BRAIN BASED DISORDERS RELATED TO WHITE MATTER INTEGRITY

Brain Based Disorders Related To White Matter Integrity

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Submitted in partial fulfillment of the requirements of the

Master of Education in Special Education degree at the

University of Alaska Southeast

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Date

Abstract

Although students with reading and math deficits seem to be on the rise, and referrals for special education continue to grow, research in neuroimaging over the last 10 to 15 years has identified root causes to most of these problems and researchers are beginning to develop interventions to greatly reduce the negative results of these disorders. Structural integrity of the brain's white matter is in many ways connected to most difficulties in learning, and brain based disorders. Researchers are developing computer software designed to allow students to practice skills at home. In doing this, students will induce activation of specific region of the brain intended to strengthen white matter integrity and lessen the negative effects of many brain based disorders. These interventions have already been proven effective for brain damage from cancer and cancer treatments, TBI, attention deficits, autism, dyslexia and other reading deficits, and math related disorders.

1. Introduction

1.1 Background

With the advancements in magnetic resonance imaging (MRI), scientists have been able to better understand the brain and how its development relates to many specific disabilities. One study, performed by Dr. Christian Beaulieu of the University of Alberta has found that the structure of a student's white matter could play a part in that student's reading abilities.

> White matter comprises the bulk of the deep parts of the brain and is responsible for information transmission, whereas grey matter is responsible for information processing. Researchers have long suspected that white matter pattern is indicative of reading performance. Also equally important during reading is that different parts of the brain need to communicate and the way they communicate is through these white matter tracks of the brain. The white matter is basically the wiring in the middle. (University of Alberta, 2005)

According to research by Beaulieu, the white matter is thought to be the part of the brain that interconnects the other parts as the brain functions. Those parts that relate to reading are thought by Beaulieu (2005), to be in the temporal-parietal white matter and possibly the Broca's area and the Wernicke's area, both known to control language comprehension and interpretation of speech. In 2005, Beaulieu anticipated his findings as useful in the possible development of reading interventions and the use of functional Magnetic Resonance Imaging as a way of measuring the effectiveness of those interventions. By 2008, Ann Meyler and her fellow researchers from Carnegie Mellon University were learning more about white matter's involvement in reading and remedial instruction to improve skills (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008).

Again, brain imaging was revealing new and previously unknown secrets of the brain. The studies from Carnegie Mellon showed that poor readers had significantly less activation in the parietotemporal areas of the brain while reading than that of good readers. This would coincide with Beaulieu's findings in 2005. However, the new studies recognized that through remedial reading instruction, these activation levels could be raised to near normal levels and that they would remain higher well after instruction is completed (Carnegie Mellon University, 2008). According to neuroscientist Marcel Just, director of Carnegie Mellon's Center for Cognitive Brain Imaging, "With the right kind of intensive instruction, the brain can begin to permanently rewire itself and overcome reading deficits, even if it can't entirely eliminate them." (2008)

Furthermore, the researchers at Carnegie Mellon University showed that the brain could permanently rewire itself and overcome reading deficits in students with dyslexia and other poor readers. This rewiring of the brain takes place when students are given 100 hours of intense remedial instruction. "This study demonstrates how remedial instruction can use the plasticity of the human brain to gain an educational improvement," states senior author of the study, Marcel Just (Carnegie Mellon University, 2008). In this research, the connections that have been observed between reading performance and white matter in the brain, have now turned around to show that through remediation individuals could make permanent improvements to their brain structure, overcoming some disabilities. Not only did this study show near normal activity in the brains of poor readers immediately after remediation, but also after one year the gap of brain activity between good and poor readers was nearly gone. Neurologists credit this to continued reading activity (Carnegie Mellon University, 2008).

This however is not the most exciting discovery that researchers were to find as they continued to use brain imaging to better understand how the connectiveness of the brain relates to cognitive abilities. In 2009, Marcel Just and his colleague Timothy Keller reported that not only did remedial instruction improve reading ability and rewire the white matter; they observed that it created new white matter that improves communication within the brain. It was also shown that the most white matter change directly related to the most improvement in reading ability (Keller & Just, 2009). After this, Just said, “The indication that behavioral intervention can improve both cognitive performance and the microstructure of white matter tracts is a breakthrough for treating and understanding development problems” (Carenegie Mellon University, 2009)

The exciting part of all this new research is that it goes beyond reading performance. If the structure of the brain can be altered and improved, then this could have a positive impact on disabilities and disorders that are impacted by the structure of the brain. Connections are already being made to Autism Spectrum Disorders, dyslexia, many specific learning disorders and attention deficit hyperactivity disorder (ADHD). By intentionally activating specific parts of the brain, connections within the brain may be able to be enhanced and disabilities can be overcome or at least minimized (Keller & Just, 2009).

After further studies, the researchers at Carnegie Mellon have still more evidence that the white matter inside the brain is not only improving but there is actually new white matter being created. These findings have important implications not only on reading disabilities, but also with other developmental disorders such as autism. Dr. Thomas R. Insel, director of the National Institute of Mental Health, is excited about possible new treatment techniques that may come from this research. Many of the mental disorders today could be greatly affected by these studies since they are increasingly being linked to specific brain circuits (Keller & Just, 2009). There could even be possible treatment possibilities for children with fetal alcohol syndrome and fetal alcohol effect. It is almost as if science is at the point of determining which exercises are more effective for strengthening which parts of the brain.

Through much of this new science, researchers are on the edge of making possible improvements to the psychological, language development, and especially the cognitive domains of children in our society. With all of its new technology, research is moving faster than imaginable. However, the indirect effects these studies are having on a child's educational social domain are no less ground breaking. When one understands that the preeminent struggle that students have with both their social and emotional development is directly related to the behavior they exhibit, then the connections begin to open up. By the time, students reach their middle school years, and if they are struggling with reading or any other part of feeling normal, the usual response is one of disruption and distraction. If this new research can help mitigate various types of disabilities, and even reverse them later in life, then students can feel and be successful. This allows them to fit in with peers and exhibit a more positive behavior. As students in these formative years of 10 to 14 years old are given the opportunity to develop feeling normal and without deficits, they develop socially appropriate relationships. As they do this, they are given a better chance of finding positive peer models and mentors that will assist them in developing a more positive emotional base.

1.2 Author's beliefs and experiences

In 2007, I began a new career at a separate Day school facility, teaching students with extreme behaviors that made it difficult for these students to learn in a general education and a typical special education setting. After many years working around mostly adolescents as a bus driver and church youth leader, I quickly learned how ill prepared I was for this new challenge. The behaviors I observed were like none I had seen before. The majority of the students lacked control of their emotions and become extremely agitated over minor incidents. While in this emotional distress, some students could become unsafe for themselves and others around them. Over the last five years of my work at the Day School, I have worked with a wide variety of students with highly varied disabilities, which they worked to overcome. At the same time I was experiencing both the behaviors and the lives of these young people; I was learning in education classes about how disabilities like fetal alcohol syndrome disorder, and autism affected the everyday lives of students. Meanwhile I searched for effective ways to teach them and build trust with them. Although this was in many ways new to me, I understood that my personal way of helping young people was by developing a real relationship with them.

One of the things I began to realize is that no matter the specific diagnosis a student was given they often responded well to similar interventions. At the same time, I was learning how many disabilities affected how impulses traveled through the parts of the brain and formed connections to be made. At this time, I had primarily been learning about Autism and Fetal Alcohol Spectrum Disorder (FASD). Both these groups of students did not seem to build strong connections between what they would do wrong and the punishments they received. They did not connect yesterday's consequence for a certain behavior to today's choice of behavior. Whatever the disability the result was a lack of these connections, requiring a different approach to discipline. In talking to professors with intimate experience with these conditions, there was not usually much improvement into adulthood. My professor had raised a son into his fifties and he still needed to seek assistance with important decisions in his life.

It would be easy to become discouraged with the prognosis for the future of many of these diverse students. Early on while teaching these students it became evident that many of the students responded well to experiencing success. Small successes seemed to be contagious within a small group of students. Students whom had little success in the education setting thrived when they started realizing regular success. This success seemed to be more prevalent when the instruction was more direct and most of the work performance was done collectively within the group, allowing the group to experience each other's individual success as well as that of the entire group. Students with autism, FASD, and other disabilities that exhibit social, emotional, and behavioral deficits responded well to the successes in school. Not only did there appear to be academic improvement, there also seemed to be a marked improvement in the student's behaviors. At first, I noticed this phenomenon in all academic areas however after a couple of years my job began to focus primarily in the area of reading intervention.

In 2010, I was given some articles that looked at the prospect of comparing a student's brain development as they were given interventions to improve their reading performance. In 2005, one such study by the University of Alberta conducted a study on 32 children from the ages of nine to twelve. Using a technique known as functional MRI, researchers were able to look at the neurons on the surface of the brain and "see which ones 'turn on' when you read or perform a task" (University of Alberta, 2005). Observing these patterns during cognitive tasks allow researchers to develop structural signatures in the brain that relate to a persons' reading ability.

These initial studies showed promise for identifying struggling readers as well as which parts of the brain were related to reading performance. However, it was not the relationship to reading intervention that interested me. Instead, scientist observed how the remedial instruction in reading was changing the brain. Early studies had recognized that white matter in the brain is where communication takes place. "The way I see it, the grey matter is the computer and the white matter is the wiring or the Ethernet cable that connects them all up and lets them communicate" (University of Alberta, 2005). Researchers found that the stronger the patterns in the white matter were connecting the parts of the brain, the better the child's ability to read could develop. Scientists have actually been able to identify which parts of the brain are related to reading abilities.

It has always excited me that possibly it is more than just the experience of success that is impacting some students. I have spent six years teaching, and the last four primarily teaching remedial reading interventions to students with emotional and behavioral disorders, and other specific learning disabilities. I have observed first hand improvements in both social and academic performance. It seems to me that if utilizing the brain can physically improve the brain, then there is great hope for all the discussed disabilities and possibly many more.

With this meta-synthesis, I hope to investigate the following research questions:

1. What is physically being changed within the white matter of the brain as students are undergoing remedial instruction?

2. What are the different disabilities and disorders that these types of interventions can help to improve?

3. As a result, of this new research, what types of teaching techniques will best help me to insure that my students will activate their brains on a regular basis so that they are utilizing the findings of this research to best assist them to overcome their divers learning needs?

1.3. The purpose of this meta-synthesis

This meta-synthesis focuses on the recent science of using new brain scanning technology to observe and record the interconnectedness of the brain. More importantly, this technology has found that activation of different parts of the brain by repetitive and remedial tasks not only detects the connections between the different parts of the brain and how they interact during certain tasks, but the same scans can record new growth of myelin within the white matter of the brain. The myelin serves much like the insulation on an electrical wire allowing neuron transmissions within the brain to be more focused and the connections clearer. One purpose was to review peer reviewed journal articles pertaining to brain development and the advances over the last five years with brain scans. Many of these articles have been correlated with reading performance and the development of new white matter, through intense remedial reading intervention. Another purpose was to analyze where articles are researching other types of brain activation other than reading instruction and how the white matter was affected. A third purpose was to research the connections of these improvements as interventions for different disabilities related to brain connectivity. Finally, this meta-synthesis will identify new strategies and interventions that will make specific improvements in the lives of students with various disabilities in my classrooms.

2. Methods

2.1. Selection criteria

The 35 journal articles included in this meta-synthesis met the following selection criteria.

1. The articles explored issues related to brain imaging of students for the purpose of determining issues of connectivity of different parts of the brain and the structure of the brain.

2. The articles explored issues related to white matter, myelin, and how improving the integrity of these relates to other brain-based learning differences and disabilities.

3. The articles were published in peer-reviewed journals related to the fields of neuroscience and education.

4. The articles were published between 2005 and 2011.

2.2. Search procedures

Database searches and ancestral searches were conducted to locate articles for this meta-synthesis. I began with seven articles that I had collected over the years due to my own interests all published in “Science Daily” an online magazine. Although these articles were not peer reviewed, I was able to find the six original peer reviewed articles that the magazine had reported on and include them in my research. After reviewing these articles, I began database searches to find where the research had continued.

2.2.1. Database searches

I began this search with seven articles from “Science Daily” that I had collected over the years. Science Daily is a website founded by Dan Hogan in 1995 where universities and research institutions can submit news releases concerning research they are conducting. The seven articles retrieved from “Science Daily” www.sciencedaily.com are (White Matter Matters in Reading Performance, Study Finds, 2005; Researchers Discover Brain Abnormality in Kids with Autism, 2006; Remedial Instruction Can Make Strong Readers Out of Poor Readers, Brain Imaging Study

Reveals, 2008; Remedial Instruction Rewires Dyslexic Brains, Provides Lasting Results, Study Shows, 2008; First Evidence of Brain Rewiring in Children: Reading Remediation Positively Alters Brain Tissue, 2009; Breakthrough in Understanding White Matter Development, 2011; New Brain Imaging and Computer Modeling Predicts Autistic Brain Activity and Behavior, 2012).

I conducted Boolean searches within the Educational Resources Information Center (ERIC, Ebscohost) using these specific search terms:

1. (“Brain Scans”) AND (“White Matter”) AND (“Reading Ability”)
2. (“Brain Scans”) AND (“Myelin”) AND (“Reading Interventions”)
3. (“Brain Imaging”) AND (“Myelin”) AND (“Neuroscience”)
4. (“ Brain Imaging”) AND (“Connectiveness”) AND (“Myelin Integrity”)
5. (“Magnetic Resonance Imaging”) AND (“White Matter”) AND (“Reading”)
6. (“Magnetic Resonance Imaging”) AND (“White Matter”) AND (“Mathematics”)

The other database searches yielded 19 more articles. The 19 other results of database searches are (Elliot, 2001; Pugh, Sandak, Frost, Moore, & Mencl, 2005; Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005; Kumar, Mattan, & Vellis, 2006; Mostofsky, Burgess, & Larson,2007; Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008; Rykhlevskaia, Gratton, & Fabiani, 2008; Odegard, Ring, Smith, Biggan, & Black, 2008; Choudhury, Charman & Blakemore, 2008; Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, et al., 2009; Guerri, Bazinet, & Riley, 2009; Halpern-Felsher, 2009; Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, et al., 2009; Bava, Jacobus, Mahmood, Yant & Tapert, 2010; Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011; Kesler, Lacayo, & Jo, 2011; Nunez, Foussotter, & Sowell, 2011; Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011; Hurley 2012;).

2.2.2. Ancestral searches

By conducting ancestral searches on the seven articles by “Science Daily,” I was able to locate the six research studies that had been reported on in the seven articles I had started with. The six articles that are reviewed by “Science Daily” are (Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips, 2005; Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008; Keller & Just 2008; Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011; Just, Keller, Malave, Kana, & Varma, 2012.

2.3. Coding Procedures

I used a coding form to categorize the information presented in each of the 35 articles. This coding form was based on: (a) publication type; (b) research design; (c) participants; (d) data sources; and (e) findings of the studies.

2.3.1. Publication Types

Each journal article was evaluated and classified according to publication type (e.g., research study, theoretical work, descriptive work, opinion piece/position paper, guide, annotated bibliography, and review of the literature). *Research studies* use a formal research design to gather and/or analyze quantitative and/or qualitative data. *Theoretical works* use existing literature to analyze, expand, or further define a specific philosophical and/or theoretical assumption. *Descriptive works* describe phenomena and experiences, but do not disclose particular methods for attaining data. *Opinion pieces/position papers* explain, justify, or recommend a particular course of action based on the author's opinions and/or beliefs. *Guides* give instructions or advice, explaining how practitioners might implement a particular agenda. An *annotated bibliography* is a list of cited works on a particular topic, followed by a descriptive paragraph describing, evaluating, or critiquing the source. *Reviews of the literature* critically analyze the published literature on a topic through summary, classification, and comparison.

2.3.2. Research design

Each empirical study was further classified by research design (i.e., quantitative, qualitative, mixed methods research). *Quantitative* research utilizes numbers to convey information. Instead of numbers, *qualitative* research uses language to explore issues and phenomenon. *Mixed methods* research involves the use of both quantitative and qualitative methods to present information within a single study.

2.3.3. Participants, data sources, and findings

I identified the participants in each study. (e.g., individuals with different brain based disabilities or delays). I also identified the data sources used in each study (e.g., observations, brain scans,). Lastly, I summarized the findings of each study (Table 2).

2.4. Data analysis

I used a modified version of the Stevick-Colaizzi-Keen method previously employed by Duke (2011) and Duke and Ward (2009) to analyze the 35 articles included in this meta-synthesis. Significant statements were first identified within each article. For the purpose of this meta-synthesis, significant statements were identified as statements that addressed issues related to: (a) advancements in methods for using magnetic resonance to identify the combination of the regions of the brain activated while performing certain skills, such as visual recognition, reading , math or social interaction; (b) advancements in methods of magnetic resonance that identify how parts of the brain are activated by specific remedial or repetitive tasks; (c) advancements in methods of using magnetic resonance to measure structural properties of the white matter within the brain; (d) how different disorders and delays are related to poor connectivity between parts of the brain; and/or (e) any research that observes an improvement in deficits caused by these disorders or delays that are connected to practice-induced activation of the brain, intended to improve the connectivity of the brain. I then generated a list of non-repetitive, verbatim significant statements with paraphrased formulated meanings. These paraphrased formulated meanings represented my interpretation of each significant statement. Lastly, the formulated meanings from all 35 articles were grouped into theme clusters, represented as emergent themes. These emergent themes represented the fundamental elements of the entire body of literature.

3. Results

3.1. Publication type

I located 35 articles that met my selection criteria. The publication type is located in Table 1. Seventeen of the 35 articles (48.6%) included in this meta-synthesis were research studies (Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011; Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005; Bava, Jacobus, Mahmood, Yant & Tapert, 2009; Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips,2005; Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, Troncoso, Muhlhausen, Zschocke, Boy, Hoffmann, Garbade & Kolker, 2009; Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008; Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011; Keller & Just, 2009; Kesler, Lacayo, & Jo, 2011; Kesler, Sheau, Koovakkattu, & Reiss, 2011; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008; Mostofsky, Burgess, & Larson,2007; Odegard, Ring, Smith, Biggan, & Black, 2008; Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006; Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011; Smedt, Taylor, Archibald, & Ansari, 2010; Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, Job, Hall, Bastin, Johnstone, Lawrie & McIntosh, 2009)

Seven of the articles (20%) were reviews of literature, all published in the online publication, “Science Daily” (Science Daily, 2005 (White Matter); Science Daily, 2006 (Kids with Autism); Science Daily, 2008 (Remedial Instruction); Science Daily, 2008 (Dyslexic); Science Daily, 2009 (Brain Rewiring); Science Daily, 2011 (WM Development); Science Daily, 2012 (Autistic Brain Activity)).

Another eight of the articles (22.9%) were Theoretical works (Choudhury, Charman & Blakemore, 2008; Guerri, Bazinet, & Riley, 2009; Just, Keller, Malave, Kana, & Varma, 2012; Kumar, Mattan, & Vellis, 2006; Nunez, Foussotter, & Sowell, 2011;

Pugh, Sandak, Frost, Moore, & Mencl, 2005; Rykhlevskaia, Gratton, & Fabiani, 2008; Spreen, 2011).

Finally, three of the articles (8.6%) were descriptive works (Elliot, 2001; Halpern-Felsher, 2009; Hurley 2012).

Table 1

Author(s) & Year of Publication	Publication Type
Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011	Research Study
Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005	Research Study
Bava, Jacobus, Mahmood, Yant & Tapert, 2009	Research Study
Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips,2005	Research Study
Choudhury, Charman & Blakemore, 2008	Theoretical Works
De Smedt, Taylor, Archibald, & Ansari, 2010	Research Study
Elliot, 2001	Descriptive Work
Guerri, Bazinet, & Riley, 2009	Theoretical Works
Halpern-Felsher, 2009	Descriptive Work
Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, Troncoso, Muhlhausen, Zschocke, Boy, Hoffmann, Garbade & Kolker, 2009	Research Study
Hurley 2012	Descriptive Work
Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008	Research Study
Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011	Research Study
Just, Keller, Malave, Kana, & Varma, 2012	Theoretical Works
Keller & Just, 2009	Research Study
Kesler, Lacayo, & Jo, 2011	Research Study
Kesler, Sheau, Koovakkattu, & Reiss, 2011	Research Study
Kumar, Mattan, & Vellis, 2006	Theoretical Works
Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008	Research Study
Mostofsky, Burgess, & Larson,2007	Research Study
Nunez, Foussotter, & Sowell, 2011	Theoretical Works
Odegard, Ring, Smith, Biggan, & Black, 2008	Research Study
Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006	Research Study
Pugh, Sandak, Frost, Moore, & Mencl, 2005	Theoretical Works
Rykhlevskaia, Gratton, & Fabiani, 2008	Theoretical Works
Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011	Research Study
Science Daily, 2005 (white matter)	Reviews of the literature
Science Daily, 2006 (kids with autism)	Reviews of the literature
Science Daily, 2008 (dyslexic)	Reviews of the

	literature
Science Daily, 2008 (remedial instruction)	Reviews of the literature
Science Daily, 2009 (Brain Rewiring)	Reviews of the literature
Science Daily, 2011 (WM development)	Reviews of the literature
Science Daily, 2012 (autistic brain activity)	Reviews of the literature
Spreen, 2011	Theoretical Works
Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, Job, Hall, Bastin, Johnstone, Lawrie & McIntosh, 2009	Research Study

3.2. Research design, participants, data sources, and findings of the studies

In the following table, I have included the 17 research studies that contributed valuable insight to this meta-synthesis. The 17 research studies are (Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011; Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005; Bava, Jacobus, Mahmood, Yant & Tapert, 2009; Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips,2005; Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, Troncoso, Muhlhausen, Zschocke, Boy, Hoffmann, Garbade & Kolker, 2009; Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008; Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011; Keller & Just, 2009; Kesler, Lacayo, & Jo, 2011; Kesler, Sheau, Koovakkattu, & Reiss, 2011; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008; Mostofsky, Burgess, & Larson,2007; Odegard, Ring, Smith, Biggan, & Black, 2008; Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006; Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011; Smedt, Taylor, Archibald, & Ansari, 2010; Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, Job, Hall, Bastin, Johnstone, Lawrie & McIntosh, 2009). The research design, participants, data sources, and findings of each of research studies are identified in Table 2.

Table 2

Authors	**Research Design**	**Participants**	**Data Sources**	**Findings**
Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011	Quantitative	35 adolescent-onset psychosis patients and a control group of 31 all age 12 to 20	A battery of neuropsychological assessments and intelligent testing followed up with limited neuroimaging	Improvement in processing speed, as well as visual learning and memory, is associated with improvement in social and role functioning among adolescents and young adults at clinical high risk for developing psychosis. Members of our group recently reported that adolescents and young adults at elevated clinical risk for developing psychosis fail to show typical age-related increases in white matter integrity in tracts linking prefrontal and posterior cortex, and this aberrant developmental trajectory predicts later functional impairments.

Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005	Quantitative	15 right-handed adults.	Results from functional magnetic resonance imaging (fMRI) studies to locate regions of the brain activated along with diffusion tensor imaging (DTI) to predict structural integrity of white matter	By using data to predict cortical activity, which was then used to predict white matter integrity, these data represent an important advance in the available methods for combining magnetic resonance data sets to examine functional connectivity. Traditional methods have used behavior (e.g., reaction times) to predict blood oxygen level-dependent response and/or fractional anisotropy (FA) across subjects. The present study underscores the utility of a stepwise process whereby more of the variance across individuals was accounted for by using an index of cortical activity (derived from the reaction time) to index FA. These results suggest that behavioral performance on a task is related to cortical activity in

				multiple regions, as well as the integrity of the fibers connecting them.
Bava, Jacobus, Mahmood, Yant & Tapert, 2009	Quantitative	72 adolescents from16 to 19 years. 36 were heavy marijuana and alcohol users and 36 demographic ally similar controls with very limited substance abuse.	DTI studies compared with neurocognitive tests	We found decreased FA in temporal brain areas in adolescents with histories of marijuana and alcohol use that was related to poorer attention, working memory, and processing speed. These findings implicate substance-related alterations in white matter with corresponding functional weakness.
Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips, 2005	Quantitative	32 children (14 male 18 female) 8 to 13 years old.	DTI studies to predict structural integrity within regions which coincide with efficient reading	DTI of the brain suggests the importance of regional connectivity in left temporo-parietal white matter for enhanced reading performance in healthy children.
De Smedt, Taylor, Archibald, & Ansari, 2010	Quantitative	37 children 9-11 years old, (25 girls, 12 boys)	Results from functional imaging studies as well as some cognitive testing.	Developmental neuroimaging studies of reading have revealed that the left angular gyrus is consistently activated during phonological awareness tasks and

				that this activation is related to performance differences in phonological awareness tasks and reading ability. At the same time, studies in arithmetic have shown that the left angular gyrus is particularly active whenever the answer to a problem is directly retrieved from long-term memory, which is the case in problems of small problem size, multiplication, and problems that have been highly practiced.
Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, Troncoso, Muhlhausen, Zschocke, Boy, Hoffmann, Garbade & Kolker, 2009	Quantitative	38 patients 18 female 20 male from 9 days to 66 years old (median age 15 months)	An analysis of MRI studies of study patients	We suggest that chronic neurotoxicity affects brain maturation and myelin maintenance.

Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008	Quantitative	38 male, healthy, right-handed (practice group 20; control group 18) median age 24	Results from fMRI studies while patients performed different reading exercises	This is the first study that related GM increase induced by practice to respective task-specific activation. Gray matter (GM) increase was only found within the right hemisphere, which corresponds to the activation pattern and findings of other functional imaging studies. The GM increase in our study was located at the site of maximal task-specific activation and not at the site of maximal overall activation, which challenges the notion that GM increase is a result of mere previous activation. We speculate that short-term practice-induced changes in GM are related to intracortical remodeling.
Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011	Quantitative	20 males, 8 to 19 years, 10 with an autism spectrum disorder and 10 typically	DTI studies to evaluate the structural integrity of the regions of neural connectivity associated with	This study provides evidence of impaired neural connectivity. The clinical implications of these findings is that individuals with

		developing controls.	the structures for social perception and cognition	ASD's are, as Kanner put it, not "biologically provided" the proper neural connections between those cortical nodes vital for processing social information.
Keller & Just, 2009	Quantitative	72 participants 25 good readers and 47 children 8-12 years old who were poor readers. 35 received treatment and 12 did not	Results from diffusion tensor imaging (DTI) to predict poor readers who were the retested after intervention	Reading disability might be associated with structural properties of the white matter that provides the anatomical connectivity among the individual nodes of the reading network. Behavioral intervention can bring about a positive change in the microstructure of the human cortico-cortical white matter tracts, demonstrating the malleability of the anatomical connectivity that supports human cortical network functions.
Kesler, Lacayo, & Jo, 2011	Quantitative	25 children age 7 to 19 years, with a history of	Results from fMRI imaging studies as well as some	The current findings of increased rather than decreased prefrontal activation

		malignancy that involved radiation and/or chemotherap y treatment. Minimum age of 7.	cognitive testing to determine the effectiveness of executive function cognitive rehabilitation	related to higher level, executive function tasks might reflect the use of adaptive training. Adaptive training is designed to continuously increase learning and challenge neural systems resulting in long-term neuroplastic Changes. It has been implemented successfully in children with other forms of brain injury (cancer-related brain injury) including TBI, as well as other brain-based disorders such as attention-deficits and dyslexia.
Kesler, Sheau, Koovakkattu , & Reiss, 2011	Quantitative	16 right handed females with Turner Syndrome 7-14 years old.	Results from functional imaging studies as well as some cognitive testing.	These findings may imply that less proficient math performers rely on attention, memory and /or verbal-based strategies as these are typically subserved by frontal-striatal and temporal regions, while more proficient performers utilize more spatial/

				retrieval-based strategies that are associated with parietal regions. These findings potentially lend further evidence to this functional specialization of the parietal lobe for math skills and suggest that training may help to improve this specialization even in individuals with high risk for abnormal frontal parietal development and function.
Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008	Quantitative	25-5th grade poor readers and other 5th grade good readers	fMRI studies used to measure cortical activation during reading intervention	The central finding was that prior to instruction, the poor readers had significantly less activation than good readers bilaterally in the parietal cortex. Immediately after instruction, poor readers made substantial gains in reading ability, and demonstrated significantly increased activation in the left angular gyrus and the left superior parietal lobule. Activation in

				these regions continued to increase among poor readers 1 year post-remediation, resulting in a normalization of the activation.
Mostofsky, Burgess, & Larson, 2007	Quantitative	8 to 12 years 20 high functioning with autism 36 typically developing controls 20 children with ADHD	Testing of motor skills, Intelligence, combined with fMRI to predict the structural integrity of the white matter associated with the primary motor cortex	Investigators have proposed that the pattern of impairments associated with autism, are secondary to abnormalities in structural and functional connectivity.
Odegard, Ring, Smith, Biggan, & Black, 2008	Quantitative	18 children age 10-14years	Results from fMRI studies to record improvements in cortical activity after reading intervention	Even though the poor responders could not adequately decode words after receiving intensive reading intervention, their phonological awareness and brain activation suggest that the reading intervention rehabilitated phonological awareness.
Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006;	Quantitative	60 children 2 to 4 years old with ASD, 16 with idiopathic development	MRI studies used to measure brain maturation	Prolonged gray and white matter transverse relaxation (T2) in the children with DD likely represents a delay in

		al delay, and 10 with typical development		neuronal development and maturation. Prolonged T2 in gray matter, but not in white matter, observed in children with autism spectrum disorder may signify abnormal developmental processes specific to autism.
Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011	Quantitative	Laboratory Mice	A combination of laboratory experiments and MRI and DTI tests on mice undergoing experiments	Despite apparent recovery in the glial population and in myelin basic protein levels, the disruption in oligodendroglia development and white matter maturation during a critical period of vulnerability leads to long-term deficiencies in white matter organization and integrity.
Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, Job, Hall, Bastin, Johnstone, Lawrie &	Quantitative	108 participants	DTI studies used to determine structural integrity of white matter	In this DTI study comparing patients with Bipolar Disorder, patients with schizophrenia, and controls, deficits in white matter integrity were revealed. This suggests that abnormal structural connectivity may

McIntosh, 2009				underpin the pathology of both bipolar disorder and schizophrenia.

3.2.1. Research design

Out of the 17 research studies, all 17 (100%) used a quantitative research design. The 17 research studies are (Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011; Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005; Bava, Jacobus, Mahmood, Yant & Tapert, 2009; Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips,2005; Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, Troncoso, Muhlhausen, Zschocke, Boy, Hoffmann, Garbade & Kolker, 2009; Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008; Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011; Keller & Just, 2009; Kesler, Lacayo, & Jo, 2011; Kesler, Sheau, Koovakkattu, & Reiss, 2011; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008; Mostofsky, Burgess, & Larson,2007; Odegard, Ring, Smith, Biggan, & Black, 2008; Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006; Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011; Smedt, Taylor, Archibald, & Ansari, 2010; Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, Job, Hall, Bastin, Johnstone, Lawrie & McIntosh, 2009).

3.2.2. Participants and data sources

Two of the 17 studies (12%) used in this meta-synthesis had adults as participants. Both studies (Baird, Colvin, VanHorn, Inati, & Gazzaniga, 2005; Ilg, Wohlschlager, Gaser, Liebau, Dauner, Woller, Zimmer, Zihl & Muhlau, 2008), utilized results from functional imaging studies to investigate the structure of the brain. The majority however, 11 of the 17 studies (65%) utilized primarily school age participants ages seven to twenty years (Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011; Bava, Jacobus, Mahmood, Yant & Tapert, 2009; Beaulieu, Plewes, Paulson, Roy, Snook, Concha, & Phillips,2005; Jou, Jackowski, Papademetris, Rajeevan, Staib, & Volkmar, 2011; Keller & Just, 2009; Kesler, Lacayo, & Jo, 2011; Kesler, Sheau, Koovakkattu, & Reiss, 2011; Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008; Mostofsky, Burgess, & Larson,2007; Odegard, Ring, Smith, Biggan, & Black, 2008; Smedt, Taylor, Archibald, & Ansari, 2010). One of these studies, (Bachman, Niendam, Jalbrzikowkski, Park, Daley, Cannon & Bearden, 2011), used a battery of neuropsychological assessments and intelligent testing, while the other 10 collected their data using different types of functional imaging along with other observations and assessments. All of the school age participants in these 11 studies were also in subgroups that included poor readers, substance abusers, cancer survivors, students with autism, attention deficits, dyslexia, developmental delays, Turner Syndrome, traumatic brain injury, and adolescent-onset psychosis.

One study (6%), (Sussmann, Lymer, McKirdy, Moorhead, Munoz Maniega, Job, Hall, Bastin, Johnstone, Lawrie & McIntosh, 2009) did not mention the age of its participants, but instead studied 108 participants with bipolar disorder and schizophrenia using functional imaging studies. Two of the fifteen studies (12%) (Harting, Neumaier-Probst, Seitz, Maier, Assmann, Baric, Troncoso, Muhlhausen, Zschocke, Boy, Hoffmann, Garbade & Kolker, 2009; Petropoulos, Friedman, Shaw, Artru, Dawson, & Dager, 2006) primarily focused on young preschool children and their response to toxins at very early ages or early diagnosis of developmental delays and autism using MRI studies. Another study (6%) (Schmitz, Ritter, Mueller, Felderhoff-Mueser, Chew, & Gallo, 2011) also looked at toxic disruptions in the early critical period of life however this study did so by using laboratory mice and functional imaging.

3.2.3. Findings of the studies

The findings of the 17 research studies included in this meta-synthesis can be summarized as follows.

1. Traditional methods of determining functional connectivity of different parts of the brain involved behavior observation (e.g., measuring reaction times for a task. The advancements in functional imaging, in magnetic resonance imaging (MRI), and diffusion tensor imaging (DTI) now make it possible to eliminate many variables when studying reaction times and more importantly, detect which paths through the brain are being used during different tasks. This technology has shown that task performance is a combination of the function of various regions of the brain and the integrity of the fibers connecting them.

2. It is understood that practicing a task such as reading, improves an individual's skills. What this research using functional imaging shows is that the task of reading activates specific areas of the brain and the connecting fibers between them. This practice-induced activation, not only improves the skill but it also makes structural improvements within the brain that improve the connectivity and function of the brain, long-term. This physical growth within the brain has been determined to be caused by

myelination: the development of myelin within neurons. Myelin develops around the axon in the synapse and works as an insulator, allowing signals to flow more efficiently.

3. Poor readers, even those with dyslexia, have less activation in the regions of the brain that have been found to be activated during reading tasks than that of non-struggling readers. Remedial reading intervention, even as little as five days' worth, increases this activation. Students with dyslexia that did not respond well to the intervention still struggled with decoding words. However, their phonological awareness did improve after the intervention.

4. In terms of reading, practice-induced activation of the parts of the brain involved in reading, improve both white matter integrity through myelination, and connectivity within the brain, improving the ability to read. This has been successful at even correcting reading disabilities.

5. Studies in arithmetic show that when performing math problems with a small problem size, multiplication, and highly practiced skills, the area of the brain that is activated, the left angular gyrus, is the same that is activated in phonological awareness tasks. Further research also suggests that less proficient math performers utilize different strategies and activate in different parts of the brain than more proficient performers. In addition the area that is used by those more proficient in math, the frontal parietal may be functionally improved by practice-induced activation, even in individuals with high risk of abnormal frontal parietal development.

6. This meta-synthesis has collected data showing how substance abuse of alcohol or marijuana alters the white matter integrity in areas related to attention, working memory, and processing speed corresponding to functional weakness.

7. Functional connectivity deficiencies, caused by poor white matter integrity has been proven to be at least partially involved in many brain based learning disorders and disabilities that impact our students. Research has posited some of these to include poor readers, cancer survivors (with either damage from tumors or from radiation or chemotherapy), students with autism, attention deficits, dyslexia, developmental delays, traumatic brain injury, bipolar disorder, schizophrenia, and adolescent-onset psychosis.

8. Disruptive events such as early toxicity or exposure to hyperoxia during critical pre and post-natal childhood periods can cause myelination abnormalities and white matter injury.

3.3. Emerging themes

There were five emergent themes found in my analysis of these 35 articles that are included in this meta-synthesis. The emergent themes, or theme clusters include: (a) advancements in methods for using magnetic resonance to identify the combination of the regions of the brain activated while performing certain skills, such as visual recognition, reading , math or social interaction; (b) advancements in methods of magnetic resonance that identify how parts of the brain are activated by specific remedial or repetitive tasks; (c) advancements in methods of using magnetic resonance to measure structural properties of the white matter within the brain; (d) how different disorders and delays are related to poor connectivity between parts of the brain; and/or

(f) any research that observes an improvement in deficits caused by these disorders or delays that are connected to practice-induced activation of the brain, intended to improve the connectivity of the brain. These five emergent theme clusters and their formulated meanings are included in Table 3.

Table 3

Theme Clusters	Formulated Meanings
Advancements in methods for using magnetic resonance to identify the combinations of the regions of the brain activated while performing certain skills, such as visual recognition, reading, math, or social interaction	• Magnetic resonance is effective in examining the functional connectivity of regions of the brain during specific tasks. • Blood oxygen level-dependent functional magnetic resonance imaging (BOLDfMRI) identifies localized activity of neurons in the brain. • Diffusion tensor imaging (DTI) measures the displacement of water molecules (diffusion) within the structure of the brain, and shows when microstructural obstacles limit this diffusion. These obstacles can include integrity of axonal cell membranes, integrity of myelin, and the number and size of axons. • DTI permits virtual dissection of white matter and investigation of brain connectivity on living patients. • Results from magnetic resonance imaging (MRI), suggest that task performance is related to cortical activity in multiple regions of the brain and the integrity of the fibers connecting them. • A specific type of MRI known as diffusion tensor imaging (DTI) shows activation in the left temporal-parietal region of the brain during enhanced reading performance. • The Broca's area and the Wernicke's area, near the temporal-parietal region, control language comprehension and interpretation of speech. • The temporal-parietal region is significantly less activated in poor readers than in more proficient readers. • Children with dyslexia typically exhibit decreased activation in the left inferior parietal lobe, an area thought to be connected to orthographic and phonological representations of language. • Functional imaging studies have identified a reading cortical network that includes occipito-temporal, temporo-parietal, and inferior frontal cortical regions that are under-activated in children with reading disabilities. • The same regions of the brain that are activated during phonological processing are also used when solving smaller arithmetic problems that are more likely to be solved by retrieving the answer from memory. • Less proficient math performers typically utilize the frontal-striatial and temporal regions of the brain associated with attention, memory, and verbal based strategies while more proficient math performers use the parietal regions associated with spatial/retrieval based strategies shown as these regions are activated during math performance.

The use of magnetic resonance to identify how certain parts of the brain are activated by specific remedial or repetitive tasks	• Remedial reading instruction increases activation in the temporal-parietal region to near normal levels and these increases remain long after the remedial instruction has been ended. • Remedial reading interventions lead to increased activation of the reading cortical network that includes occipito-temporal, temporo-parietal, and inferior frontal cortical regions improving reading ability in students with reading difficulties. • Extensive piano practice as a child is connected to improved connectivity between the regions of the brain associated with motor skills. • Adaptive training, a computerized curriculum of repetitive executive skills practice brought about activation in the prefrontal regions of the brain for children with traumatic brain injury (TBI), attention deficits, dyslexia, and cancer survivors.
The use of magnetic resonance to measure structural properties of the white matter within the brain	• Results from DTI studies indicate that behavioral intervention such as remedial reading interventions can change the microstructure of the cortico-cortical white matter tracts. • Through DTI it is possible to determine if changes to white matter are caused by changes in myelin development or an increase in axon diameter. • DTI studies show increased myelination in children with 100 hours of intensive remedial reading instruction. • Higher-level cognition is based on cofunctioning of a large network of cortical areas and cortical communication, and these can be positively altered through behavioral intervention. • Increase in gray matter within the brain can be induced by task-specific activation, and the increase occurs at the point of that task-specific activation and not at other areas of overall activation. This was observed after as little as 2 weeks of 15 minutes a day and is believed to be the results of intracortical axonal remodeling.
Different disorders and delays that are related to poor connectivity between parts of the brain	• Children with autism spectrum disorder (ASD) show more signs of abnormal development within the gray matter and more typical development in the white matter while children with developmental delays (DD) show the abnormal development in both gray and white matter. This may point to children with DD having a delay in neuron development and maturation, and those with ASD an abnormal developmental process specific to Autism. • Autism has been found to be associated with higher white matter volume that consists of shorter connecting fibers that connect more locally instead of longer fibers connecting distant cortical-subcortical regions of the brain. This is believed to be a defining biological feature associated with deficits in motor skills, communication, and social skills as well as strengths in

	perceptual processing. ● Evidence has been found of impaired neural connectivity between the cortical nodes used in the processing of social information for individuals with autism. ● Chronic neurotoxicity affects brain maturation and myelin maintenance. ● Reading disability is often associated with structural properties of the white matter that provide the anatomical connectivity among the reading network within the brain. ● Abnormal structural connectivity caused by deficits in white matter integrity is found present in patients with bipolar disorder and schizophrenia. ● Studies of adolescence with a history of marijuana or alcohol use exhibit a functional weakness of white matter related to poor attention, working memory and speeded processing as a result of the substance abuse. ● Patients at high risk for adolescent-onset Psychosis are believed to have disruptions in brain developments such as myelination. ● Children born premature are more likely to develop future motor and cognitive deficits from a disorder that causes disruptions in myelination and neurological development called periventricular white matter injury. ● Children with attention deficits, dyslexia, and brain injury caused by cancer treatments, tumors or other traumatic injuries can all experience improvements from techniques intended to improve the connectivity and integrity of the white matter within the brain.
Research that observes an improvement in deficits caused by these disorders or delays that are connected to practice-induce d activation of the brain, intended to improve the connectivity and integrity of the brain	● After 100 hours of remedial reading instruction, poor readers including some with dyslexia, showed increased activation levels within the regions of the brain connected to reading to near normal levels and improved reading ability. Both reading improvement and brain activation were continuing to improve 1 year after remediation. ● Given 2 years of phonological intervention, all but 2%to 6% of children with dyslexia responded well and showed both improvements in activation of the regions of the brain associated to non-impaired reading. The non-responders still struggled with decoding words but they showed improvements to their phonological awareness and brain activation. ● Simple remedial math instruction and repeated practice on a computerized skills practice at home, bring about improved math skills and results in more activation in the regions of the brain associated with the more efficient spatial/retrieval-based strategies and less activation in the regions used when relying on attention, memory, and verbal skills. ● Adaptive training, a computerized curriculum of repetitive

	executive skills practice, brought about activation in the prefrontal regions of the brain for children with traumatic brain injury (TBI), attention deficits, dyslexia, and cancer survivors.

4. Discussion

In this section, I have summarized the emergent themes from my analysis of the 35 articles presented in this meta-synthesis. These emergent themes were then connected to my experience teaching students with diverse educational needs, and more specifically my experience teaching these students in a reading intervention program.

4.1. Advancements in methods for using magnetic resonance to identify the combinations of the regions of the brain activated while performing certain skills, such as visual recognition, reading, math, or social interaction

As magnetic resonance imaging (MRI), first came on the scene scientist realized they could technologically look into the brain to look at size and shape and even some possible deformities. However, over the last decade, science has learned to not only look at localized regions of the brain but to also look at the connective tissues carrying signals between them. Through what is called blood oxygen level-dependent functional magnetic resonance imaging (BOLD fMRI) or often fMRI, scientists have been able to recognize which cortical regions are being activated during specific activities (Baird, Covin, VanHorn, Inati, & Gazzaniga, 2005). Abigail Baird and her colleagues then utilized a new form of magnetic resonance technology called diffusion tensor imaging (DTI) to measure the displacement of water molecules within the white matter of the brain. By measuring this displacement or diffusion, Baird and her associates then determined how efficiently signals are traveling through the white matter and thus the integrity of the white matter (Baird, Covin, VanHorn, Inati, & Gazzaniga, 2005). Scientists by using this technology were now able to determine which cortical regions were activated during specific tasks, but also the integrity of the white matter in which the communication between these regions is taking place.

Functional magnetic resonance imaging (fMRI) has shown how task performance is “related to cortical activity in multiple regions, as well as the integrity of the fibers connecting them” (Baird, Covin, VanHorn, Inati, & Gazzaniga, 2005, p. 691) With the diffusion tensor imaging (DTI) technology it was now possible to look into and predict the structural integrity of those fibers. Using DTI scans, scientists at the University of Alberta, in Edmonton, Alberta, identified “the importance of regional connectivity in left temporo-parietal white matter for enhanced reading performance in healthy Children” (Beaulieu, et al., 2005, p. 1270). According to one of the universities researchers, Christian Beaulieu, this region is also in the area where the Wernicke and Broca are found. These are known to control both language comprehension and interpretation of speech (Beaulieu, et al., 2005). By recording the level of activation, scientists were now able to predict the regions of the brain involved in specific tasks like reading.

Not only was it possible to measure this activation, it was also possible to determine that poorer performing readers were experiencing less activation in the parietal cortex than proficient readers (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008). Students with developmental dyslexia exhibited less activation during reading tasks in the left inferior parietal lobe, which is a region related to both orthographic, or spelling words, and phonological representations of language (Odegard, Ring, Smith, Biggan, & Black, 2008). It has been consistently observed that in the case of students with reading disabilities, they have less activation in a network of the brain that includes the occipito-temporal, the temporo-parietal, and the inferior frontal cortical region during reading tasks (Keller & Just, 2009). Most of the earlier research focused on the task of reading, although there were studies revealing other things. Roger Jou and his associates showed through activation levels how individuals with autism had evidence of impaired neural connectivity within a combination of regions that make up what they call the social brain, or a combination of brain structures believed to be critical in social perception and cognition (Jou, et al., 2011). In addition, Bert De Smedt and his coworkers observed that while performing math problems where the answers are pulled from one's long-term memory, such as smaller easier problems or those highly practiced like times tables had higher activation in the same cortical regions as an individual performing a phonological awareness tasks (De Smedt, Taylor, Archibald, & Ansari, 2010). This coincides with previous evidence that there is indeed a connection of the development of reading and math skills.

Not only have researchers been able to detect which cortical tracts are being activated when tasks are taking place, they have also been able to identify where some individuals utilize different tracts or compensate when the typical tracts are not used. Shelli Kesler and others from Stanford University looked at females with Turner Syndrome because of the disease's high risk for math deficits. These girls typically exhibit a disrupted function to the frontal-parietal of the brain, an area known for its relationship to math processing. They typically showed a higher activation in another area, the frontal striatal and mesial temporal, as a less efficient adaptation to compensate for the disruption to the parietal lobe (Kesler, Sheau, Koovakkattu, & Reiss, 2011). A study by Ann Meyler *et al.,* found areas of over activation in the medial frontal cortex, outside of the areas associated with proficient reading. This would indicate that poor readers were compensating with a more effortful and attention based reading strategy (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008). It is not enough to just know which regions are being activated or not as well activated during specific tasks; it is important to research what can be done to make improvements to any deficits or obstacles to the connectivity throughout the brain.

4.2. The use of magnetic resonance to identify how certain parts of the brain are activated by specific remedial or repetitive tasks

During much of the early MRI research that was related to reading ability. It became evident that reading involved specific points in the brain. It also became evident that activation could be intentionally induced by performing certain tasks. Remedial, repetitive, reading instruction would induce activation in the cortical tracts that were needed for proficient reading ability. This induced activation works like reading calisthenics or working out the brain like one would work out the body (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008). These reading interventions not only increased reading skills and ability, “it brought about a positive change in the microstructure of human cortico-cortical white matter tracts, demonstrating the malleability of the anatomical connectivity that supports human cortical network function" (Keller & Just, 2009, p. 625).

This phenomenon is not only present when the activation is from reading interventions. Diffusion tensor imaging has also shown a direct link between children that receive extensive piano practice to improved structural connectivity in the tracts of the brain associated with motor skills from the activation induced from the Piano practice (Keller & Just, 2009). Another example of specific task induced activation comes from the research of Shelli Kesler and her associates at Stanford University. In her study of children recovering from cancer-related brain injury, Kesler looked for ways to activate sections of the brain involved with cognitive deficits. A cognitive rehabilitation program was developed that included tasks involving attention, cognitive flexibility, and working memory skills. The program, named adaptive training, was computerized so it could be done repetitively and from home. The results again showed increased brain activation in the areas connected to higher functioning, executive functioning skills (Kesler, Lacayo, & Jo, A Pilot Study of an Online Cognitive Rehabilitation Program for Executive Function Skills in Children with Cancer-Related Brain Injury, 2011).

4.3. The use of magnetic resonance to measure structural properties of the white matter within the brain

This research thus far has looked at how advances in magnetic resonance have allowed scientists to detect which regions of the brain are utilized for certain tasks. They have used this information to develop methods for inducing activation to these regions in order to attempt to improve the structural integrity of the brain and the fibers connecting the regions of the brain. Researchers have also been able to use new technology to better understand what is taking place to improve the structural properties.

Many of the studies in this meta-synthesis show not only behavioral improvements that lesson deficits in things like reading, arithmetic, motor skills, and cognitive ability in general, they also measure increased structure in both gray and white matter. Statements like reading calisthenics for the brain (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008), and rewiring the brain (Kesler, Sheau, Koovakkattu, & Reiss, 2011) talk about the structural improvements to the brain but through magnetic resonance and specifically diffusion tensor imaging (DTI), it has become possible to understand more about exactly just what is taking place to the microstructure of the brain.

Initially researchers could measure behavioral improvements such as quicker responses or improved skills. However, with DTI, they could now observe just what was changing. DTI measures the displacement of water molecules. Anisotropy quantifies how much the diffusion varies along a sampled axis. Fractional anisotropy shows the shape of the diffusion, whether it is tight and highly directional along the length of the axons or is scattering in a sphere shape around the axon. Obstacles that may cause this scattering of the signals within the brain include the number and size of the axons, the integrity of the axonal cell membranes, or the integrity of the myelin surrounding the axons (Baird, Covin, VanHorn, Inati, & Gazzaniga, 2005). Researchers have been able to define the changes that take place to improve the integrity of the white matter using DTI. According to Timothy Keller and Marcel Just, of the Center for Cognitive Brain Imaging, at Carnegie Mellon University, when diffusion is measured perpendicular to the primary axis of diffusion it is called radial diffusivity and when it is parallel to the axis, it is called axial diffusivity. When changes are to radial and not axial diffusivity, it is caused by changes in myelin development. If the changes are to axial and not radial diffusivity then the cause is increased axon diameter (Keller & Just, 2009).

In studies involving remedial reading instruction, Ann Meyler and her colleagues were able to measure increased integrity of white matter due to myelination after intervention (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008). When assisting young survivors of leukemia, Kesler and her fellow workers used functional magnetic resonance imaging (fMRI) to assess the neurobiological changes representing improved cognitive performance (Kesler, Lacayo, & Jo, A Pilot Study of an Online Cognitive Rehabilitation Program for Executive Function Skills in Children with Cancer-Related Brain Injury, 2011). Finally, early studies by neurologist Rudiger Ilg and many others, measured increases in gray matter from task specific activation. This increase was after as little as two weeks of fifteen minutes per day of induced activation. Because the increase of gray matter was at the point of the task specific activation and not at the spot of the most activation, and because it was measurable after a mere two weeks, researchers believe that the cause of the increase is from intracortical axonal remodeling (Ilg, et al., 2008). All the research changes our understanding of learning from merely a storing of information, to an understanding of learning as a restructuring of the microstructure within the brain. Specific instruction can improve and increase that restructuring.

4.4. Different disorders and delays that are related to poor connectivity between parts of the brain

In 2011, Otfried Spreen presented a particularly thorough review on the topic of nonverbal learning disorder (NLD) which I found interesting for two important reasons. First, the hypothesis that NLD has a frequent co-occurrence with emotional disorder, depression, and suicide concerned me in my teaching position. Second, is the hypothesis that NLD may be caused by deficiencies in white matter (Spreen, 2011). In his review, Spreen reported, “White matter anomalies are dysregulated / impaired / atypical / degenerative fibers found in just about every childhood disorder” (Spreen, 2011, p. 429). This meta-synthesis attempts to look at many of brain-based disorders that afflict our students today.

One of the most researched disorders that have been studied utilizing magnetic resonance is that of autism spectrum disorders. Researchers, from the University of Washington, School of Medicine, compared children with developmental delays to children with autism spectrum disorder. They concluded that since children with developmental delays showed effects to both gray and white matter, they most likely representing a delay in neuronal development and maturation. Children with autism spectrum disorder only showed the effects in the gray matter and not the white matter. This, researchers believe signifies an abnormal developmental process specific to autism (Petropoulos, et al., 2006). Another study involving Autism and attention-deficit / hyperactivity disorder (ADHD), performed by Stewart Mostofsky and others of John Hopkins School of Medicine looked at white matter volume and structure in relation to motor skills impairments. The findings of this study found a connection between autism and increased white matter volume in the outer radiate regions. Neuroimaging also found that individuals with autism tend to have more short connecting fibers within the radiate white matter instead of longer fibers connecting distant cortical and subcortical regions. These conditions are associated to the functional impairments of basic motor skills, which correlate to autism spectrum disorder (Mostofsky, Burgess, & Gidley Larson, 2007). Yet another study concerning individuals with autism was done by Roger Jou and associates: and this study provided evidence of impaired neural connectivity between what is known as the processing nodes of the social brain. These abnormalities are found in the structures critical for social perception and cognition, so often seen as a deficit for individuals with autism spectrum disorder (Jou, et al., 2011).

Autism is just one disorder found to be associated to poor connectivity and white matter integrity. With all the research focused on reading disabilities it is no surprise researchers understand the connections between reading disabilities, even dyslexia, and the structure of the brain. Keller and Just, of Carnegie Mellon University used DTI to reveal decreased microstructural organization within the cerebral white matter connected to reading disabilities and deficiencies (Keller & Just, 2009). Bert De Smedt *et al.* showed how connections between phonological awareness and math deficiencies are due to the white matter integrity imperative for proficient reading is the also key for math skills (De Smedt, Taylor, Archibald, & Ansari, 2010).

Not just academic skills are at risk when white matter integrity is deficient or delayed. Jessika Sussmann and her coworkers used DTI studies to reveal that both bipolar disorder and schizophrenia are also related to abnormal structural connectivity within the white matter (Sussmann, et al., 2009). Peter Bachman and his fellow researchers from the University of California studied young adults and adolescents at high risk for early onset psychosis and found that those at elevated risk had less that typical white matter integrity (Bachman, et al., 2012). As one looks at all the research, the comments from Spreen's studies that white matter anomalies are found in just about every childhood disorder, seems to be holding true. It is also important to recognize our diseases and the actions of individuals that bring about that white matter dysfunction.

Kesler, Lacayo, and Jo in their research on survivors of leukemia and brain tumors used the same cognitive rehabilitation of repeated skills practice that had proven successful with individuals with traumatic brain injury and other brain based disorders such as attention-deficits, and dyslexia. This cognitive rehabilitation called adaptive training was a computer model of repetitive skills practice that activated parts of the brain and the white matter connecting them. This research builds a connection between damage to the brain from traumatic injury, radiation, chemotherapy, or even cancer or surgery and the integrity of the fibers connecting the regions of the brain (Kesler, Lacayo, & Jo, A Pilot Study of an Online Cognitive Rehabilitation Program for Executive Function Skills in Children with Cancer-Related Brain Injury, 2011). Even when the damage is the cause of fetal alcohol spectrum disorder (FASD), it is still understood to be an effect on the white matter. Along with other alterations to the brain FASD is known to bring about reduced white matter (Guerri, Bazinet, & Riley, 2009). MRI findings have also shown significant brain activation differences for individuals with FASD on many cognitive tasks (Nunez, Roussotte, & Sowell, 2011).

A group of researchers from the University of California, led by Sunita Bava, was able to correlate marijuana and alcohol use in adolescents to alterations in their white matter causing functional weakness. These weaknesses were in the areas of attention, working memory, and speeded processing (Bava, Jacobus, Mahmood, Yang, & Tapert, 2010). Inga Harting and associates also found that neurotoxins could build within the brain of newborn infants and cause delays and damage to brain maturation and myelin development (Harting, et al., 2009). Another study found that impaired neurological development in infants born premature was linked to abnormalities in myelination. In this study, Thomas Schmitz and others performed research on neonatal rats including DTI studies and found that during a critical period, white matter vulnerability leads to long-term deficiencies to white matter integrity (Schmitz, et al., 2011). As one understands the research found in this meta-synthesis, it becomes apparent that white matter integrity is involved in the majority of disorders individuals face and many of the deficiencies.

4.5. Research that observes an improvement in deficits caused by these disorders or delays that are connected to practice-induced activation of the brain, intended to improve the connectivity and integrity of the brain

Much of the research in this meta-synthesis has focused on the temporal-parietal region of the brain and its connections to proficient reading. Ann Meyler and her colleagues observed that poor readers were not seeing the same activation levels in this region as readers that are more proficient. However, after 100 hours of intensive instruction the poorer readers made significant gains in both their activation levels and their reading ability. Even more astounding, those poorer readers continued to improve in both categories one year after the 100 hours of intervention had been completed. The gains saw many of the participants at the same reading and activation levels as the proficient readers by the end of the study (Meyler, Keller, Cherkassky, Gabrieli, & Just, 2008). In another study, Timothy Odegard and his fellow researchers looked at individuals with developmental dyslexia who did not respond well to phonological remediation. These non-responders made up between 2% to 6% with the remainder responding well to the intervention. Although, after 2 years of intervention the non-responders still struggled with decoding words, the remediation did improve activation within the cortex as well as phonological awareness (Odegard, Ring, Smith, Biggan, & Black, 2008).

Similar results were found when researchers looked at inducing practice activation in the regions of the brain used to solve math problems. Shelli Kesler and others from Stanford University provided simple math instruction and a home-based computer program for math skills to young girls with Turner Syndrome. Turner Syndrome brings a high risk of altered brain development of math related brain networks causing math difficulties. The results were functional changes in the frontal-parietal networks of the brain and improved math skills (Kesler, Sheau, Koovakkattu, & Reiss, 2011).

Another computer program designed to be used at home was developed for another of Shelli Kesler's studies as she worked this time with Norman Lacayo and Booil Jo. This time the participants were pediatric cancer survivors. The computer program was meant to be a cognitive rehabilitation that utilized repeated skills practice. Research has proven this an effective intervention for attention deficits, dyslexia, and even traumatic brain injury. The computer program called adaptive training was designed to build executive function skills and activate the prefrontal region of the brain. It is associated with higher cognitive skills and significantly increased processing speeds and improved memory (Kesler, Lacayo, & Jo, A Pilot Study of an Online Cognitive Rehabilitation Program for Executive Function Skills in Children with Cancer-Related Brain Injury, 2011). This meta-synthesis shows that while many disorders and deficiencies are related to white matter integrity, science is learning how to restructure, rehabilitate, and rebuild this integrity through practice-induced activation of specific regions of the brain.

5. Conclusion

The research evaluated in this meta-synthesis has shown that interventions designed to build academic and cognitive skills do more that build levels of competency. Advances in neuroimaging have shown us that brain matter is being restructured and even recreated to be more efficient and more connected so that disorders are often mediated. When looks at students with known damage to the brain it is exciting to know that there are interventions to not only help students to compensate for the damage but to even remediate and heal the structures effected. It is just as promising when the damage is less visible and understood as in the case of the many brain-based disorders that this same neuroimaging technology has associated with specific white matter anomalies. The many interventions that are centered on task specific practice-induced brain activation have been effective in remediating deficits and restoring structural integrity to white matter dysfunctions.

One reason that this research has caught my attention is that I have experienced some of these findings in my own career. Over the last four years, I have taught using a reading intervention that included a computer software program that worked on reading, spelling, and word recognition and decoding. This is performed through repetitive practice for 20 to 30 minutes per day during school days. I work at a separate day school setting and the students that I have taught during those four years have been students with almost every one of the conditions and disorders discussed in this meta-synthesis. I do not have the luxury of brain scans to back up my personal observations; however, I have seen the same improvements in reading improvements as well as improved social and cognitive skills for the majority of my students that engaged in the intervention for more than three months. This is not to say that reading skills improved, but that they had improved at a rate of at least two grade levels in every year. The majority of these students gaining more than three or four grade levels per year. Many of these students also exhibited behavioral problems, social and emotional deficits, and other learning disabilities; which also improved along with their reading skills. Another correlation to this body of research is that my students who discontinued the intervention and returned after six months to a year had continued to advance in their reading skills.

I continue to work with students with each of the disorders and conditions discussed in this meta-synthesis on a routine basis. I cannot help but to be excited at the direction the research has gone and appears to be going in the future. I have been privileged to be a part of student success over the last four years and hope to continue that tradition. I intend to use this new information to find and implement interventions that target both math and executive function skills. I will also follow the new research as it discovers new interventions to help students with the many brain-based disorders to remediate and even heal their deficits.

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