatial memory task (Boot et al., 2008). The COD and TT group similarly revealed no significant improvements on the WAIS-Spatial span task.

In addition, the WAIS-Block Design test demonstrated a statistical trend for both the NT and COD group, which may suggest enhanced changes in spatial perception, visual abstract processing and problem solving. The areas of the brain that would explain these outcomes are the hippocampus and occipital cortex. QEEG analysis can not observe deep hippocampal activity and strangely, occipital cortex activity was also not observed in the NT or COD groups either. The WAIS-Code test improved for all four groups following training. However, the significant improvements in the 3D-MOT group comparative to the three other groups, revealed greater benefits in visual-motor coordination, motor and mental speed and visual working memory. This improvement in visual information processing was obvious after each subsequent training session, as the participants' 3D-MOT thresholds continuously improved throughout study.

The neuropsychological assessment was designed to replicate a previous laboratory study by Parsons and colleagues (2014). The pre-post within-group t-tests were similar for the NT group on all tests with exception for IVA+Plus-Auditory and WAIS-Block design tasks. The NT group averaged two standard deviations above the norm on the IVA+Plus-Auditory test and yet still improved from pre to post session. The WAIS-Block design task also demonstrated a statistical trend for the NT group and the COD group. With a larger sample size, these deviations would likely show significant results.

4.4. Limitations and future directions

Although the study design took into account different visually stimulating video games and a pencil and paper task, the study lacked a conventional non-active control group. In retrospect, a non-active control group would have provided insight on the extent of test re-test scores and overall brain changes after training. Training studies that included non-trained controls are less likely to experience placebo effects (Basak, Boot, Voss, & Kramer, 2008; Berry et al., 2010). The participants in each active group were aware of the nature of the study and understood that their attentive skills were being exercised to observe their cognitive abilities before and after training. This effectively may have motivated placebo effects on certain cognitive tests. For example, the group trained on Tetris may have assumed their scores would improve on a cognitive test that requires fast processing speed such as WAIS-Symbol Search, whereas the group trained on Sudoku may not have felt their training would exercise the same skill. Similarly, participants may have improved their performance on a task simply because they were being observed, also known as the *Hawthorne Effect* (Benson, 2001). Perhaps a non-active control would have avoided these effects and offered a more efficient means to compare the four groups.

A common limitation among many training studies is the strength of a large sample size. The number of participants in each group was adequate for the extent of a preliminary training study, however more conclusive conclusions could have been achieved with a greater sample size. The sample size in this study was chosen to maintain similar parameters as the Parsons (2014) study. Future researchers may want to consider using the variable data obtained in this study to determine a suitable number of participants. Nevertheless, the NT group attained significant results on numerous neuropsychological tests and positive cortical activity. Now that compelling data have been revealed, the next step would be to expand the sample size. Additionally, all participants were trained on their training program for a total of 5 hours for the duration of the study. Many of the training studies by Green and Bavelier (2003; 2006b) that observed cognitive benefits had trained NVGPs for 10 hours and had some train on a video game for 30 hours. It would be interesting to compare cognitive changes after increasing the amount of training across all four groups as well as increasing the sample. An interesting idea for future research could replicate the study and additionally look at expert video game players compared to those trained on 3D-MOT. Finally, there is a relative amount of ambiguity when observing individual EEG frequencies as well as limited spatial resolution. Future research should aim to integrate EEG data coupled with fMRI scans to provide more accurate brain images with greater temporal and spatial resolution. Although this study had several analytic components that were mainly interpreted independently, future endeavours can incorporate both the qEEG and neuropsychological tests for a more comprehensive conclusion.

It is without question that video games can provide an attractive platform that, if manipulated properly, can be harnessed into a learning tool. Dr. Michael Merzenich eloquently described video games as "[…] controlled training regimens delivered in highly motivating behavioural contexts" (Bavelier et al., 2011, p. 763). In fact, video games have shown to improve reading speed with children affected by dyslexia (Franceschini et al., 2013), have helped young cancer patients adhere to life-saving treatments (Kato, Cole, Bradlyn, & Pollock, 2008) and improved fundamental visual functions in adults suffering amblyopia (Li, Ngo, Nguyen, & Levi, 2011). AVG training has also been examined as a job-related training tool and has revealed an increase in performance in laparoscopic surgeons during endoscopic simulations (Schlickum, Hedman, Enochsson, Kjellin, & Fellander-Tsai, 2008) as well as pilots of unmanned aerial systems (McKinley, McIntire, & Funke, 2011). Perhaps video games would be more beneficial to populations that aim to train specific tasks rather than enhancing overall cognition. Future research in the benefits of video games should work in close collaboration with video game developers to produce task specific training games that can be used in multifaceted settings. Conversely, 3D-MOT appears to have a greater effect on overall perceptual-cognitive abilities and can be used to improve the lives of many individuals.

Conclusion

The potential implications of 3D-MOT on cognitive enhancement are growing in strength with each replicated study and the varieties of populations it can impact are promising. In comparison with the extensive research on video games, it appears that training on 3D-MOT for the same length of time as playing a video game significantly improves perceptual-cognitive abilities. Forty healthy young-adults, who were inexperienced in video games, were divided into four equal groups. One group received perceptual-cognitive training with 3D-MOT while the 3 other groups received training on one of three different levels of stimulating video games (COD, TT, and SD). Training on 3D-MOT for 10 sessions revealed convincing effects on attention, working memory, and visual information processing compared to training on video games. Neuropsychological tests and qEEG data provided quantitative support that 3D-MOT enhances perceptual–cognitive abilities eminently better than video games. Our modern world is unquestionably loaded with visual and auditory information, and individuals are often required to employ all their attentional resources to be able to keep up with the demanding environment. It is for these reasons that individuals who wish to enhance their cognitive capacity may benefit more form a general cognitive training technique like 3D-MOT rather than a commercial video game. Other specialized fields such as professional sports teams, human spaceflight agencies, and armed forces may use the technique to sharpen the cognitive abilities of their teammates, partners or comrades. The current study is one of the first comparative studies that examined cognitive enhancement acquired through video games to a technique that is fundamentally different and contributed to the first steps involved in understanding the benefits of 3D-MOT as a cognitive enhancer.

References

Ackerman, P. L., Kanfer, R., & Calderwood, C. (2010). Use it or lose it? Wii brain exercise practice and reading for domain knowledge. *Psychology and aging, 25*(4), 753-766. doi: 10.1037/a0019277

Alnaes, D., Sneve, M. H., Richard, G., Skatun, K. C., Kaufmann, T., Nordvik, J. E., . . . Westlye, L. T. (2015). Functional connectivity indicates differential roles for the intraparietal sulcus and the superior parietal lobule in multiple object tracking. *NeuroImage, 123*, 129-137. doi: 10.1016/j.neuroimage.2015.08.029

Alvarez, G. A., & Cavanagh, P. (2005). Independent resources for attentional tracking in the left and right visual hemifields. *Psychological science, 16*(8), 637-643. doi: 10.1111/j.1467-9280.2005.01587.x

Anguera, J. A., Boccanfuso, J., Rintoul, J. L., Al-Hashimi, O., Faraji, F., Janowich, J., . . . Gazzaley, A. (2013). Video game training enhances cognitive control in older adults. *Nature, 501*(7465), 97-101. doi: 10.1038/nature12486

Arble, E., Kuentzel, J., & Barnett, D. (2014). Convergent validity of the Integrated Visual and Auditory Continuous Performance Test (IVA+Plus): associations with working memory, processing speed, and behavioral ratings. *Archives of clinical neuropsychology, 29*(3), 300-312. doi: 10.1093/arclin/acu006

Arns, M., Heinrich, H., & Strehl, U. (2014). Evaluation of neurofeedback in ADHD: the long and winding road. *Biological psychology, 95*, 108-115. doi: 10.1016/j.biopsycho.2013.11.013

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., . . . Vital Elderly Study, G. (2002). Effects of cognitive training interventions with older adults: a randomized controlled trial. *Jama, 288*(18), 2271-2281.

Baniqued, P. L., Kranz, M. B., Voss, M. W., Lee, H., Cosman, J. D., Severson, J., & Kramer, A. F. (2014). Cognitive training with casual video games: points to consider. *Frontiers in psychology, 4*, 1010. doi: 10.3389/fpsyg.2013.01010

Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological bulletin, 128*(4), 612-637.

Baroncelli, L., Braschi, C., Spolidoro, M., Begenisic, T., Maffei, L., & Sale, A. (2011). Brain plasticity and disease: a matter of inhibition. *Neural plasticity, 2011*, 286073. doi: 10.1155/2011/286073

Barry, R. J., Clarke, A. R., Hajos, M., McCarthy, R., Selikowitz, M., & Dupuy, F. E. (2010). Resting-state EEG gamma activity in children with attention-deficit/hyperactivity disorder. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology, 121*(11), 1871-1877. doi: 10.1016/j.clinph.2010.04.022

Barry, R. J., Clarke, A. R., & Johnstone, S. J. (2003). A review of electrophysiology in attention-deficit/hyperactivity disorder: I. Qualitative and quantitative electroencephalography. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology, 114*(2), 171-183.

Basak, C., Boot, W. R., Voss, M. W., & Kramer, A. F. (2008). Can training in a real-time strategy video game attenuate cognitive decline in older adults? *Psychology and aging, 23*(4), 765-777. doi: 10.1037/a0013494

Bavelier, D., Green, C. S., Han, D. H., Renshaw, P. F., Merzenich, M. M., & Gentile, D. A. (2011). Brains on video games. *Nature reviews. Neuroscience, 12*(12), 763-768. doi: 10.1038/nrn3135

Benson, P. (2001). The hawthorne effect. *The Corsini encyclopedia of psychology and behavioral science, 3*.

Berardi, N., Pizzorusso, T., & Maffei, L. (2000). Critical periods during sensory development. *Current opinion in neurobiology, 10*(1), 138-145.

Berry, A. S., Zanto, T. P., Clapp, W. C., Hardy, J. L., Delahunt, P. B., Mahncke, H. W., & Gazzaley, A. (2010). The influence of perceptual training on working memory in older adults. *PloS one, 5*(7), e11537. doi: 10.1371/journal.pone.0011537

Blacker, K. J., & Curby, K. M. (2013). Enhanced visual short-term memory in action video game players. *Attention, perception & psychophysics, 75*(6), 1128-1136. doi: 10.3758/s13414-013-0487-0

Boot, W. R., Basak, C., Erickson, K. I., Neider, M., Simons, D. J., Fabiani, M., . . . Kramer, A. F. (2010). Transfer of skill engendered by complex task training under conditions of variable priority. *Acta psychologica, 135*(3), 349-357. doi: 10.1016/j.actpsy.2010.09.005

Boot, W. R., & Kramer, A. F. (2014). The brain-games conundrum: does cognitive training really sharpen the mind? *Cerebrum : the Dana forum on brain science, 2014*, 15.

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta psychologica, 129*(3), 387-398. doi: 10.1016/j.actpsy.2008.09.005

Boroojerdi, B., Phipps, M., Kopylev, L., Wharton, C. M., Cohen, L. G., & Grafman, J. (2001). Enhancing analogic reasoning with rTMS over the left prefrontal cortex. *Neurology, 56*(4), 526-528.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience and school*. Washington, DC: National Academy Press.

Brickenkamp, R., & Zillmer, E. (1998). *The d2 Test of Attention.* . Toronto: Hogrefe & Huber Publishers.

Buckner, R. L., Andrews-Hanna, J. R., & Schacter, D. L. (2008). The brain's default network: anatomy, function, and relevance to disease. *Annals of the New York Academy of Sciences, 1124*, 1-38. doi: 10.1196/annals.1440.011

CGA. (2014). Towards The Global Games Market in 2017: A broad look at market growth by screen & region - Casual Games Sector Report. Retrieved September 30 2015, from https://s3.amazonaws.com/CGA_Report/CCNewzooSpringReport-pages.pdf

Chen, A. C., Feng, W., Zhao, H., Yin, Y., & Wang, P. (2008). EEG default mode network in the human brain: spectral regional field powers. *NeuroImage, 41*(2), 561-574. doi: 10.1016/j.neuroimage.2007.12.064

Cooper, A. C., Humphreys, G. W., Hulleman, J., Praamstra, P., & Georgeson, M. (2004). Transcranial magnetic stimulation to right parietal cortex modifies the attentional blink. *Experimental brain research, 155*(1), 24-29. doi: 10.1007/s00221-003-1697-9

Culham, J. C., Cavanagh, P., & Kanwisher, N. G. (2001). Attention response functions: characterizing brain areas using fMRI activation during parametric variations of attentional load. *Neuron, 32*(4), 737-745.

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual review of neuroscience, 18*, 193-222. doi: 10.1146/annurev.ne.18.030195.001205

Donchin, E. (1989). The learning strategies project: Introductory remarks. *Acta psychologica, 71*(1–3), 1-15. doi: http://dx.doi.org/10.1016/0001-6918(89)90002-4

Donohue, S. E., James, B., Eslick, A. N., & Mitroff, S. R. (2012). Cognitive pitfall! Videogame players are not immune to dual-task costs. *Attention, perception & psychophysics, 74*(5), 803-809. doi: 10.3758/s13414-012-0323-y

Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: changes in grey matter induced by training. *Nature, 427*(6972), 311-312. doi: 10.1038/427311a

Draganski, B., & May, A. (2008). Training-induced structural changes in the adult human brain. *Behavioural brain research, 192*(1), 137-142. doi: 10.1016/j.bbr.2008.02.015

Dye, M. W., Green, C. S., & Bavelier, D. (2009). The development of attention skills in action video game players. *Neuropsychologia, 47*(8-9), 1780-1789. doi: 10.1016/j.neuropsychologia.2009.02.002

Eriksen, B., & Eriksen, C. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics, 16*(1), 143-149. doi: 10.3758/BF03203267

ESA. (2015). Essential facts about the computer and video game industry. Retrieved October 2015, from http://www.theesa.com/wp-content/uploads/2015/04/ESA-Essential-Facts-2015.pdf

Faubert, J. (2013). Professional athletes have extraordinary skills for rapidly learning complex and neutral dynamic visual scenes. *Scientific reports, 3*, 1154. doi: 10.1038/srep01154

Faubert, J., & Allard, R. (2013). Stereoscopy benefits processing of dynamic visual scenes by disambiguating object occlusions. *Journal of vision, 13*(9), 1292.

Faubert, J., & Sidebottom, L. (2012). Perceptual-Cognitive Training of Athletes. *Journal of Clinical Sports Psychology, 6*, 85-102.

Feria, C. S. (2012). The effects of distractors in multiple object tracking are modulated by the similarity of distractor and target features. *Perception, 41*(3), 287-304.

Franceschini, S., Gori, S., Ruffino, M., Viola, S., Molteni, M., & Facoetti, A. (2013). Action video games make dyslexic children read better. *Current biology : CB, 23*(6), 462-466. doi: 10.1016/j.cub.2013.01.044

FTC. (2016). Lumosity to Pay $2 Million to Settle FTC Deceptive Advertising Charges for Its “Brain Training” Program. Retrieved February, 2016, from https://http://www.ftc.gov/news-events/press-releases/2016/01/lumosity-pay-2-million-settle-ftc-deceptive-advertising-charges

Gobet, F., Johnston, S. J., Ferrufino, G., Johnston, M., Jones, M. B., Molyneux, A., . . . Weeden, L. (2014). "No level up!": no effects of video game specialization and expertise on cognitive performance. *Frontiers in psychology, 5*, 1337. doi: 10.3389/fpsyg.2014.01337

Gomez-Pinilla, F. (2011). Collaborative effects of diet and exercise on cognitive enhancement. *Nutrition and health, 20*(3-4), 165-169.

Grabbe, J. W. (2011). Sudoku and Working Memory Performance for Older Adults. *Activities, Adaptation & Aging, 35*(3), 241-254. doi: 10.1080/01924788.2011.596748

Green, & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*(6939), 534-537. doi: 10.1038/nature01647

Green, & Bavelier, D. (2006a). Enumeration versus multiple object tracking: the case of action video game players. *Cognition, 101*(1), 217-245. doi: 10.1016/j.cognition.2005.10.004

Green, S., & Bavelier, D. (2006b). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of experimental psychology. Human perception and performance, 32*(6), 1465-1478. doi: 10.1037/0096-1523.32.6.1465

Green, S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological science, 18*(1), 88-94. doi: 10.1111/j.1467-9280.2007.01853.x

Green, S., Pouget, A., & Bavelier, D. (2010). Improved probabilistic inference as a general learning mechanism with action video games. *Current biology : CB, 20*(17), 1573-1579. doi: 10.1016/j.cub.2010.07.040

Gruber, T., Muller, M. M., & Keil, A. (2002). Modulation of induced gamma band responses in a perceptual learning task in the human EEG. *Journal of cognitive neuroscience, 14*(5), 732-744. doi: 10.1162/08989290260138636

Gruber, T., Muller, M. M., Keil, A., & Elbert, T. (1999). Selective visual-spatial attention alters induced gamma band responses in the human EEG. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology, 110*(12), 2074-2085.

Haier, R. J., Karama, S., Leyba, L., & Jung, R. E. (2009). MRI assessment of cortical thickness and functional activity changes in adolescent girls following three months of practice on a visual-spatial task. *BMC research notes, 2*, 174. doi: 10.1186/1756-0500-2-174

Hermens, D. F., Soei, E. X., Clarke, S. D., Kohn, M. R., Gordon, E., & Williams, L. M. (2005). Resting EEG theta activity predicts cognitive performance in attention-deficit hyperactivity disorder. *Pediatric neurology, 32*(4), 248-256. doi: 10.1016/j.pediatrneurol.2004.11.009

Huster, R. J., Debener, S., Eichele, T., & Herrmann, C. S. (2012). Methods for simultaneous EEG-fMRI: an introductory review. *The Journal of neuroscience : the official journal of the Society for Neuroscience, 32*(18), 6053-6060. doi: 10.1523/JNEUROSCI.0447-12.2012

Irons, J. L., Remington, R. W., & McLean, J. P. (2011). Not so fast: Rethinking the effects of action video games on attentional capacity. *Australian Journal of Psychology, 63*(4), 224-231. doi: 10.1111/j.1742-9536.2011.00001.x

Ishii, R., Shinosaki, K., Ukai, S., Inouye, T., Ishihara, T., Yoshimine, T., . . . Takeda, M. (1999). Medial prefrontal cortex generates frontal midline theta rhythm. *Neuroreport, 10*(4), 675-679.

Jak, A. J., Seelye, A. M., & Jurick, S. M. (2013). Crosswords to computers: a critical review of popular approaches to cognitive enhancement. *Neuropsychology review, 23*(1), 13-26. doi: 10.1007/s11065-013-9226-5

Jensen, O., Kaiser, J., & Lachaux, J. P. (2007). Human gamma-frequency oscillations associated with attention and memory. *Trends in neurosciences, 30*(7), 317-324. doi: 10.1016/j.tins.2007.05.001

Jensen, O., & Tesche, C. D. (2002). Frontal theta activity in humans increases with memory load in a working memory task. *The European journal of neuroscience, 15*(8), 1395-1399.

Kato, P. M., Cole, S. W., Bradlyn, A. S., & Pollock, B. H. (2008). A video game improves behavioral outcomes in adolescents and young adults with cancer: a randomized trial. *Pediatrics, 122*(2), e305-317. doi: 10.1542/peds.2007-3134

Kellman, P. J., & Garrigan, P. (2009). Perceptual learning and human expertise. *Physics of life reviews, 6*(2), 53-84. doi: 10.1016/j.plrev.2008.12.001

Kessels, R. P., Van Zandvoort, M. J., Postma, A., Kappelle, L. J., & De Haan, E. H. (2000). The Corsi block-tapping task: standardization and normative data. *Applied neuropsychology, 7*(4), 252-258.

Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. *Brain research. Brain research reviews, 29*(2-3), 169-195.

Kohler, S., Paus, T., Buckner, R. L., & Milner, B. (2004). Effects of left inferior prefrontal stimulation on episodic memory formation: a two-stage fMRI-rTMS study. *Journal of cognitive neuroscience, 16*(2), 178-188. doi: 10.1162/089892904322984490

Kramer, A., & Willis, S. (2003). Cognitive plasticity and aging. *The psychology of learning and motivation: Advances in research and theory, Vol. 43*, 267-302.

Kramer, A. F., & Erickson, K. I. (2007). Capitalizing on cortical plasticity: influence of physical activity on cognition and brain function. *Trends in cognitive sciences, 11*(8), 342-348. doi: 10.1016/j.tics.2007.06.009

Kupers, R., Chebat, D. R., Madsen, K. H., Paulson, O. B., & Ptito, M. (2010). Neural correlates of virtual route recognition in congenital blindness. *Proceedings of the National Academy of Sciences of the United States of America, 107*(28), 12716-12721. doi: 10.1073/pnas.1006199107

Leat, S. J., Li, W., & Epp, K. (1999). Crowding in central and eccentric vision: the effects of contour interaction and attention. *Investigative ophthalmology & visual science, 40*(2), 504-512.

Lee, H., Boot, W. R., Basak, C., Voss, M. W., Prakash, R. S., Neider, M., . . . Kramer, A. F. (2012). Performance gains from directed training do not transfer to untrained tasks. *Acta psychologica, 139*(1), 146-158. doi: 10.1016/j.actpsy.2011.11.003

Legault, I., Allard, R., & Faubert, J. (2013). Healthy older observers show equivalent perceptual-cognitive training benefits to young adults for multiple object tracking. *Frontiers in psychology, 4*, 323. doi: 10.3389/fpsyg.2013.00323

Legault, I., & Faubert, J. (2012). Perceptual-cognitive training improves biological motion perception: evidence for transferability of training in healthy aging. *Neuroreport, 23*(8), 469-473. doi: 10.1097/WNR.0b013e328353e48a

Levitt, H. (1971). Transformed up-down methods in psychoacoustics. *The Journal of the Acoustical Society of America, 49*(2), Suppl 2:467+.

Li, R. W., Ngo, C., Nguyen, J., & Levi, D. M. (2011). Video-game play induces plasticity in the visual system of adults with amblyopia. *PLoS biology, 9*(8), e1001135. doi: 10.1371/journal.pbio.1001135

Lindstedt, J. K., & Gray, W. D. (2015). Meta-T: Tetris as an experimental paradigm for cognitive skills research. *Behavior research methods*. doi: 10.3758/s13428-014-0547-y

Logothetis, N. K., & Pfeuffer, J. (2004). On the nature of the BOLD fMRI contrast mechanism. *Magnetic resonance imaging, 22*(10), 1517-1531. doi: 10.1016/j.mri.2004.10.018

Lototska, M. (2014). Dfc intelligence takes a look at Candy Crush Saga's Q1 performance Retrieved November, 2014, from http://gamesauce.org/news/?s=candy+crush

Lubar, J. F. (1991). Discourse on the development of EEG diagnostics and biofeedback for attention-deficit/hyperactivity disorders. *Biofeedback and self-regulation, 16*(3), 201-225.

Luber, B., Kinnunen, L. H., Rakitin, B. C., Ellsasser, R., Stern, Y., & Lisanby, S. H. (2007). Facilitation of performance in a working memory task with rTMS stimulation of the precuneus: frequency- and time-dependent effects. *Brain research, 1128*(1), 120-129. doi: 10.1016/j.brainres.2006.10.011

Luber, B., & Lisanby, S. H. (2014). Enhancement of human cognitive performance using transcranial magnetic stimulation (TMS). *NeuroImage, 85 Pt 3*, 961-970. doi: 10.1016/j.neuroimage.2013.06.007

MacLean, M. H., Arnell, K. M., & Cote, K. A. (2012). Resting EEG in alpha and beta bands predicts individual differences in attentional blink magnitude. *Brain and cognition, 78*(3), 218-229. doi: 10.1016/j.bandc.2011.12.010

Maclin, E. L., Mathewson, K. E., Low, K. A., Boot, W. R., Kramer, A. F., Fabiani, M., & Gratton, G. (2011). Learning to multitask: effects of video game practice on electrophysiological indices of attention and resource allocation. *Psychophysiology, 48*(9), 1173-1183. doi: 10.1111/j.1469-8986.2011.01189.x

Mahncke, H. W., Connor, B. B., Appelman, J., Ahsanuddin, O. N., Hardy, J. L., Wood, R. A., . . . Merzenich, M. M. (2006). Memory enhancement in healthy older adults using a brain plasticity-based training program: a randomized, controlled study. *Proceedings of the National Academy of Sciences of the United States of America, 103*(33), 12523-12528. doi: 10.1073/pnas.0605194103

Mann, C. A., Lubar, J. F., Zimmerman, A. W., Miller, C. A., & Muenchen, R. A. (1992). Quantitative analysis of EEG in boys with attention-deficit-hyperactivity disorder: controlled study with clinical implications. *Pediatric neurology, 8*(1), 30-36.

Mathewson, K. E., Basak, C., Maclin, E. L., Low, K. A., Boot, W. R., Kramer, A. F., . . . Gratton, G. (2012). Different slopes for different folks: alpha and delta EEG power predict subsequent video game learning rate and improvements in cognitive control tasks. *Psychophysiology, 49*(12), 1558-1570. doi: 10.1111/j.1469-8986.2012.01474.x

McKinley, R. A., McIntire, L. K., & Funke, M. A. (2011). Operator selection for unmanned aerial systems: comparing video game players and pilots. *Aviation, space, and environmental medicine, 82*(6), 635-642.

Merzenich, M. (1998). Long-term change of mind. *Science, 282*(5391), 1062-1063.

Monastra, V. J., Lubar, J. F., Linden, M., VanDeusen, P., Green, G., Wing, W., . . . Fenger, T. N. (1999). Assessing attention deficit hyperactivity disorder via quantitative electroencephalography: an initial validation study. *Neuropsychology, 13*(3), 424-433.

Monastra, V. J., Lynn, S., Linden, M., Lubar, J. F., Gruzelier, J., & LaVaque, T. J. (2005). Electroencephalographic biofeedback in the treatment of attention-deficit/hyperactivity disorder. *Applied psychophysiology and biofeedback, 30*(2), 95-114.

Murphy, K., & Spencer, A. (2009). Playing video-games does not make for better visual attention skills. *Journal of Articles in Support of the Null Hypothesis, 6*(1), 20.

Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Akitsuki, Y., Shigemune, Y., . . . Kawashima, R. (2012). Brain training game improves executive functions and processing speed in the elderly: a randomized controlled trial. *PloS one, 7*(1), e29676. doi: 10.1371/journal.pone.0029676

Nouchi, R., Taki, Y., Takeuchi, H., Hashizume, H., Nozawa, T., Kambara, T., . . . Kawashima, R. (2013). Brain training game boosts executive functions, working memory and processing speed in the young adults: a randomized controlled trial. *PloS one, 8*(2), e55518. doi: 10.1371/journal.pone.0055518

Oei, A. C., & Patterson, M. D. (2013). Enhancing cognition with video games: a multiple game training study. *PloS one, 8*(3), e58546. doi: 10.1371/journal.pone.0058546

Ogrim, G., Kropotov, J., & Hestad, K. (2012). The quantitative EEG theta/beta ratio in attention deficit/hyperactivity disorder and normal controls: sensitivity, specificity, and behavioral correlates. *Psychiatry research, 198*(3), 482-488. doi: 10.1016/j.psychres.2011.12.041

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: Gender effects in late adolescence. *Journal of Applied Developmental Psychology, 15*(1), 33-58.

Owen, A. M., Hampshire, A., Grahn, J. A., Stenton, R., Dajani, S., Burns, A. S., . . . Ballard, C. G. (2010). Putting brain training to the test. *Nature, 465*(7299), 775-778. doi: 10.1038/nature09042

Parsons, B., Magill, T., Boucher, A., Zhang, M., Zogbo, K., Berube, S., . . . Faubert, J. (2014). Enhancing Cognitive Function Using Perceptual-Cognitive Training. *Clinical EEG and neuroscience*. doi: 10.1177/1550059414563746

Piracetam. (2015). Piracetam vs Modafinil. Retrieved 12 September 2015, from http://piracetam.net/piracetam-vs-modafinil/

Ptito, M., Kupers, R., Lomber, S., & Pietrini, P. (2012). Sensory deprivation and brain plasticity. *Neural plasticity, 2012*, 810370. doi: 10.1155/2012/810370

Pylyshyn. (1994). Some primitive mechanisms of spatial attention. *Cognition, 50*(1-3), 363-384.

Pylyshyn, & Storm. (1988). Tracking multiple independent targets: evidence for a parallel tracking mechanism. *Spatial vision, 3*(3), 179-197.

Pylyshyn, Z. (1989). The role of location indexes in spatial perception: a sketch of the FINST spatial-index model. *Cognition, 32*(1), 65-97.

Rabipour, S., & Raz, A. (2012). Training the brain: fact and fad in cognitive and behavioral remediation. *Brain and cognition, 79*(2), 159-179. doi: 10.1016/j.bandc.2012.02.006

Raichle, M. E., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., & Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America, 98*(2), 676-682. doi: 10.1073/pnas.98.2.676

Raichle, M. E., & Snyder, A. Z. (2007). A default mode of brain function: a brief history of an evolving idea. *NeuroImage, 37*(4), 1083-1090; discussion 1097-1089. doi: 10.1016/j.neuroimage.2007.02.041

Ray, W. J., & Cole, H. W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science, 228*(4700), 750-752.

Romeas, T., Guldner, A., & Faubert, J. (2016). 3D-Multiple Object Tracking training task improves passing decision-making accuracy in soccer players. *Psychology of Sport and Exercise, 22*, 1-9. doi: http://dx.doi.org/10.1016/j.psychsport.2015.06.002

Romei, V., Driver, J., Schyns, P. G., & Thut, G. (2011). Rhythmic TMS over parietal cortex links distinct brain frequencies to global versus local visual processing. *Current biology : CB, 21*(4), 334-337. doi: 10.1016/j.cub.2011.01.035

Sabel, B. A., Henrich-Noack, P., Fedorov, A., & Gall, C. (2011). Vision restoration after brain and retina damage: the "residual vision activation theory". *Progress in brain research, 192*, 199-262. doi: 10.1016/B978-0-444-53355-5.00013-0

Sandberg, A., & Bostrom, N. (2006). Converging cognitive enhancements. *Annals of the New York Academy of Sciences, 1093*, 201-227. doi: 10.1196/annals.1382.015

Sanford, J. A., & Turner, A. (2009). *IVA+Plus Integrated Visual and Auditory Continous Performace Test: Interpretation Manual.*: BrainTrain Inc.

Scheeringa, R., Bastiaansen, M. C., Petersson, K. M., Oostenveld, R., Norris, D. G., & Hagoort, P. (2008). Frontal theta EEG activity correlates negatively with the default mode network in resting state. *International journal of psychophysiology : official journal of the International Organization of Psychophysiology, 67*(3), 242-251. doi: 10.1016/j.ijpsycho.2007.05.017

Schlickum, M., Hedman, L., Enochsson, L., Kjellin, A., & Fellander-Tsai, L. (2008). Transfer of systematic computer game training in surgical novices on performance in virtual reality image guided surgical simulators. *Studies in health technology and informatics, 132*, 210-215.

Sekuler, R., McLaughlin, C., & Yotsumoto, Y. (2008). Age-related changes in attentional tracking of multiple moving objects. *Perception, 37*(6), 867-876.

SharpBrains. (2013). Executive summary: Infographic on the digital brain health market 2012-2020. Retrieved July 28, 2015, from http://sharpbrains.com/executive-summary/

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: the case of video game players. *Applied Cognitive Psychology, 16*(1), 97-115. doi: 10.1002/acp.759

Snyder, S. M., & Hall, J. R. (2006). A meta-analysis of quantitative EEG power associated with attention-deficit hyperactivity disorder. *Journal of clinical neurophysiology : official publication of the American Electroencephalographic Society, 23*(5), 440-455. doi: 10.1097/01.wnp.0000221363.12503.78

Spence, I., & Feng, J. (2010). Video games and spatial cognition. *Review of General Psychology, 14*(2), 92-104. doi: 10.1037/a0019491

Sterman, M. B. (2000). EEG markers for attention deficit disorder: Pharmacological and neurofeedback applications. *Child Study Journal, 30*(1), 1-24.

Terlecki, M. S., Newcombe, N. S., & Little, M. (2008). Durable and generalized effects of spatial experience on mental rotation: gender differences in growth patterns. *Applied Cognitive Psychology, 22*(7), 996-1013. doi: 10.1002/acp.1420

Thompson, M., & Thompson, L. (2003). *The Neurofeedback Book: An Introduction to Basic Concepts in Applied Psychophysiology.* Wheat Ridge, Colorado USA: The Association for Applied Psychophysiology and BioFeedback.

Tiitinen, H., Sinkkonen, J., Reinikainen, K., Alho, K., Lavikainen, J., & Naatanen, R. (1993). Selective attention enhances the auditory 40-Hz transient response in humans. *Nature, 364*(6432), 59-60. doi: 10.1038/364059a0

Tinius, T. P. (2003). The intermediate visual and auditory continuous performance test as a neuropsychological measure. *Archives of clinical neuropsychology, 18*(2), 199-214.

Trick, Jaspers-Fayer, & Sethi. (2005). Multiple-object tracking in children: The "Catch the Spies" task. *Cognitive Development, 20*(3), 373-387. doi: http://dx.doi.org/10.1016/j.cogdev.2005.05.009

Trick, Perl, T., & Sethi, N. (2005). Age-related differences in multiple-object tracking. *The journals of gerontology. Series B, Psychological sciences and social sciences, 60*(2), P102-105.

van Praag, H., Schinder, A. F., Christie, B. R., Toni, N., Palmer, T. D., & Gage, F. H. (2002). Functional neurogenesis in the adult hippocampus. *Nature, 415*(6875), 1030-1034. doi: 10.1038/4151030a

Vaynman, S., & Gomez-Pinilla, F. (2006). Revenge of the "sit": how lifestyle impacts neuronal and cognitive health through molecular systems that interface energy metabolism with neuronal plasticity. *Journal of neuroscience research, 84*(4), 699-715. doi: 10.1002/jnr.20979

Vivar, C., Potter, M. C., & van Praag, H. (2013). All about running: synaptic plasticity, growth factors and adult hippocampal neurogenesis. *Current topics in behavioral neurosciences, 15*, 189-210. doi: 10.1007/7854_2012_220

Wechsler, D. (1997). *WAIS-III administration and scoring manual.* San Antonio, TX: Psychological Corporation.

Wibral, M., Bledowski, C., & Turi, G. (2010). Integration of separately recorded EEG/MEG and fMRI data. *Simultaneous EEG and fMRI: recording, analysis, and application (Ullsperger M, Debener S, eds)*, 209-234.

Wiesel, T. N., & Hubel, D. H. (1963). Single-Cell Responses in Striate Cortex of Kittens Deprived of Vision in One Eye. *Journal of neurophysiology, 26*, 1003-1017.

Willis, S. L., Tennstedt, S. L., Marsiske, M., Ball, K., Elias, J., Koepke, K. M., . . . Group, A. S. (2006). Long-term effects of cognitive training on everyday functional outcomes in older adults. *Jama, 296*(23), 2805-2814. doi: 10.1001/jama.296.23.2805

Wilms, I. L., Petersen, A., & Vangkilde, S. (2013). Intensive video gaming improves encoding speed to visual short-term memory in young male adults. *Acta psychologica, 142*(1), 108-118. doi: 10.1016/j.actpsy.2012.11.003

Yamanaka, K., Yamagata, B., Tomioka, H., Kawasaki, S., & Mimura, M. (2010). Transcranial magnetic stimulation of the parietal cortex facilitates spatial working memory: near-infrared spectroscopy study. *Cerebral cortex, 20*(5), 1037-1045. doi: 10.1093/cercor/bhp163

Yantis, S. (1992). Multielement visual tracking: attention and perceptual organization. *Cognitive psychology, 24*(3), 295-340.

Zhang, P. (2014). Infographic: celebrating 50 million Lumosity members. Retrieved July 28, 2015, from http://blog.lumosity.com/50millioninfographic/

Annex

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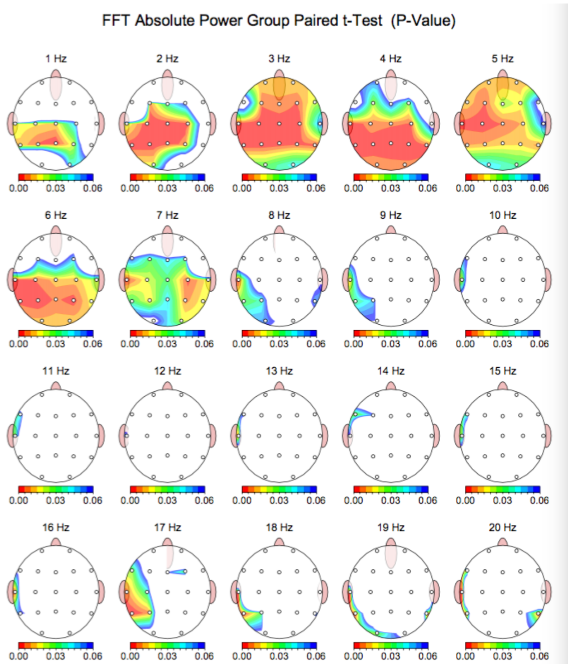
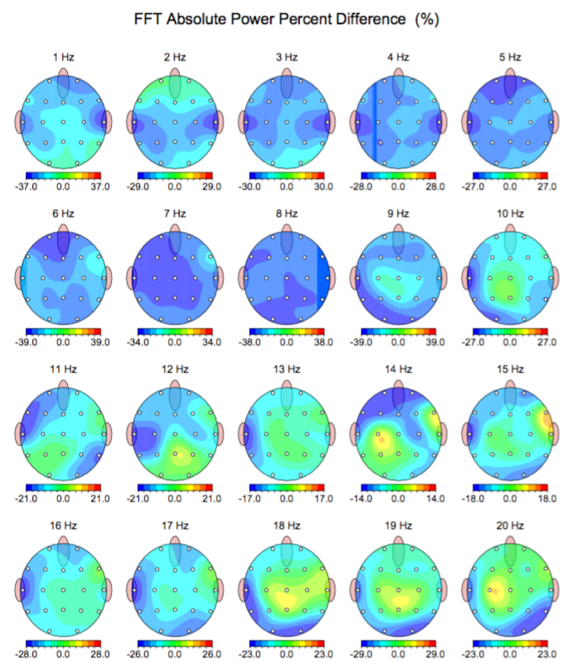
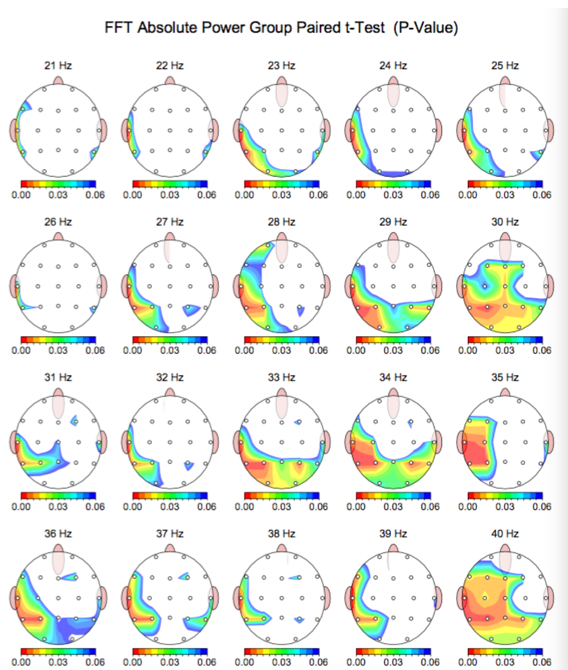
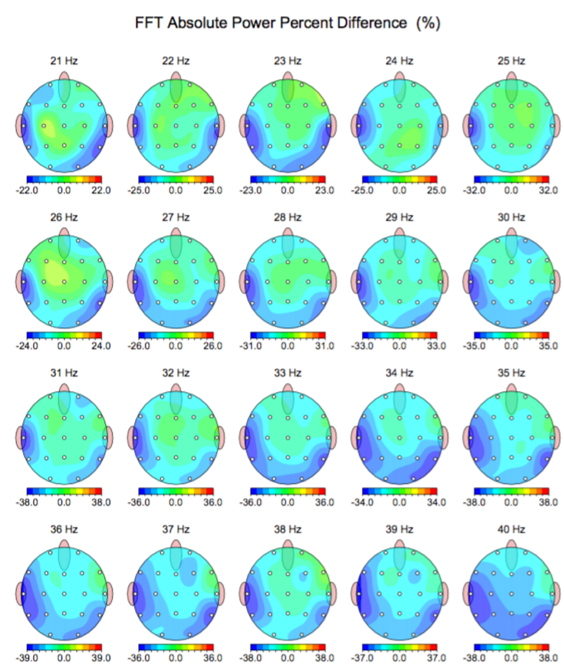
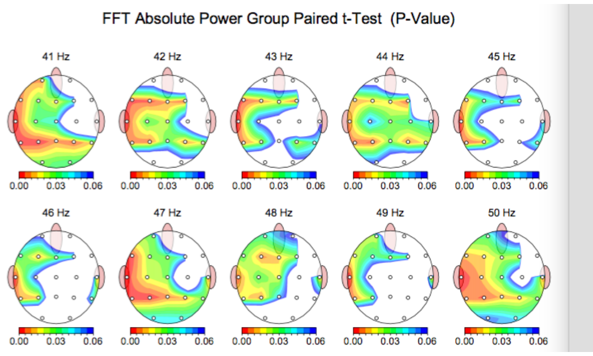
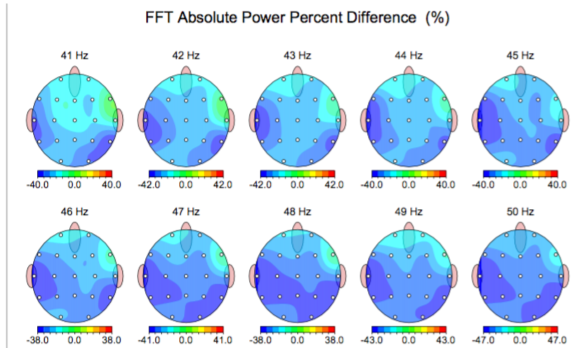

FFT Absolute Power Group Paired t-Test (P-Value)

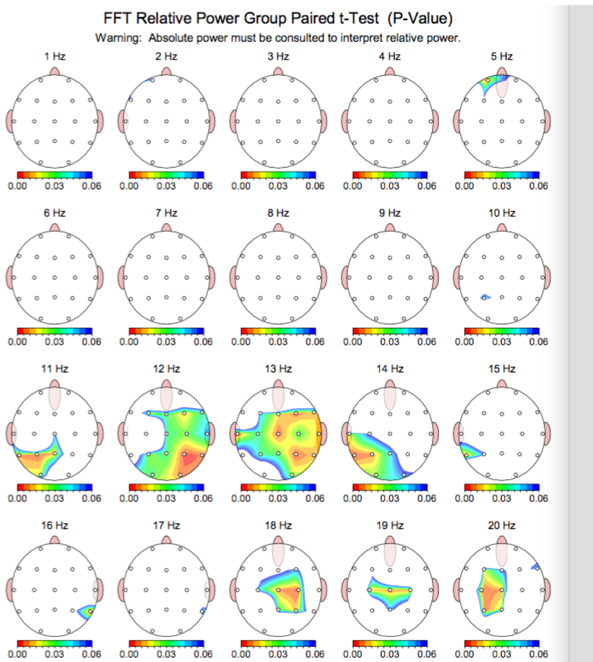

FFT Absolute Power Percent Difference (%)

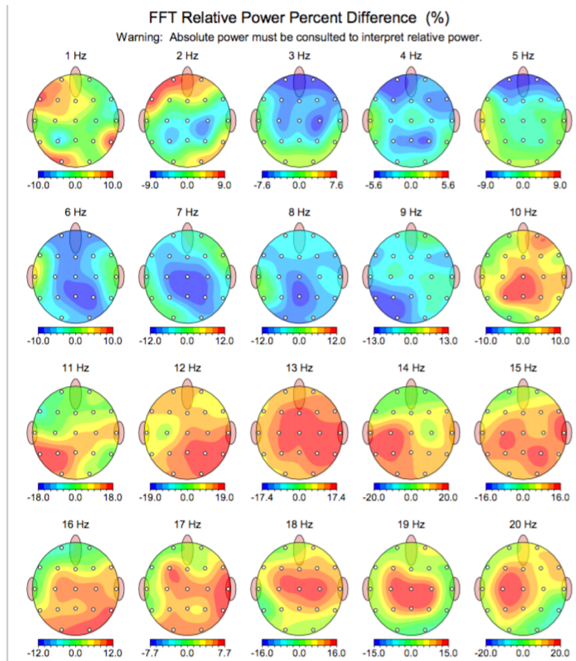

FFT Absolute Power Group Paired t-Test (P-Value)

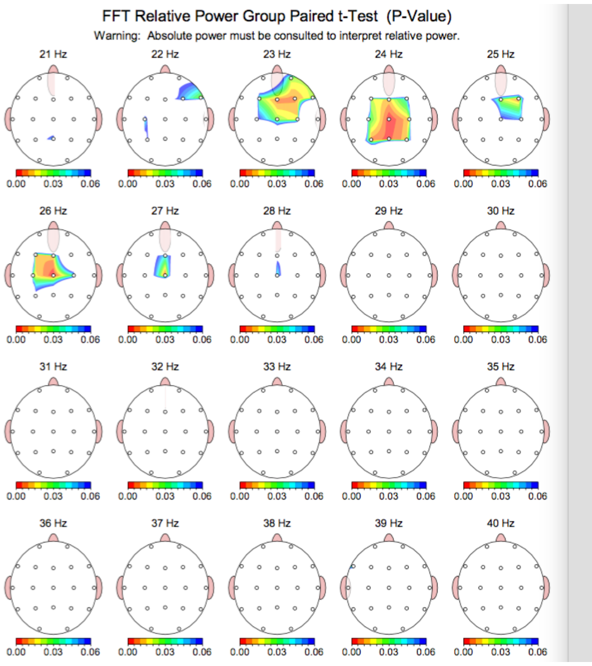

FFT Absolute Power Percent Difference (%)


FFT Absolute Power Group Paired t-Test (P-Value)
41 Hz 42 Hz 43 Hz 44 Hz 45 Hz
46 Hz 47 Hz 48 Hz 49 Hz 50 Hz
0.00 0.03 0.06


FFT Absolute Power Percent Difference (%)
41 Hz 42 Hz 43 Hz 44 Hz 45 Hz
46 Hz 47 Hz 48 Hz 49 Hz 50 Hz


FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz
0.00 0.03 0.06


FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz


FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
21 Hz
22 Hz
23 Hz
24 Hz
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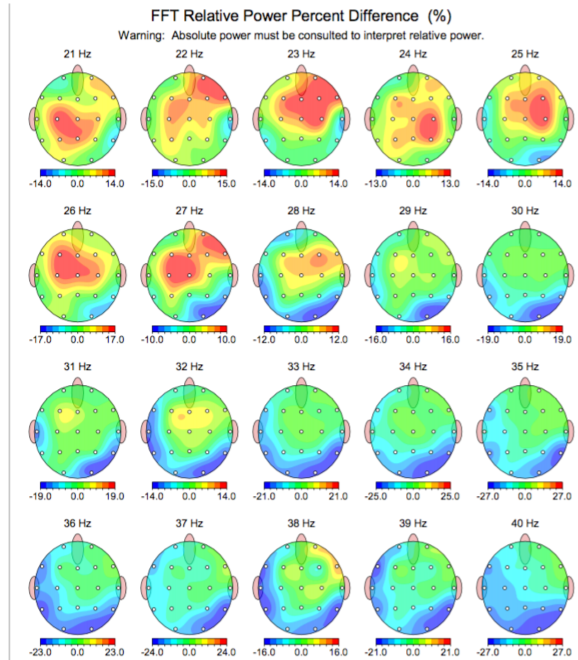
31 Hz
32 Hz
33 Hz
34 Hz
35 Hz
36 Hz
37 Hz
38 Hz
39 Hz
40 Hz


FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
21 Hz
22 Hz
23 Hz
24 Hz
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26 Hz
27 Hz
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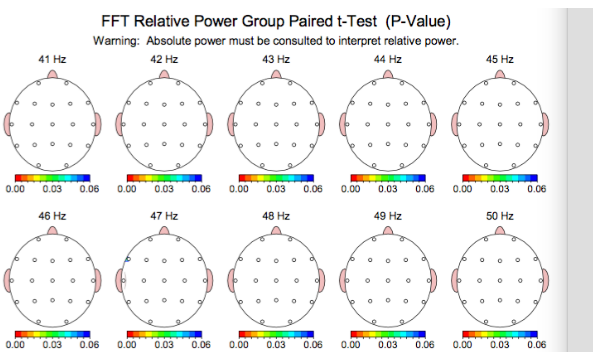
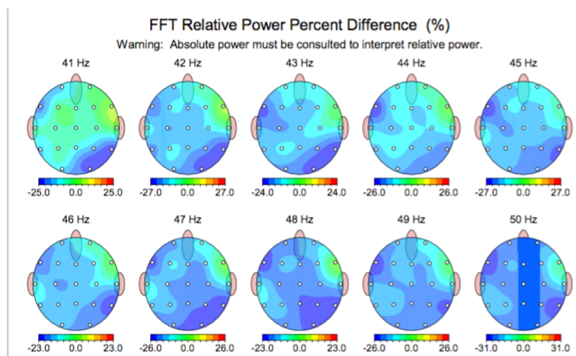
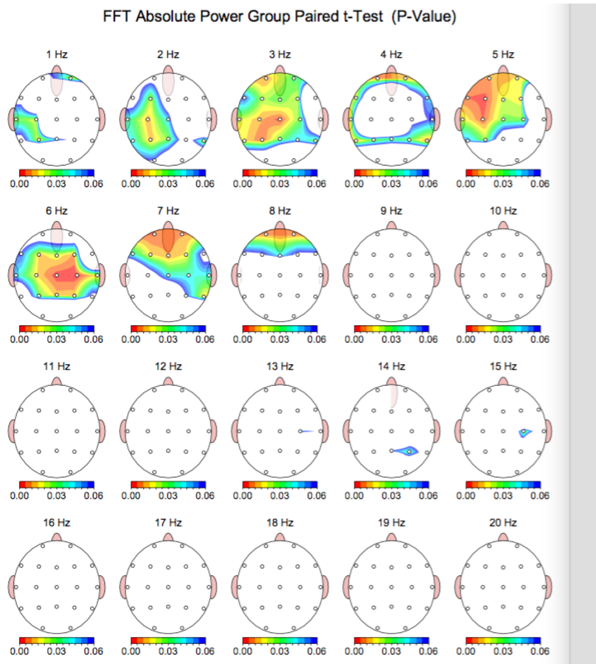
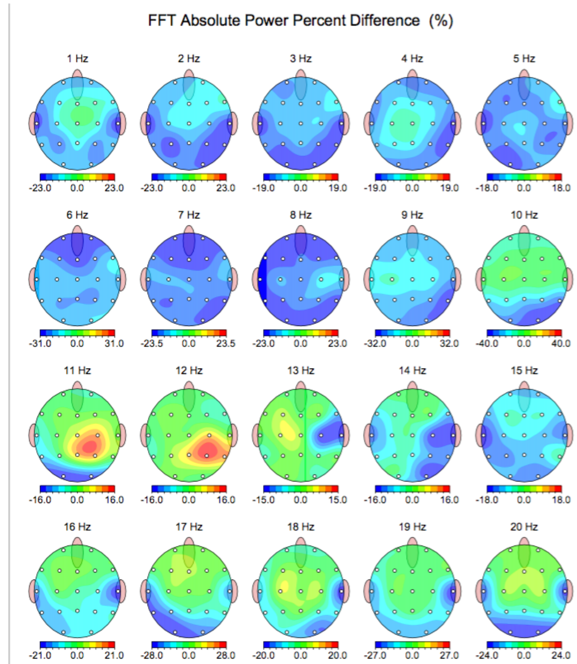
37 Hz
38 Hz
39 Hz
40 Hz

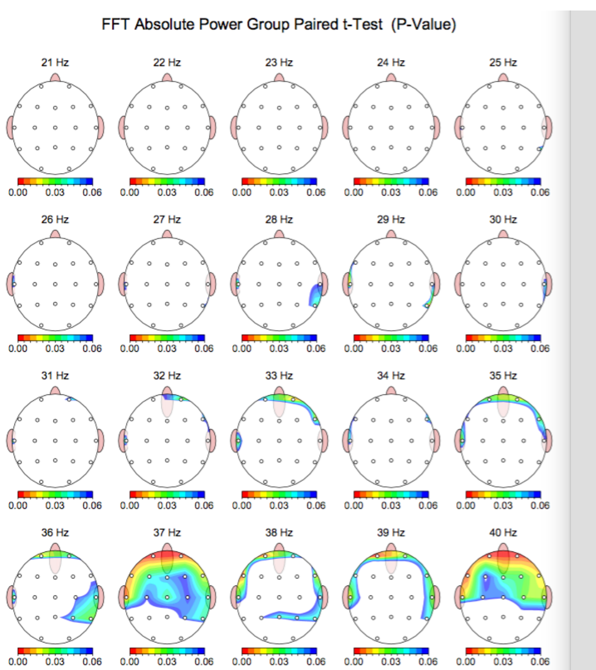

FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz
42 Hz
43 Hz
44 Hz
45 Hz
46 Hz
47 Hz
48 Hz
49 Hz
50 Hz

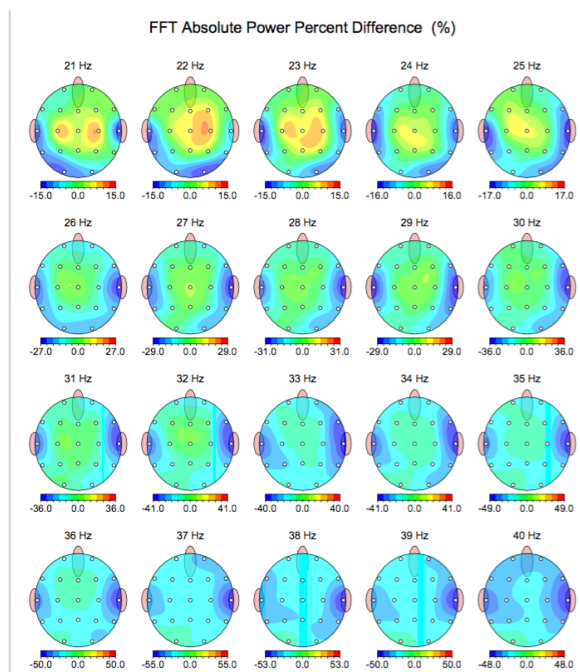

FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz
42 Hz
43 Hz
44 Hz
45 Hz
46 Hz
47 Hz
48 Hz
49 Hz
50 Hz

NT EC


FFT Absolute Power Group Paired t-Test (P-Value)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz
0.00 0.03 0.06


FFT Absolute Power Percent Difference (%)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
-23.0 0.0 23.0
-23.0 0.0 23.0
-19.0 0.0 19.0
-19.0 0.0 19.0
-18.0 0.0 18.0
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
-31.0 0.0 31.0
-23.5 0.0 23.5
-23.0 0.0 23.0
-32.0 0.0 32.0
-40.0 0.0 40.0
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
-16.0 0.0 16.0
-16.0 0.0 16.0
-15.0 0.0 15.0
-16.0 0.0 16.0
-18.0 0.0 18.0
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz
-21.0 0.0 21.0
-28.0 0.0 28.0
-20.0 0.0 20.0
-27.0 0.0 27.0
-24.0 0.0 24.0


FFT Absolute Power Group Paired t-Test (P-Value)
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz
0.00 0.03 0.06


FFT Absolute Power Percent Difference (%)
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
-15.0 0.0 15.0
-15.0 0.0 15.0
-15.0 0.0 15.0
-16.0 0.0 16.0
-17.0 0.0 17.0
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
-27.0 0.0 27.0
-29.0 0.0 29.0
-31.0 0.0 31.0
-29.0 0.0 29.0
-36.0 0.0 36.0
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
-36.0 0.0 36.0
-41.0 0.0 41.0
-40.0 0.0 40.0
-41.0 0.0 41.0
-49.0 0.0 49.0
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz
-50.0 0.0 50.0
-55.0 0.0 55.0
-53.0 0.0 53.0
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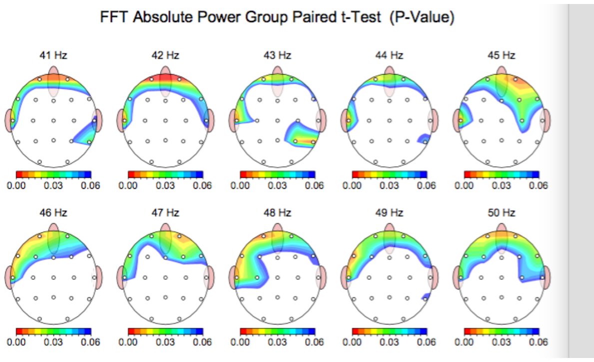
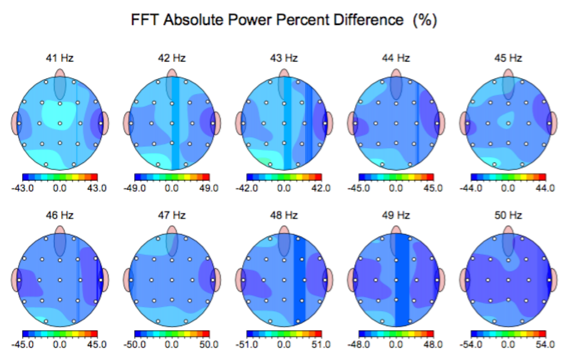
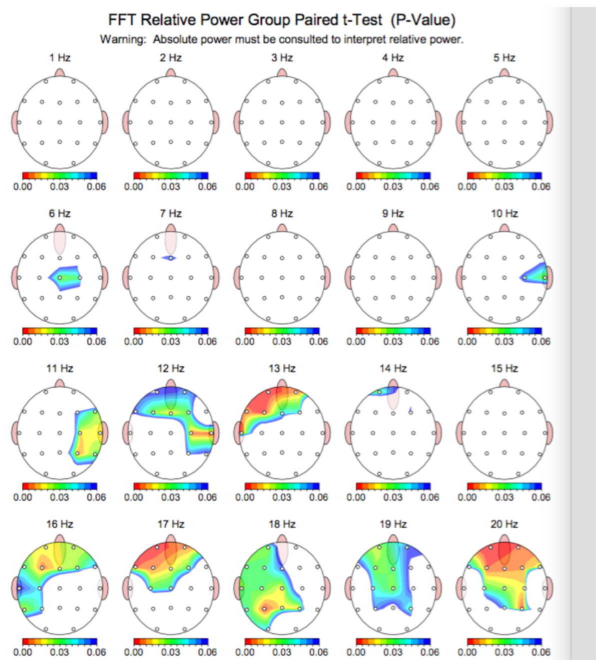
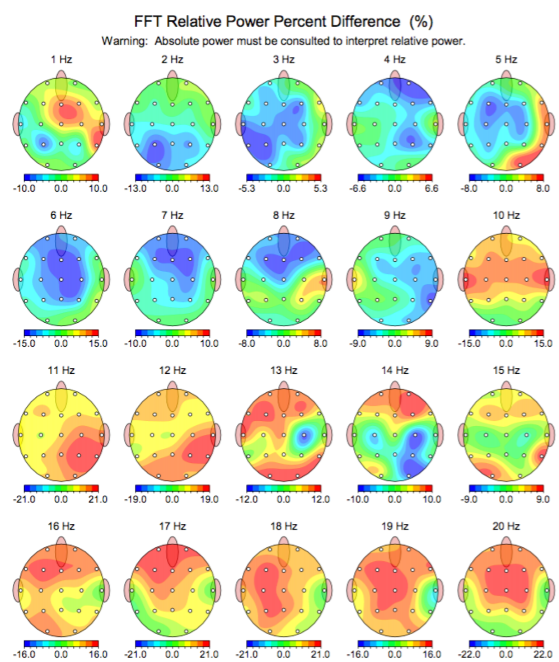
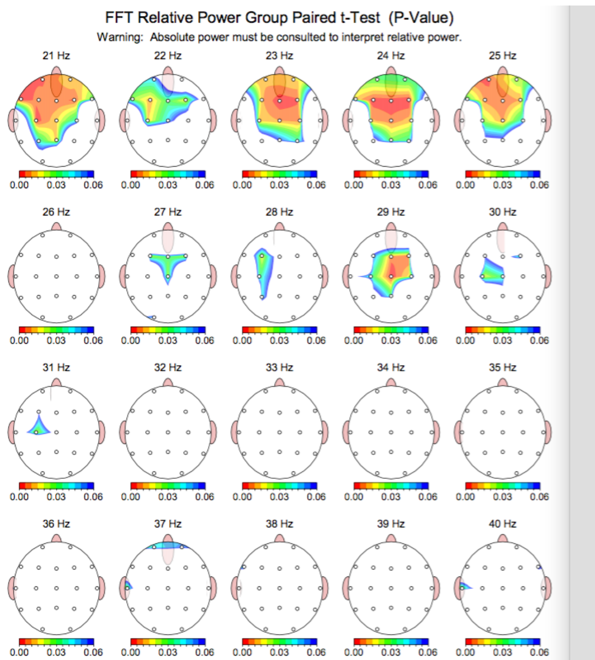
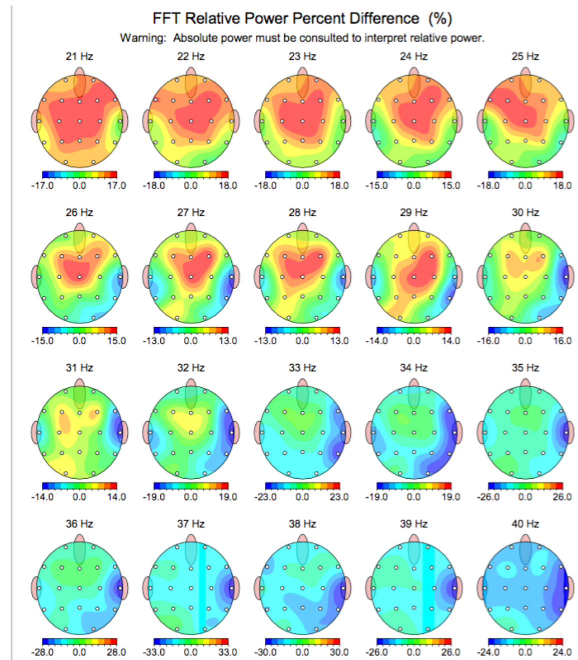

FFT Absolute Power Group Paired t-Test (P-Value)

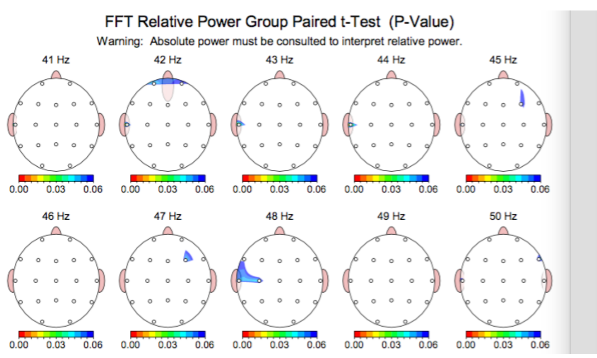

FFT Absolute Power Percent Difference (%)

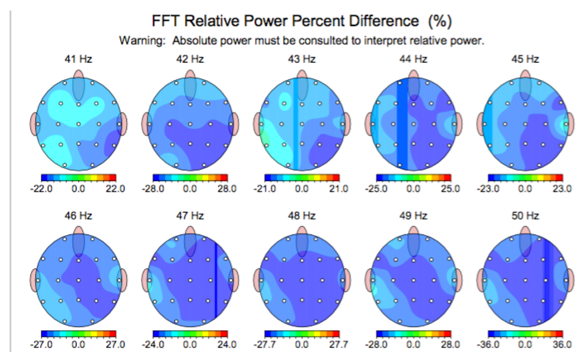

FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.


FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.

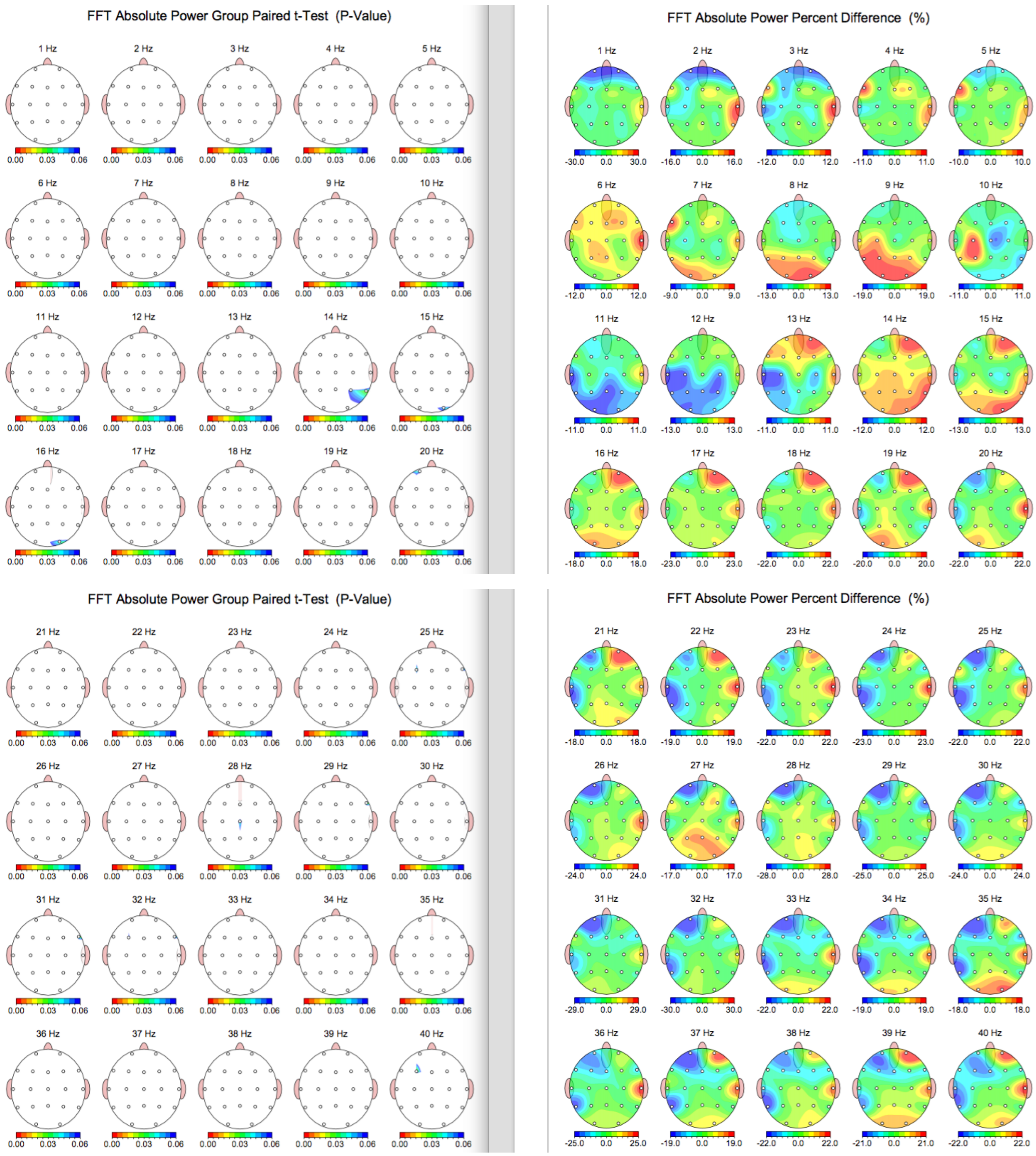

FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz
0.00 0.03 0.06

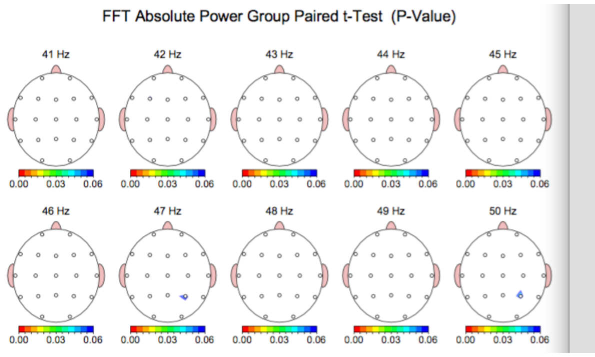

FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz

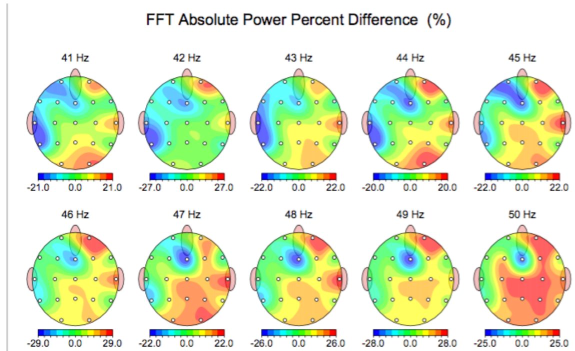

FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz 42 Hz 43 Hz 44 Hz 45 Hz
46 Hz 47 Hz 48 Hz 49 Hz 50 Hz
0.00 0.03 0.06

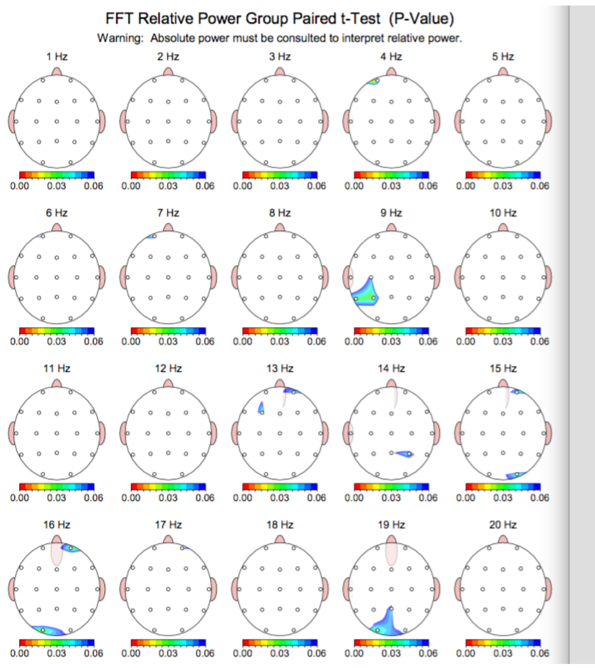

FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz 42 Hz 43 Hz 44 Hz 45 Hz
46 Hz 47 Hz 48 Hz 49 Hz 50 Hz

CD EO


FFT Absolute Power Group Paired t-Test (P-Value)
FFT Absolute Power Percent Difference (%)
FFT Absolute Power Group Paired t-Test (P-Value)
FFT Absolute Power Percent Difference (%)


FFT Absolute Power Group Paired t-Test (P-Value)


FFT Absolute Power Percent Difference (%)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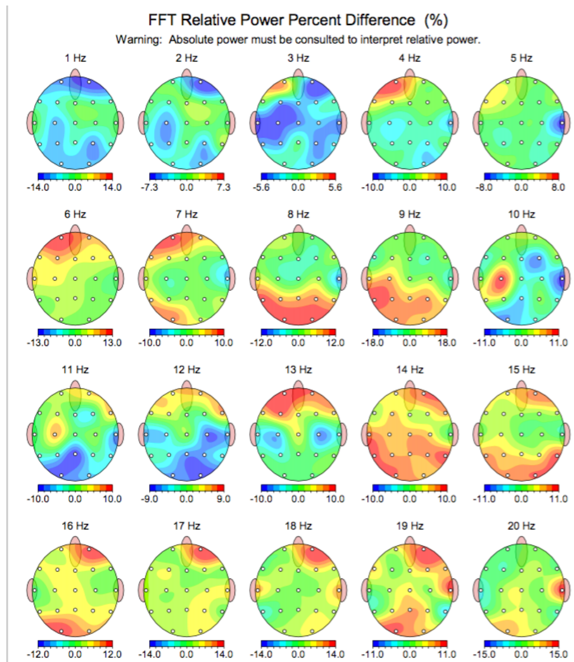
Warning: Absolute power must be consulted to interpret relative power.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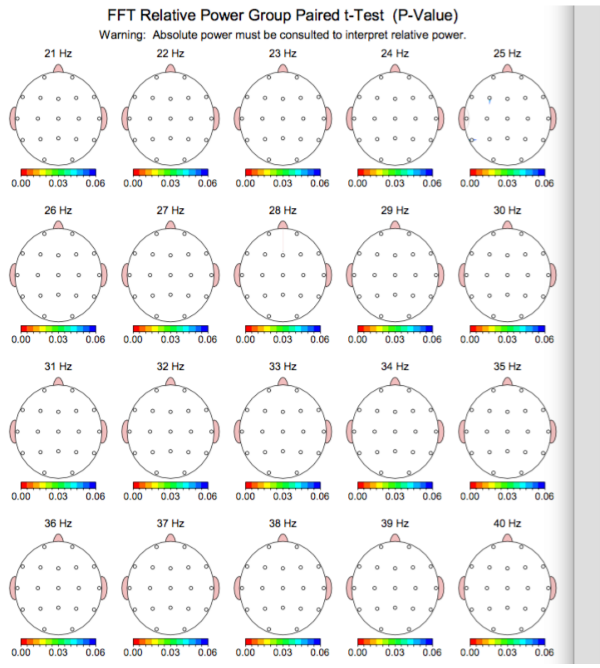
FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
21 Hz
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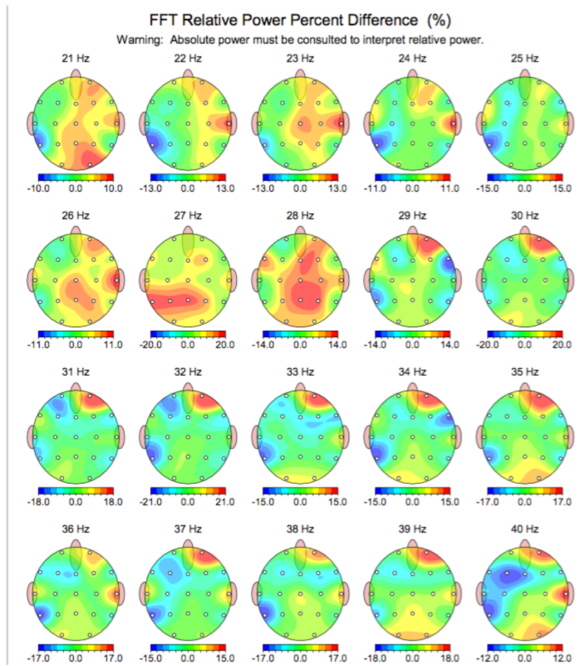
36 Hz
37 Hz
38 Hz
39 Hz
40 Hz
0.00 0.03 0.06


FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
21 Hz
22 Hz
23 Hz
24 Hz
25 Hz
-10.0 0.0 10.0
-13.0 0.0 13.0
-13.0 0.0 13.0
-11.0 0.0 11.0
-15.0 0.0 15.0
26 Hz
27 Hz
28 Hz
29 Hz
30 Hz
-11.0 0.0 11.0
-20.0 0.0 20.0
-14.0 0.0 14.0
-14.0 0.0 14.0
-20.0 0.0 20.0
31 Hz
32 Hz
33 Hz
34 Hz
35 Hz
-18.0 0.0 18.0
-21.0 0.0 21.0
-15.0 0.0 15.0
-15.0 0.0 15.0
-17.0 0.0 17.0
36 Hz
37 Hz
38 Hz
39 Hz
40 Hz
-17.0 0.0 17.0
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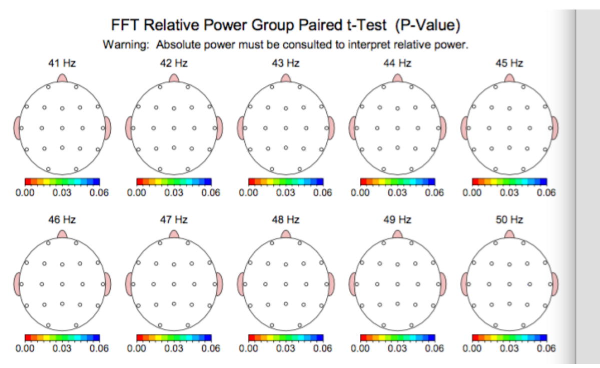
-18.0 0.0 18.0
-12.0 0.0 12.0


FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz
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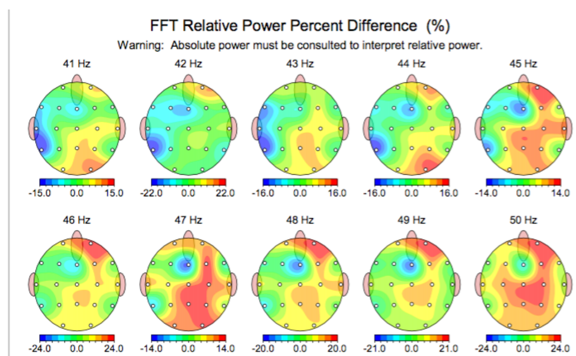
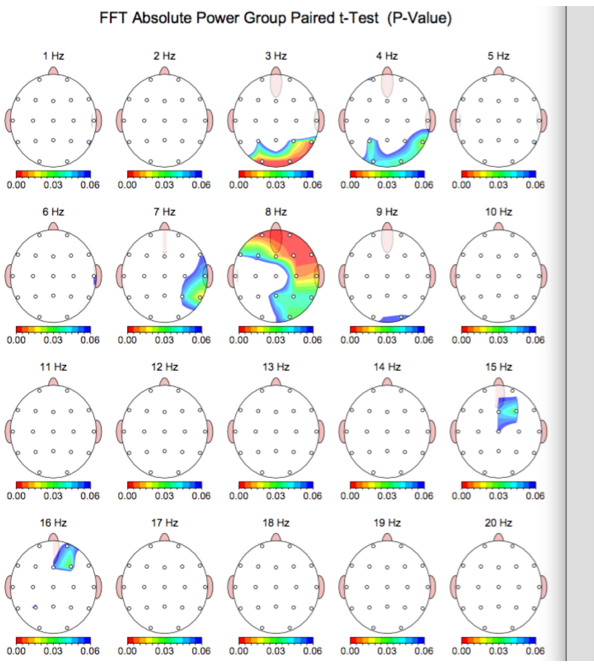
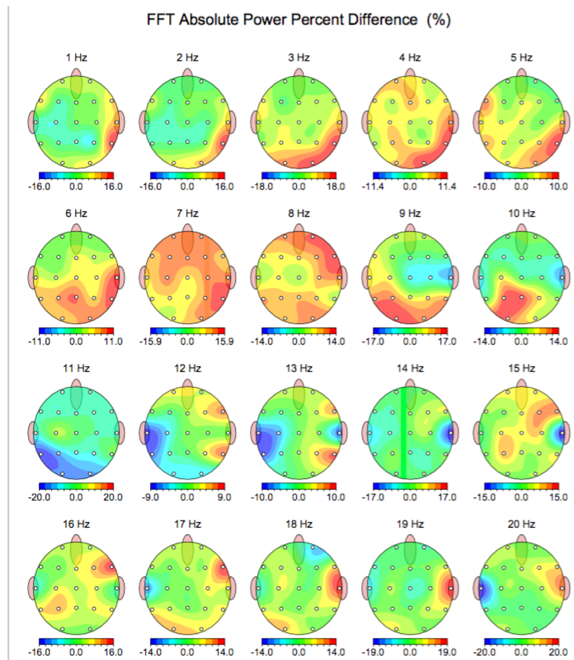
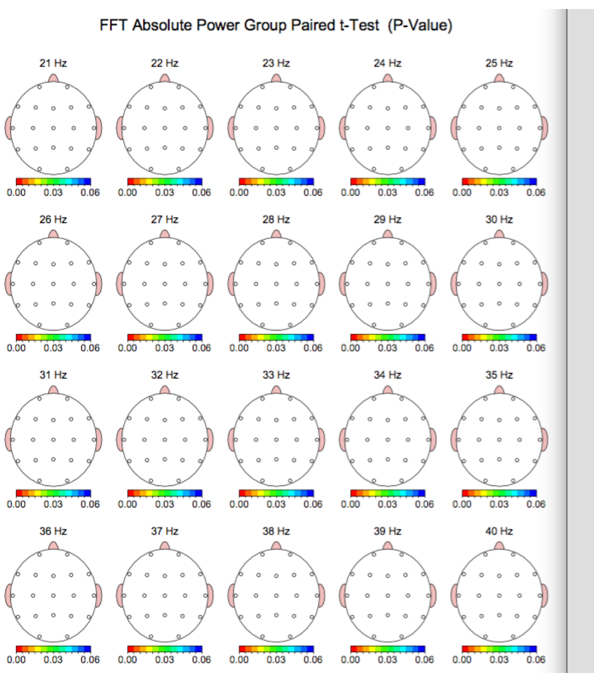
46 Hz
47 Hz
48 Hz
49 Hz
50 Hz
0.00 0.03 0.06

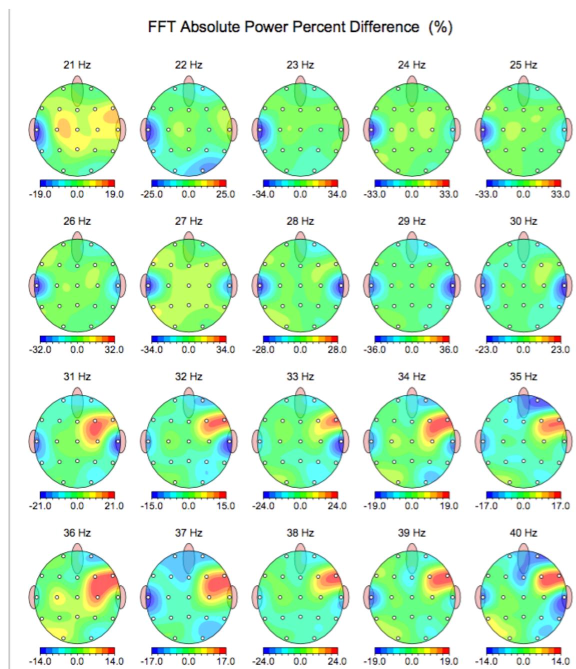

FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz
42 Hz
43 Hz
44 Hz
45 Hz
-15.0 0.0 15.0
-22.0 0.0 22.0
-16.0 0.0 16.0
-16.0 0.0 16.0
-14.0 0.0 14.0
46 Hz
47 Hz
48 Hz
49 Hz
50 Hz
-24.0 0.0 24.0
-14.0 0.0 14.0
-20.0 0.0 20.0
-21.0 0.0 21.0
-24.0 0.0 24.0

CD EC

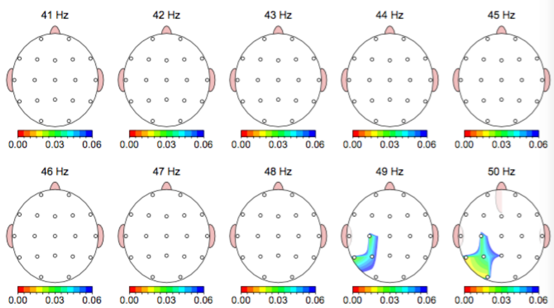

FFT Absolute Power Group Paired t-Test (P-Value)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz


FFT Absolute Power Percent Difference (%)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz

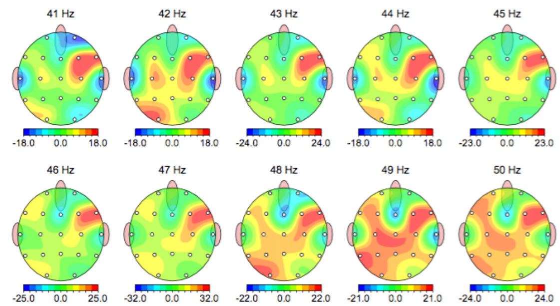

FFT Absolute Power Group Paired t-Test (P-Value)
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz


FFT Absolute Power Percent Difference (%)
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz

FFT Absolute Power Group Paired t-Test (P-Value)

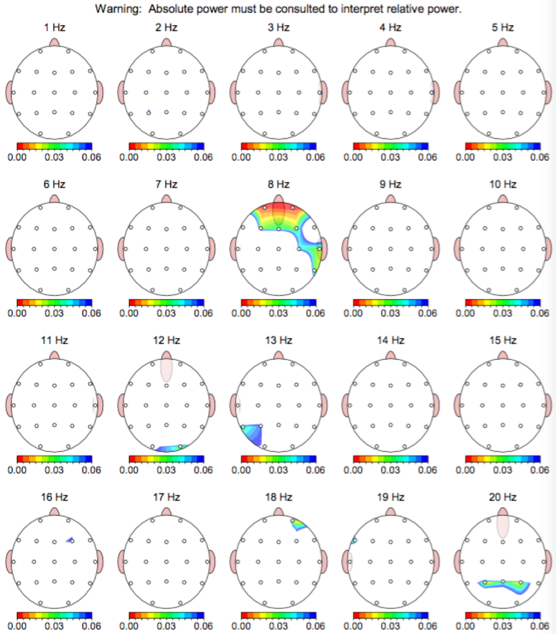


FFT Absolute Power Percent Difference (%)



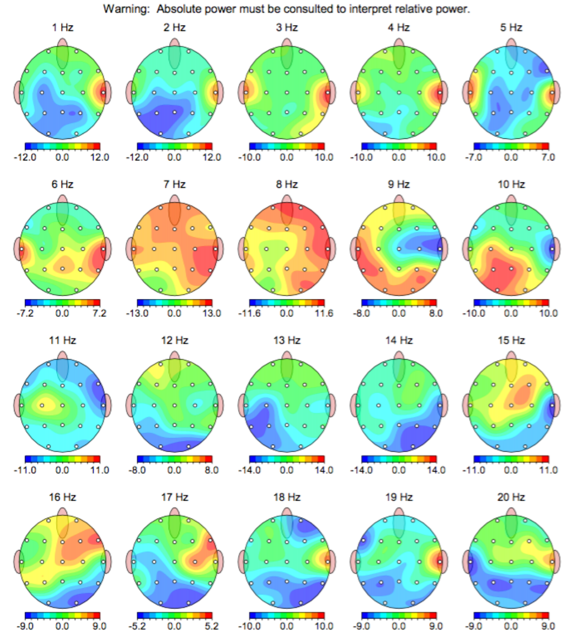
FFT Relative Power Group Paired t-Test (P-Value)

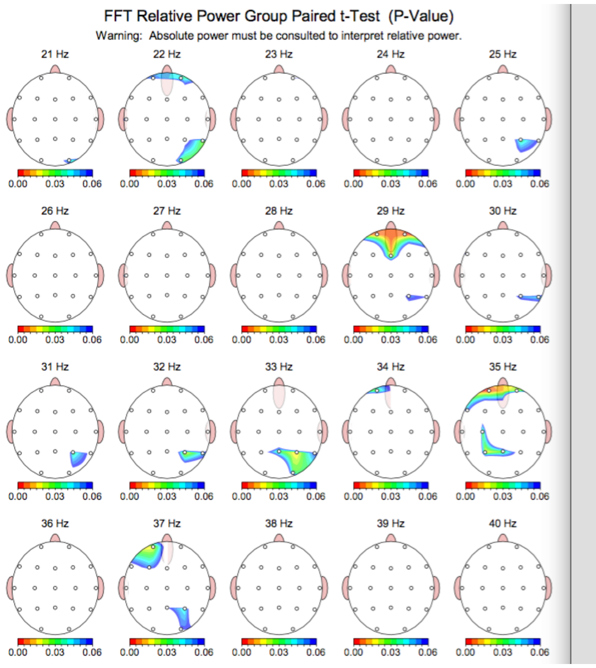
Warning: Absolute power must be consulted to interpret relative power.



FFT Relative Power Percent Difference (%)

Warning: Absolute power must be consulted to interpret relative power.




FFT Relative Power Group Paired t-Test (P-Value)
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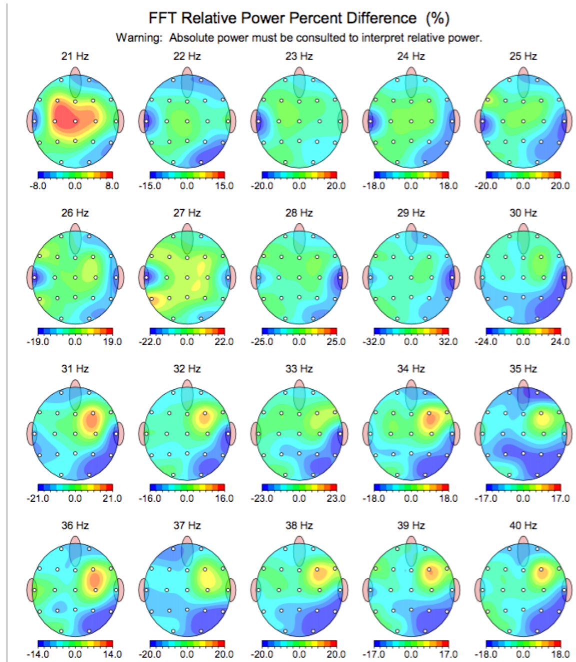
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz


FFT Relative Power Percent Difference (%)
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31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
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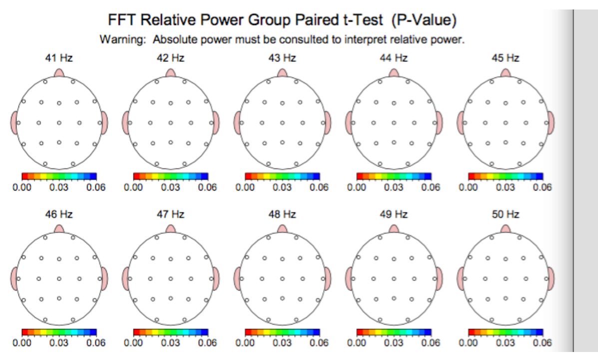
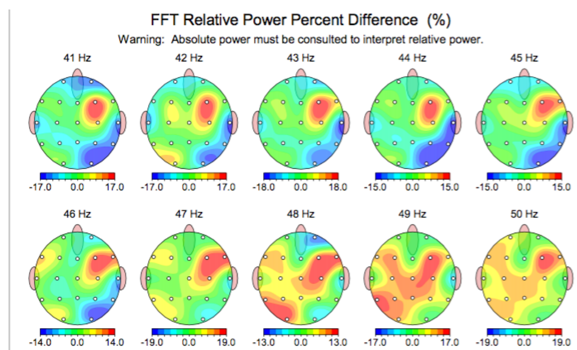
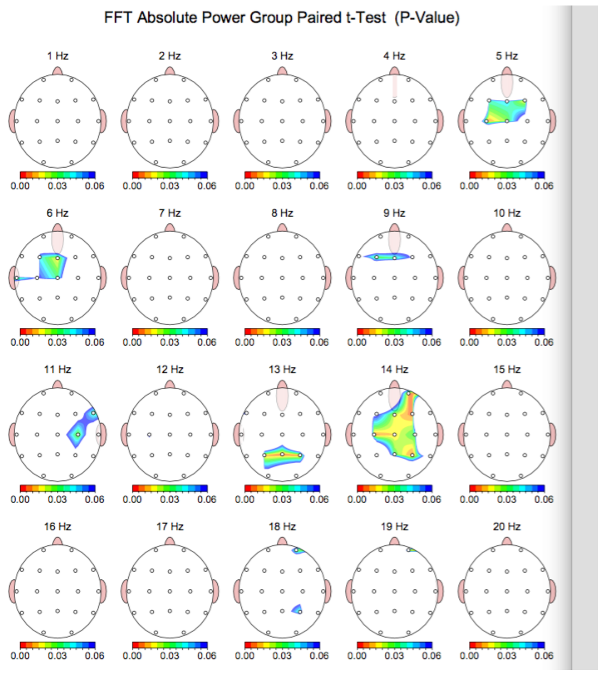
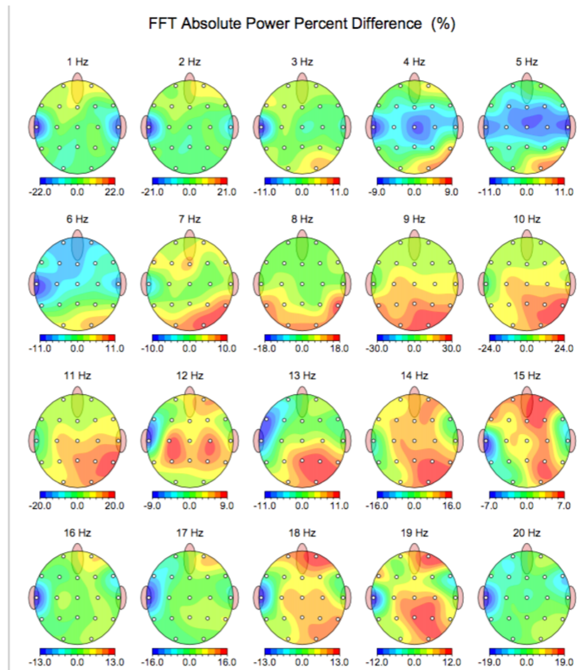

FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz 42 Hz 43 Hz 44 Hz 45 Hz
46 Hz 47 Hz 48 Hz 49 Hz 50 Hz


FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
41 Hz 42 Hz 43 Hz 44 Hz 45 Hz
46 Hz 47 Hz 48 Hz 49 Hz 50 Hz

TT EO


FFT Absolute Power Group Paired t-Test (P-Value)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz


FFT Absolute Power Percent Difference (%)
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11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
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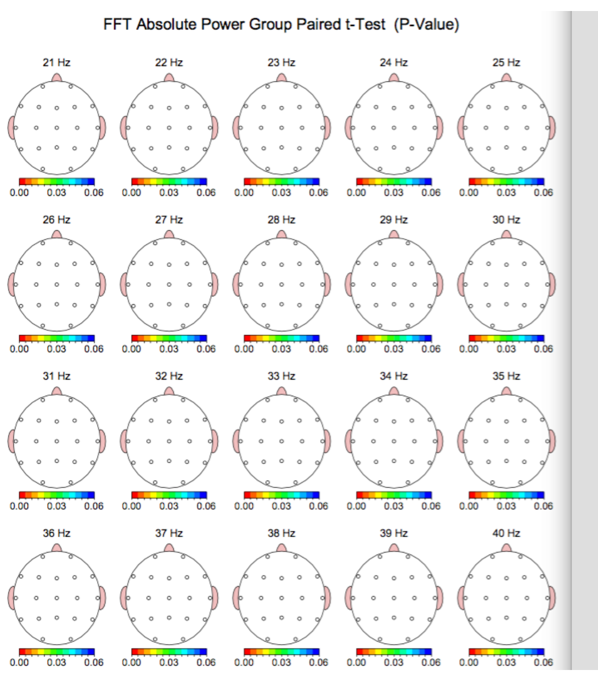
FFT Absolute Power Group Paired t-Test (P-Value)
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
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31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
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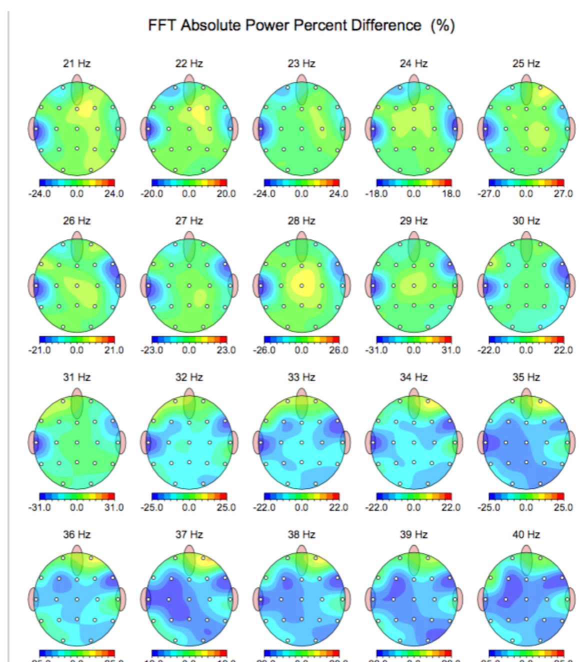
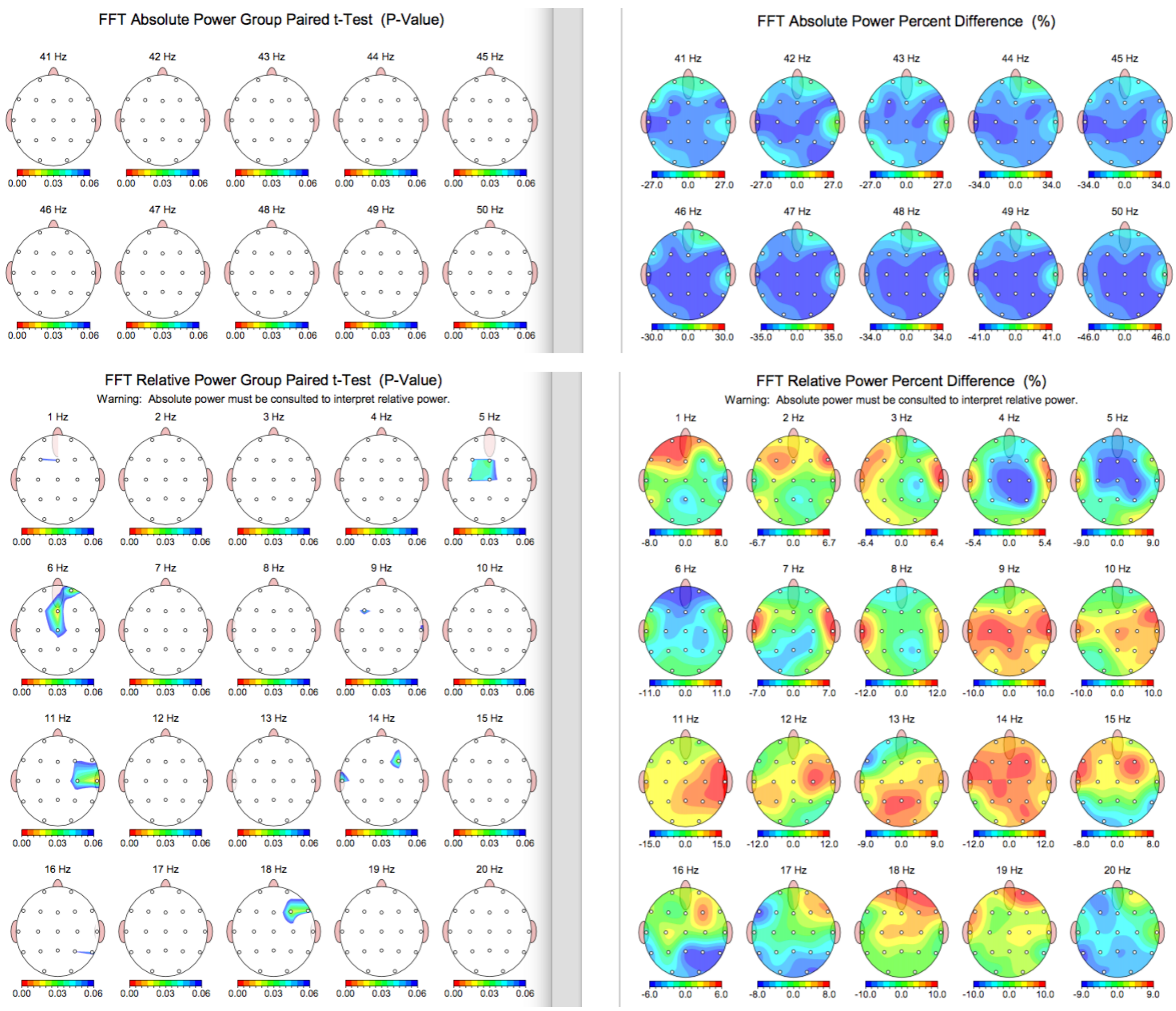
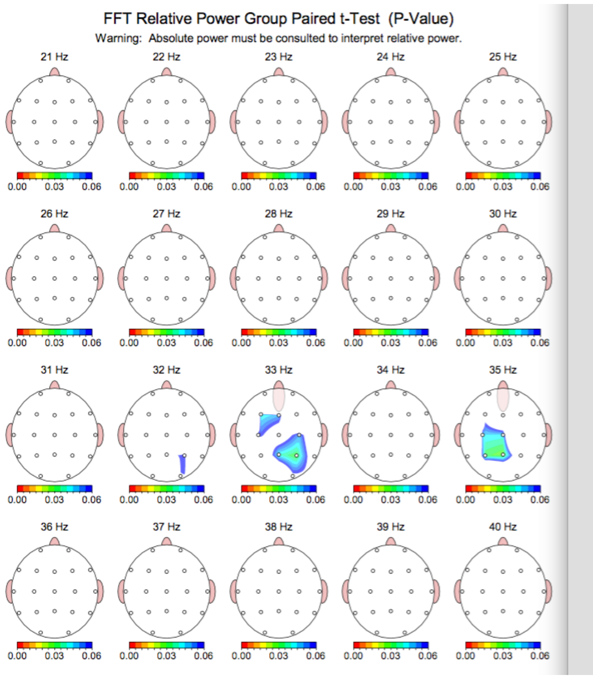

FFT Absolute Power Percent Difference (%)
21 Hz 22 Hz 23 Hz 24 Hz 25 Hz
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz


FFT Absolute Power Group Paired t-Test (P-Value)
FFT Absolute Power Percent Difference (%)
FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.


FFT Relative Power Group Paired t-Test (P-Value)
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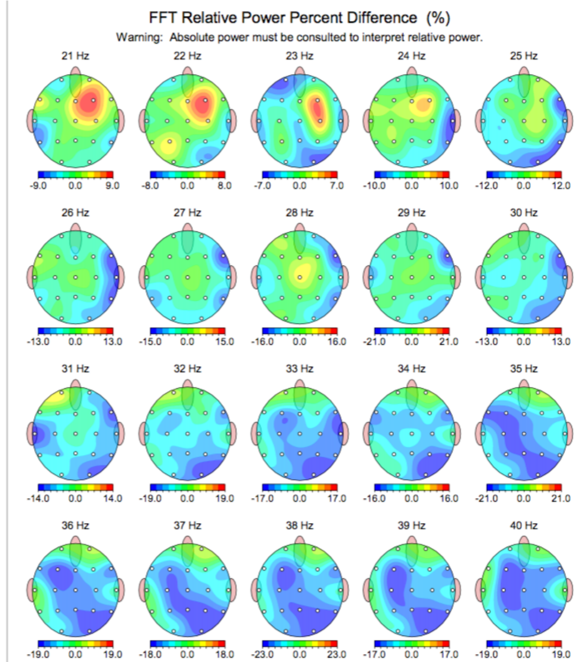
FFT Relative Power Percent Difference (%)
Warning: Absolute power must be consulted to interpret relative power.
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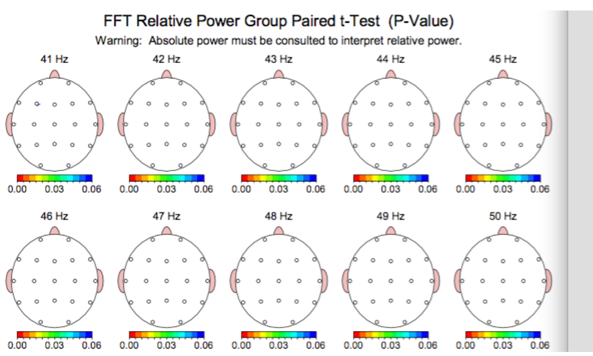
FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
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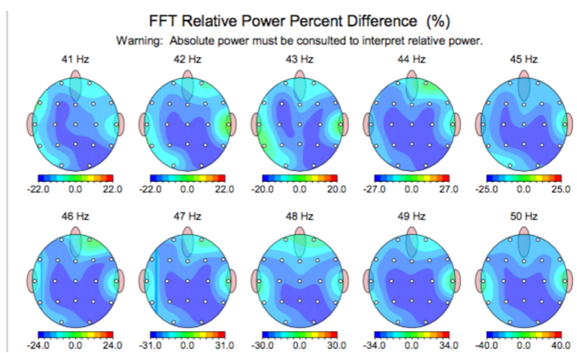
FFT Relative Power Percent Difference (%)
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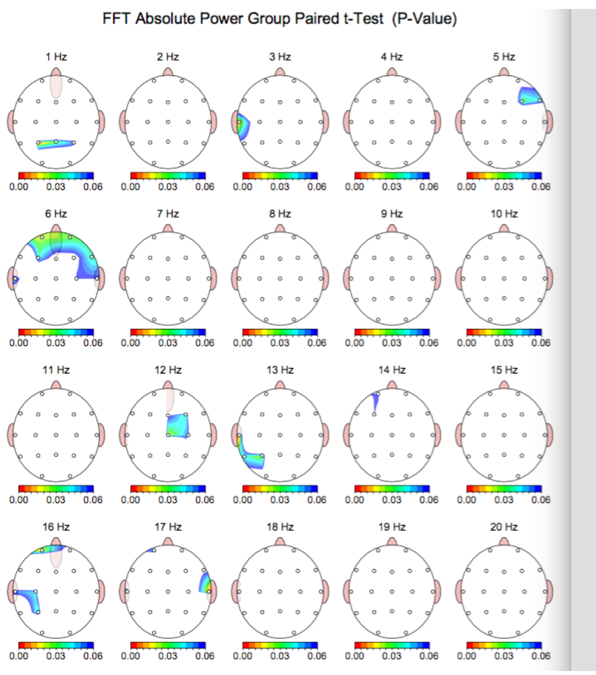
FFT Absolute Power Group Paired t-Test (P-Value)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz
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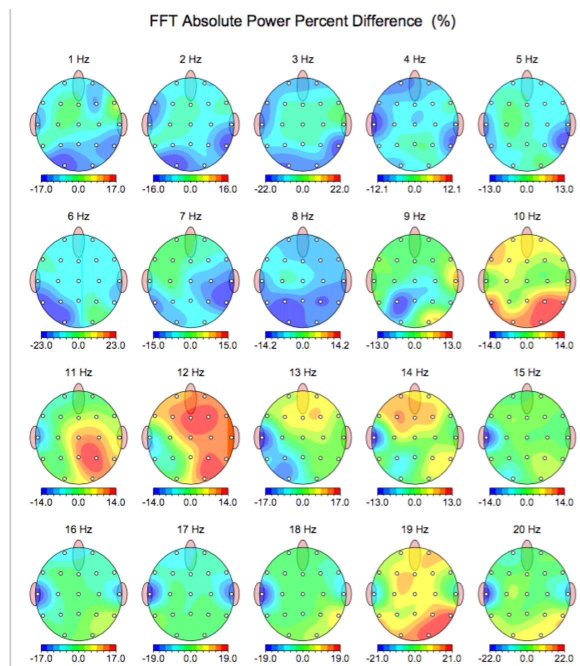
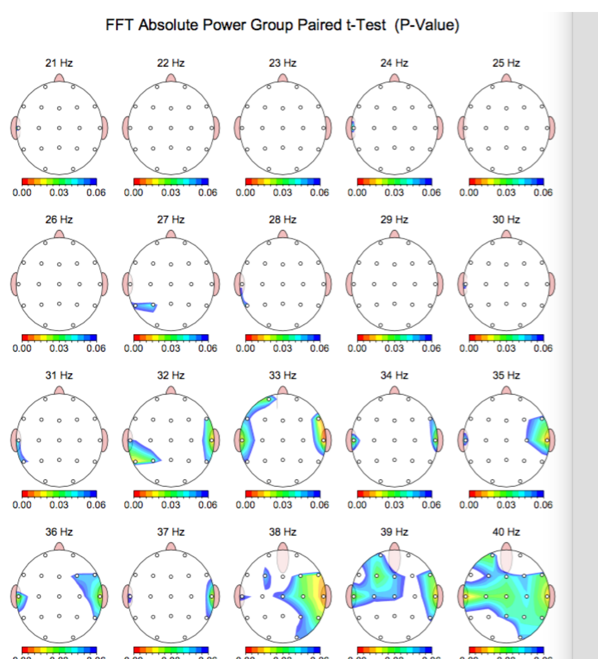

FFT Absolute Power Percent Difference (%)
1 Hz 2 Hz 3 Hz 4 Hz 5 Hz
-17.0 0.0 17.0 -16.0 0.0 16.0 -22.0 0.0 22.0 -12.1 0.0 12.1 -13.0 0.0 13.0
6 Hz 7 Hz 8 Hz 9 Hz 10 Hz
-23.0 0.0 23.0 -15.0 0.0 15.0 -14.2 0.0 14.2 -13.0 0.0 13.0 -14.0 0.0 14.0
11 Hz 12 Hz 13 Hz 14 Hz 15 Hz
-14.0 0.0 14.0 -14.0 0.0 14.0 -17.0 0.0 17.0 -13.0 0.0 13.0 -14.0 0.0 14.0
16 Hz 17 Hz 18 Hz 19 Hz 20 Hz
-17.0 0.0 17.0 -19.0 0.0 19.0 -19.0 0.0 19.0 -21.0 0.0 21.0 -22.0 0.0 22.0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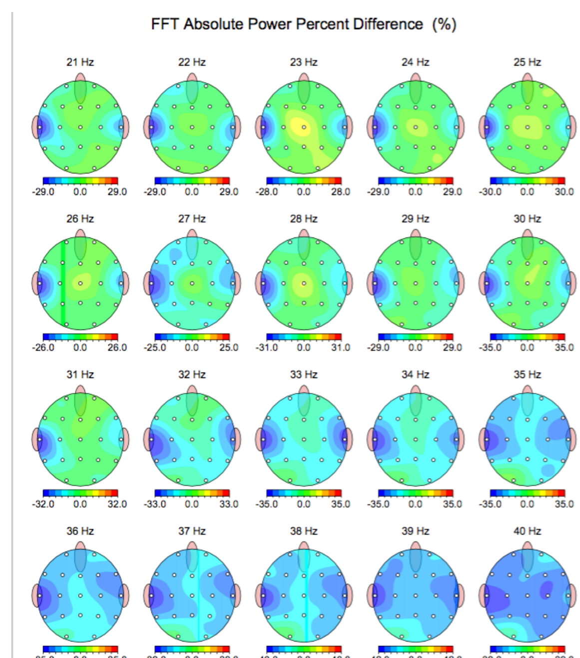
FFT Absolute Power Percent Difference (%)
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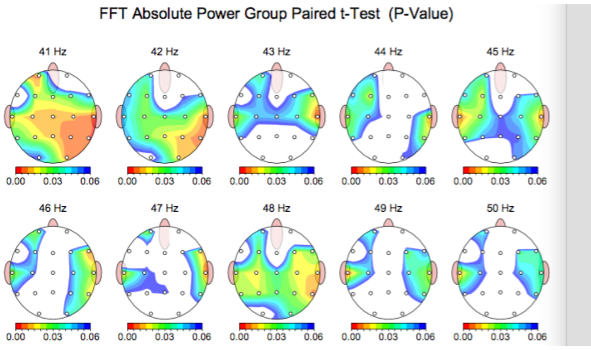
26 Hz 27 Hz 28 Hz 29 Hz 30 Hz
-26.0 0.0 26.0 -25.0 0.0 25.0 -31.0 0.0 31.0 -29.0 0.0 29.0 -35.0 0.0 35.0
31 Hz 32 Hz 33 Hz 34 Hz 35 Hz
-32.0 0.0 32.0 -33.0 0.0 33.0 -35.0 0.0 35.0 -35.0 0.0 35.0 -35.0 0.0 35.0
36 Hz 37 Hz 38 Hz 39 Hz 40 Hz
-35.0 0.0 35.0 -39.0 0.0 39.0 -40.0 0.0 40.0 -42.0 0.0 42.0 -39.0 0.0 39.0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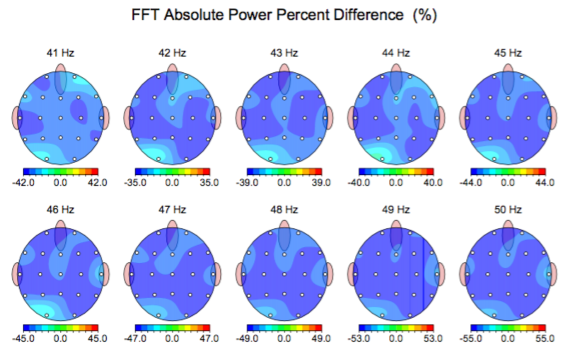
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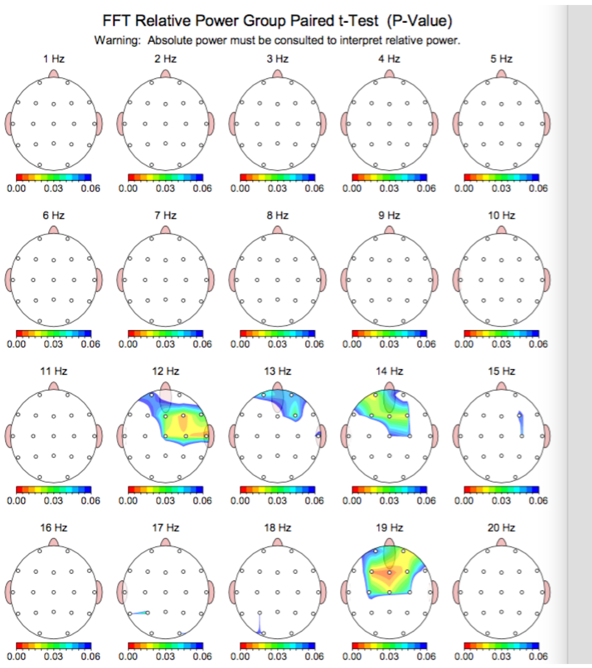
FFT Relative Power Group Paired t-Test (P-Value)
Warning: Absolute power must be consulted to interpret relative power.
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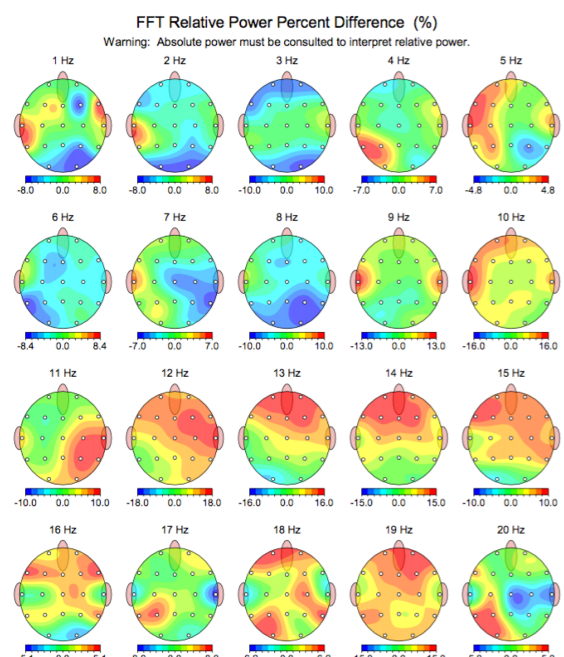
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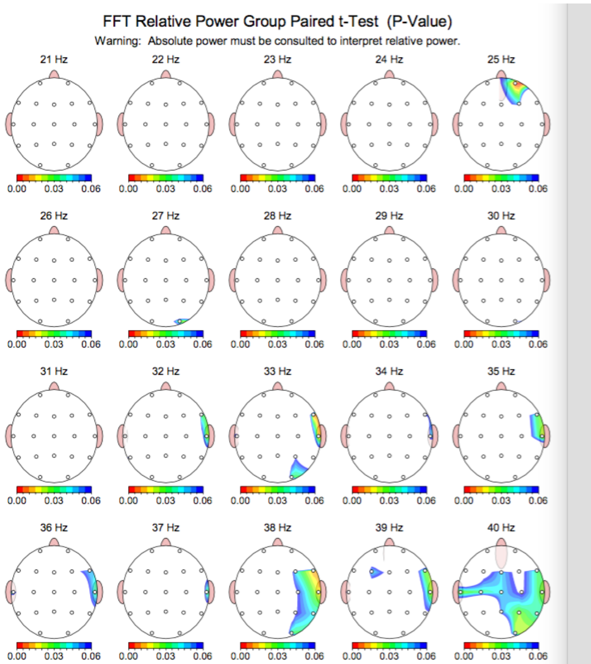
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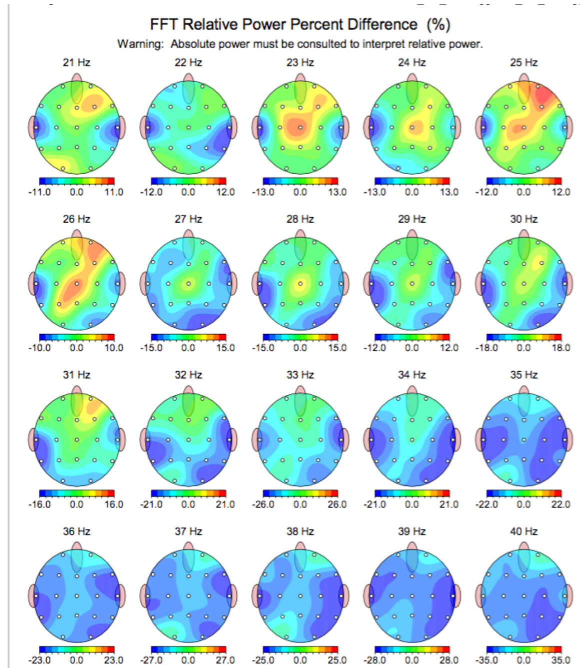
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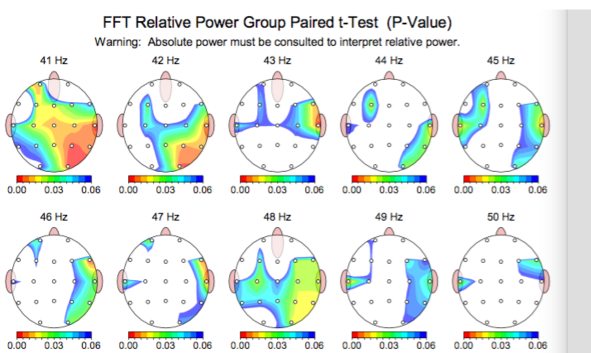
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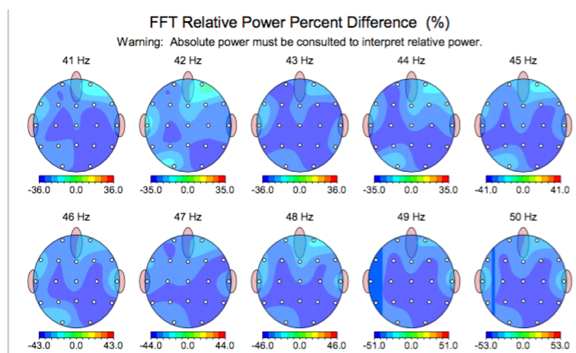
FFT Relative Power Percent Difference (%)
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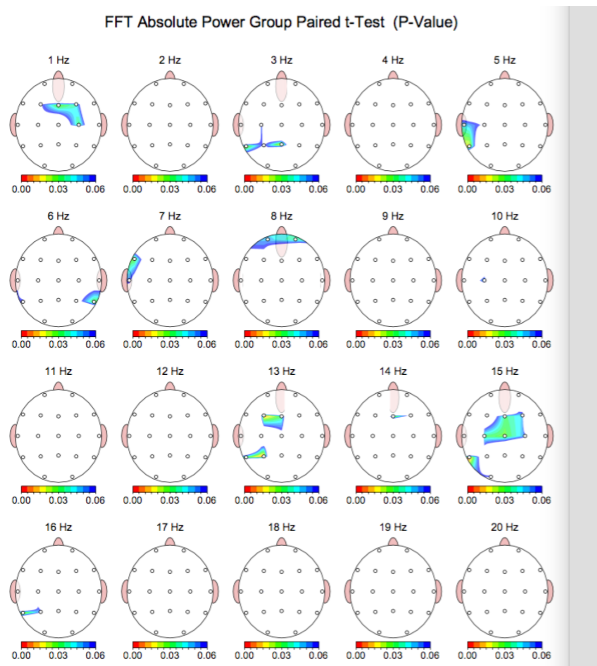
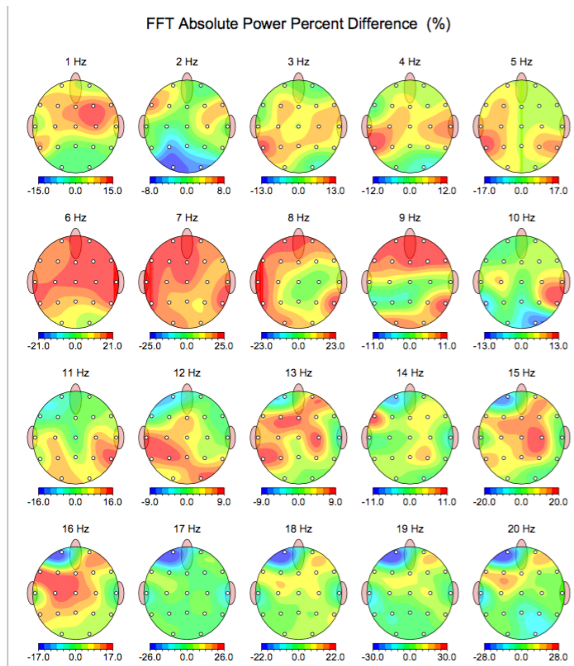
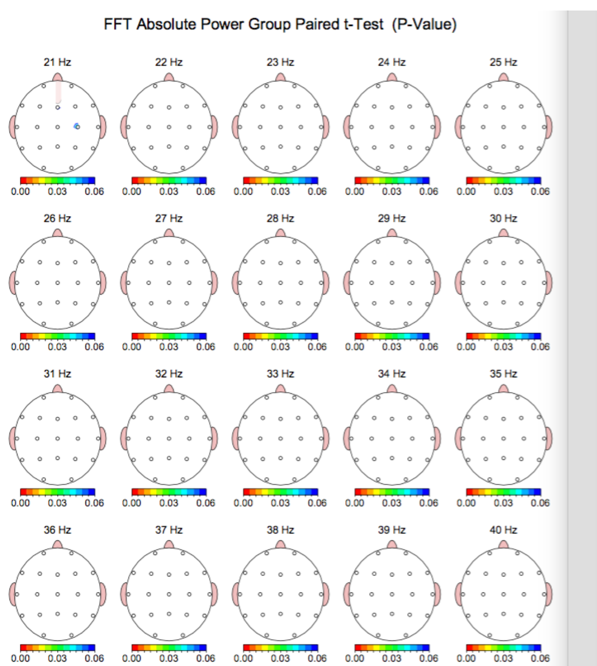
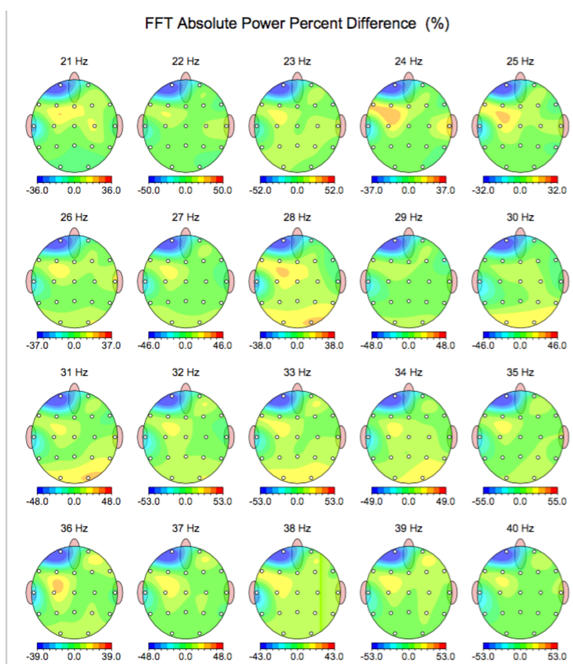
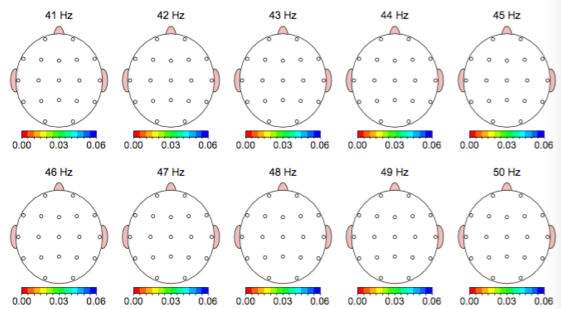

FFT Absolute Power Group Paired t-Test (P-Value)


FFT Absolute Power Percent Difference (%)

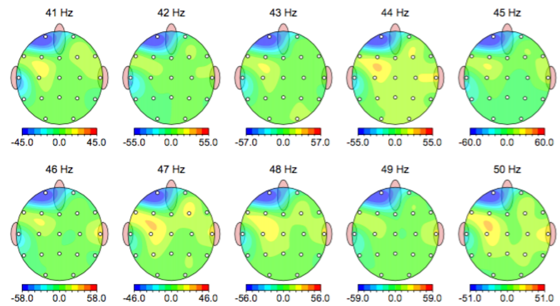

FFT Absolute Power Group Paired t-Test (P-Value)


FFT Absolute Power Percent Difference (%)

FFT Absolute Power Group Paired t-Test (P-Value)



FFT Absolute Power Percent Difference (%)



FFT Relative Power Group Paired t-Test (P-Value)

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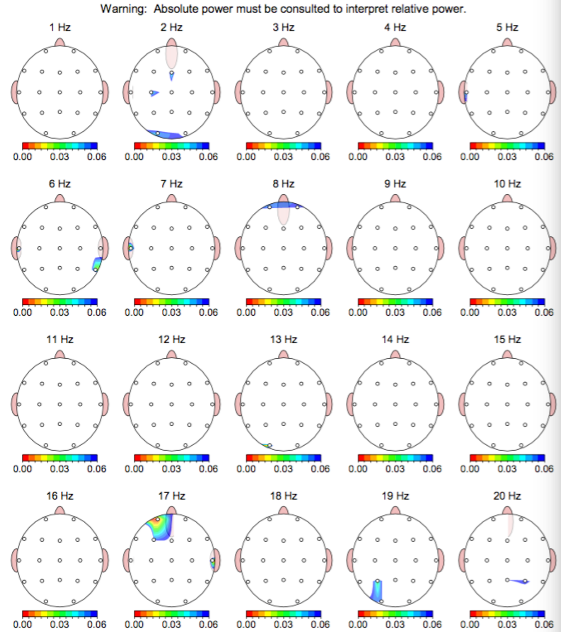

FFT Relative Power Percent Difference (%)

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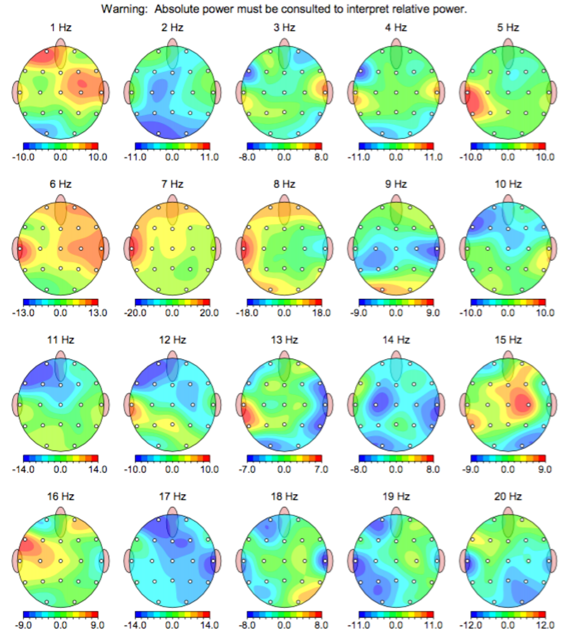

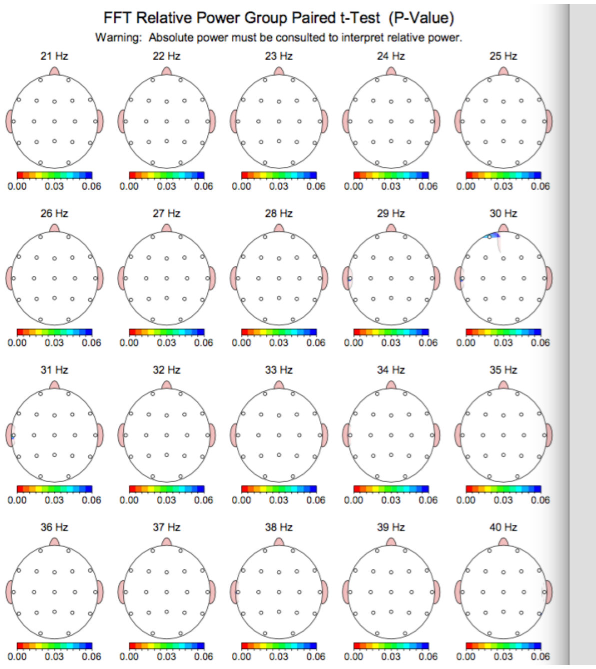
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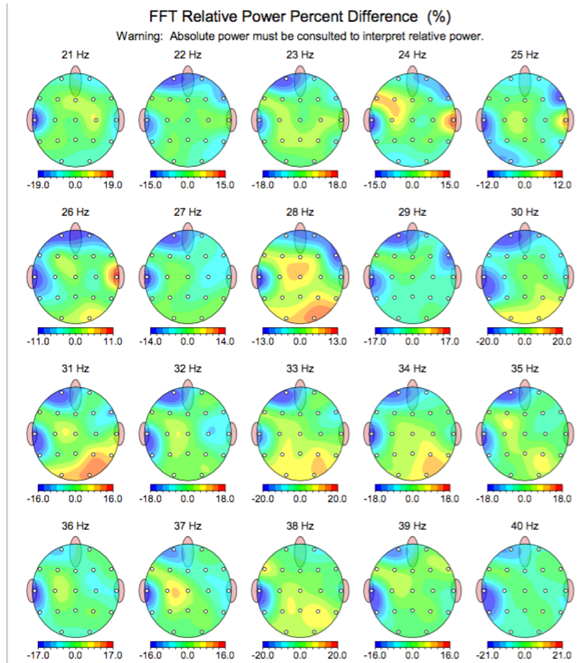
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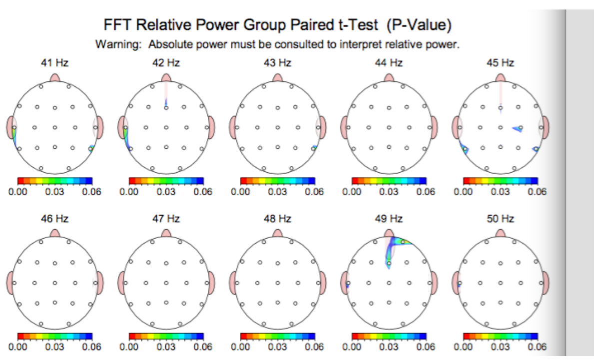
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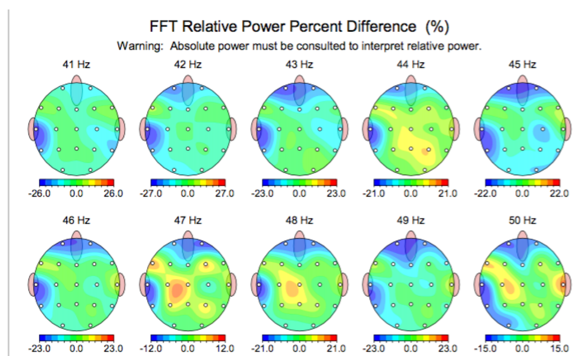
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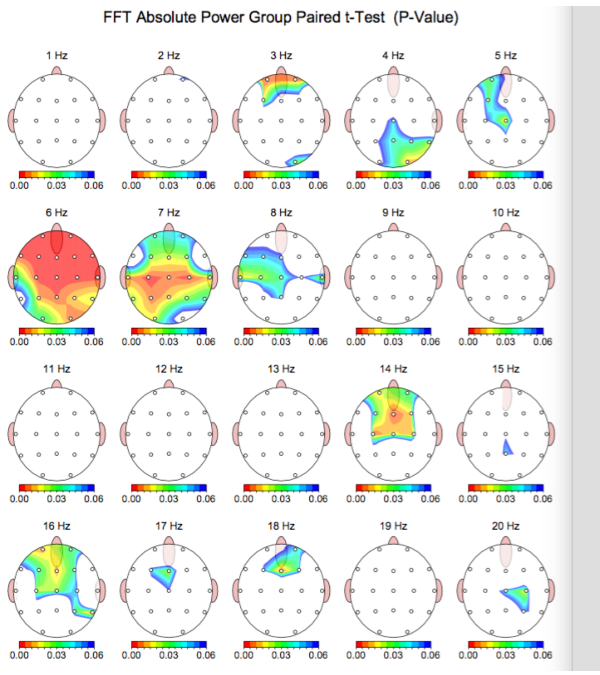
FFT Absolute Power Group Paired t-Test (P-Value)
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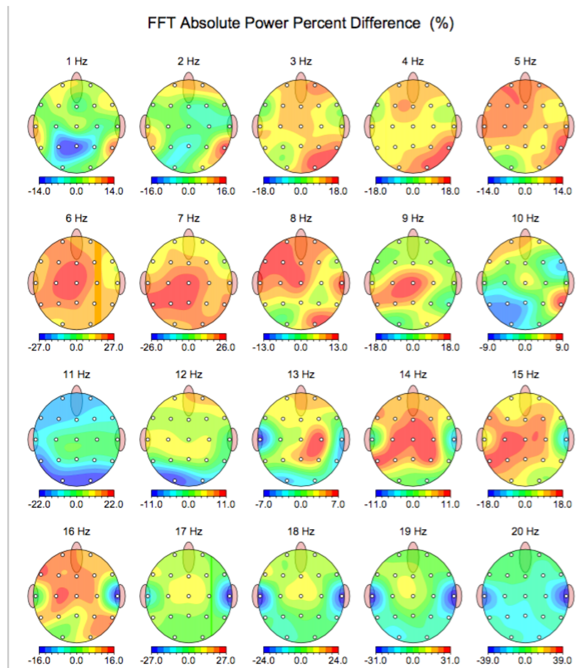
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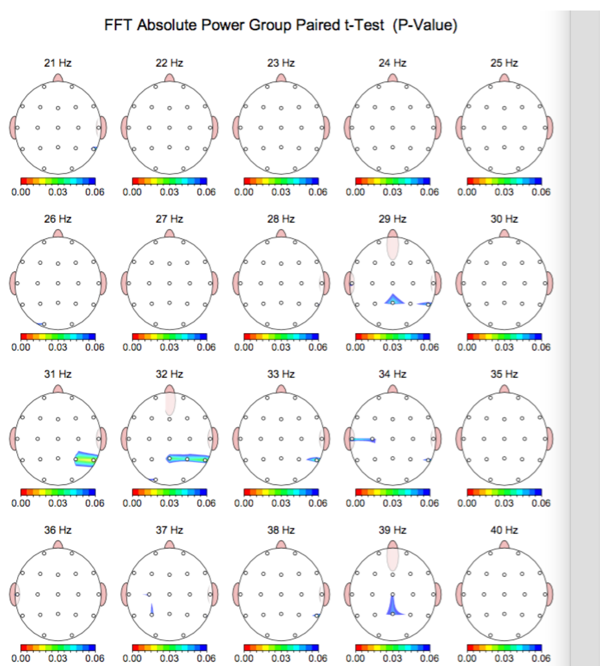
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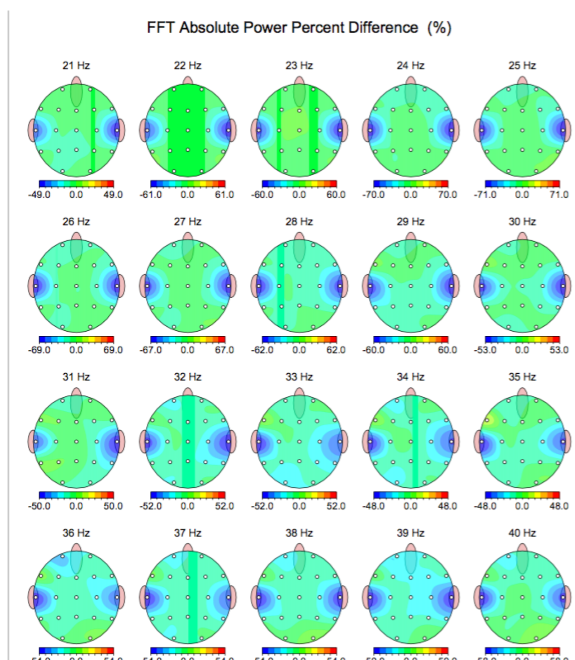
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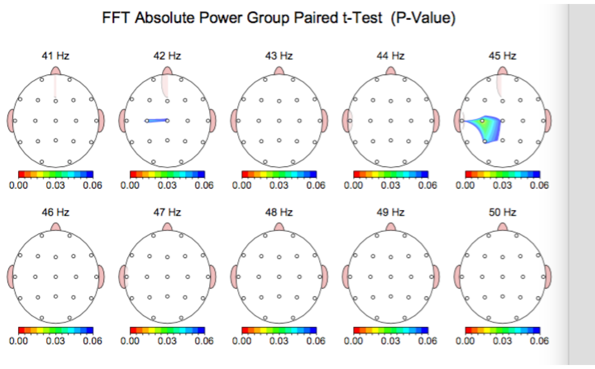
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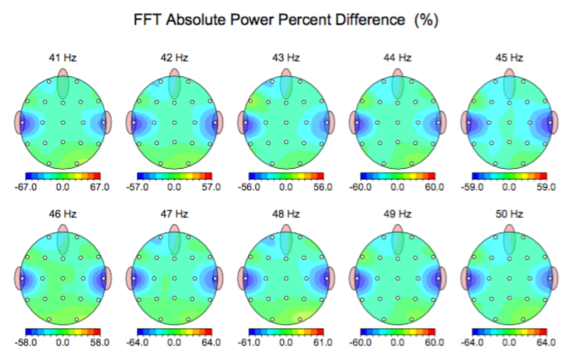
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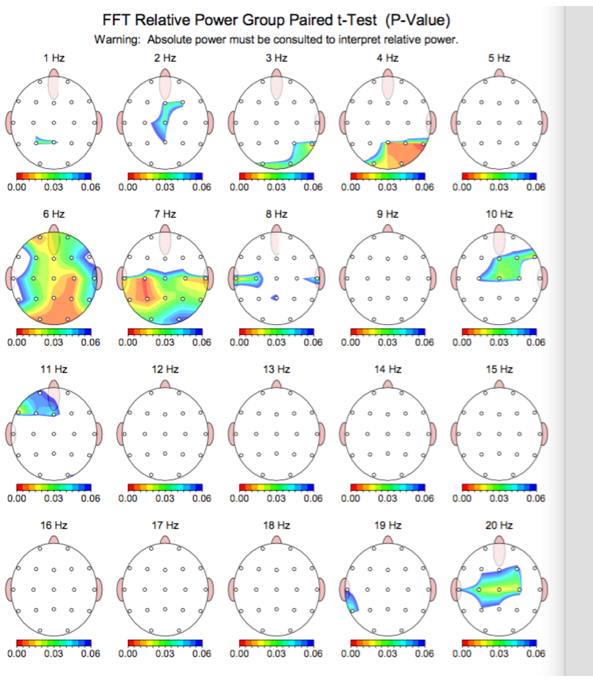
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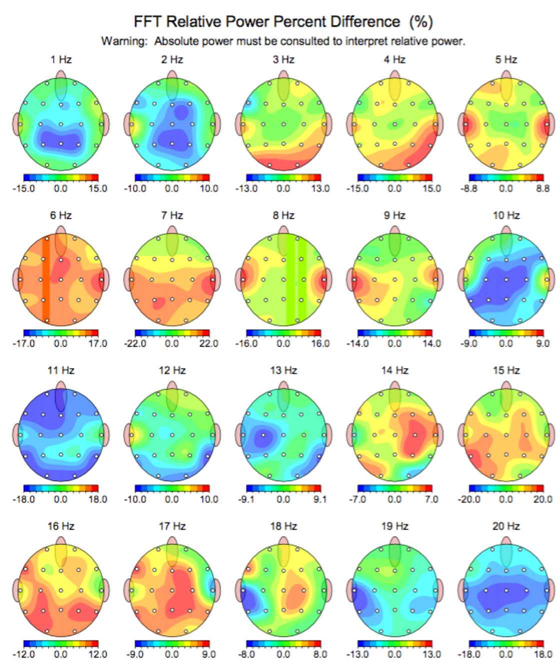
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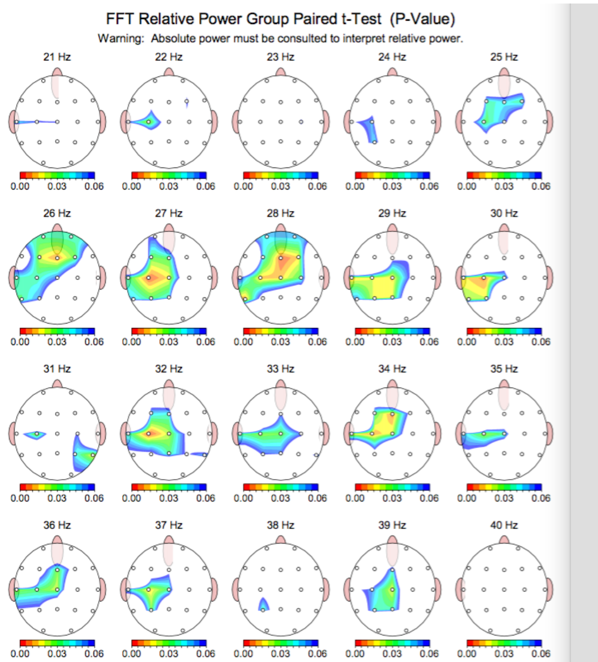
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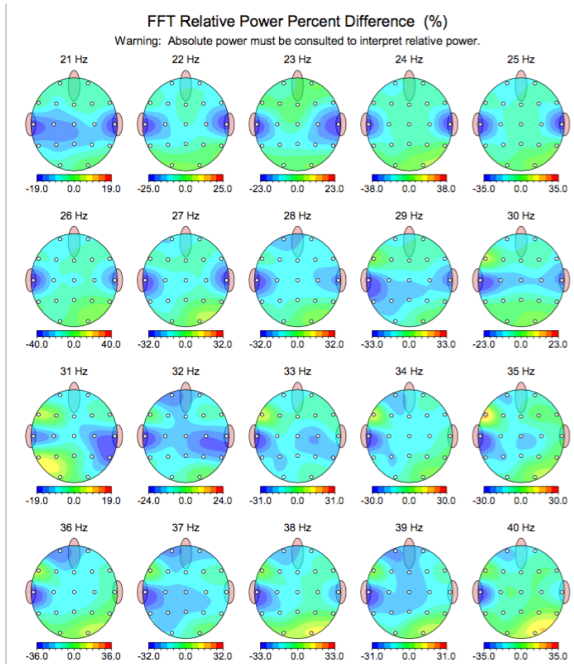
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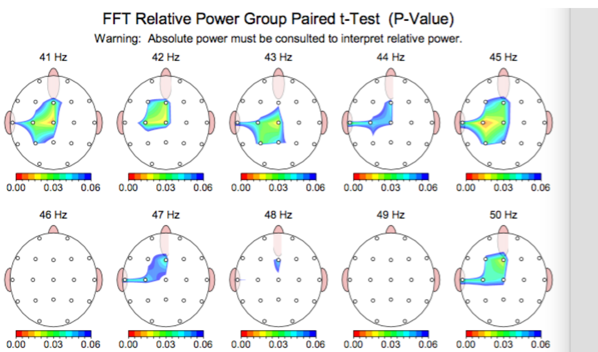
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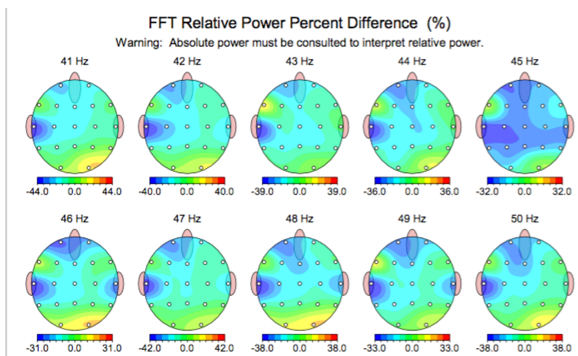
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