Traumatic Brain Injury in Pediatrics

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Traumatic Brain Injury in Pediatrics

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Abstract

Traumatic Brain Injury (TBI) is an acquired brain injury as a result of an external force to the head. Common causes for these injuries include falls, motor vehicle accidents, sports, and abuse. The affected location of the brain, severity, and age at the time of injury affect what deficits are present. Resulting deficits can be in speech, language, behavior, motor, and cognition/executive functions (Manasco, 2020). Traumatic brain injuries can affect all ages. No parent wants to experience their child going through this. TBIs do not just affect the patient but also loved ones. During this difficult time, parents or caregivers may not understand what is being explained to them by healthcare professionals. The main objective of this project is to synthesize the literature on executive function in children with traumatic brain injury. The second objective is to develop a family-friendly tutorial on executive functions in children with TBI, so caregivers have information they need about the brain, traumatic brain injuries, and the available options for intervention for executive function deficits.

Keywords: traumatic brain injury, pediatrics, cognition, executive functioning, interventions
**Traumatic Brain Injury in Pediatrics**

A traumatic brain injury (TBI) is a traumatically-induced structural injury or physiological disruption of brain function as a result of external force. TBI is indicated by the presence or worsening of at least one of the following signs immediately after the event; loss of consciousness, loss of memory, altered mental state, neurological deficit, or intracranial lesion (Manasco, 2020). In simpler terms, TBI is an acquired brain injury that occurs when there is a blow to the head (Cleveland Clinic, 2021). In 2020, there were more than 214,000 TBI-related hospitalizations (Centers for Disease Control and Prevention, 2023). Some causes of traumatic brain injury include motor vehicle accidents, falls, being struck by an object, sports accidents, and violent assaults. The risks of acquiring a traumatic brain injury are associated with age and gender. For instance, children younger than 4 years of age and older adults greater than 75 years have a higher risk of acquiring a TBI mainly due to falls. Adolescent males between the ages of 15-19 are more likely to acquire a TBI as a result of a motor vehicle accident. Overall, males are more likely to experience a TBI due to the likelihood of high-risk activities (Manasco, 2020).

The leading causes of traumatic brain injury in the United States for the pediatric population as of 2022 are falls (which account for about half of brain injuries in children), unintentional blunt trauma (28% of brain injuries in children are caused by being hit on the head by an object, like a baseball or soccer ball), motor vehicle accidents (leading cause of TBI-related death in children older than age 5), and homicide (leading cause of death in children age four and younger) (Traumatic Brain Injury (TBI): Pediatric Causes and Prevention Strategies, 2022).
**Types of Traumatic Brain Injury**

Traumatic Brain Injuries can be split into two categories, traumatic impact and traumatic inertial (Brain Injury Association of America, 2023). Traumatic impact injuries are contact injuries where the head is struck by or against an object. There are two types of traumatic impact injuries which are open head and closed head injuries. Open head injuries are when the skull is opened due to penetration (Cleveland Clinic, 2021). Closed head injuries are non-penetrating meaning the meninges are still intact (Brain Injury Association of America, 2023).

Open head injuries can be caused by gunshot wounds, stabbing, falls, motor vehicle accidents, and sports accidents. Typically, these injuries are focalized, meaning just the area that is penetrated is affected. Closed head injuries can be caused by blast-related injuries, assaults, falls, motor vehicle accidents, and sports accidents. These injuries can be either focal or diffuse. Diffuse injuries are characterized by widespread damage (Brain Injury Association of America, 2023).

Traumatic inertial brain injuries are non-contact injuries. These occur when the brain moves within the skull. Causes of these include falls, motor vehicle accidents, and sports-related accidents (Brain Injury Association of America, 2023). These injuries are typically diffuse due to the nature of these injuries. One example of a traumatic inertial brain injury is an acceleration-deceleration head injury. This is when a person’s body is moving quickly through space and then comes to an abrupt stop that is sudden enough to cause the brain to slam into and bounce around inside of the skull. Another name for these types of accidents is coup-contrecoup injuries. The coup is the force forward that causes the initial injury. The contrecoup is the second injury to occur that causes an equal injury to the opposite side of the brain as the initial injury.
This is very common in motor vehicle accidents (Manasco, 2020). For example, when a person is in a fender bender, they slam on the brakes causing their body to propel forward (coup). Then if they hit the car in front of them, that would cause their body to propel backwards (contre-coup).

**Symptoms and Deficits Following Traumatic Brain Injury**

Symptoms and deficits that follow traumatic brain injury depend on the degree, type, and severity of the injury. Key symptoms for adults include loss of consciousness, loss of memory, nausea or vomiting, dizziness or fatigue, behavioral changes, sensitivity to light, slurred speech, and sleeping too much or too little. The symptoms for infants and children are different and may include crying nonstop and refusal to eat, drink, or breastfeed (Cleveland Clinic, 2021).

Deficits that can be seen can affect motor and cognitive functioning. Motor deficits can include fine and gross motor deficits. Cognitive deficits following a TBI can include deficits in orientation, attention, memory, and executive functions (Manasco, 2020).

**What are Executive Functions?**

Executive functioning (EF) is an umbrella term to encompass goal-oriented control functions of the prefrontal cortex (Best et al., 2009). These mental processes enable us to plan, focus attention, remember instructions, and juggle multiple tasks successfully (Center on the Developing Child Harvard University, 2017). Executive functions are essential for mental and physical health, success in school and life, and cognitive, social, and psychological development (Diamond, 2013). There are significant associations between executive functions and academic achievement. The Cognitive Assessment System scale (CAS) was used to examine the
associations between specific math skills and cognition. Deficits in basic math skills were found to be related to lower performance on all CAS scales. Deficits in word problem-solving were associated with deficits in attention and successive planning. In general, deficits in EF have also been shown to be related to poor reading and writing skills (Best et al, 2009).

According to Zelazo and Carlson (2020), there are three core executive functions including inhibitory control, working memory, and cognitive flexibility. Inhibitory control involves deliberately suppressing attention to something like a distraction or impulse (Zelazo and Carlson, 2020). This skill is responsible for controlling attention, behavior, and one’s emotions (Diamond, 2013). Working memory is the ability to hold onto information and manipulate it in some way (Zelazo and Carlson, 2020). This is crucial for making sense of both written and oral language and translating instructions and related information together (Diamond, 2013). Lastly, cognitive flexibility involves thinking about a single stimulus in multiple ways (Zelazo and Carlson, 2020).

**Development of Executive Functions**

Executive functions are not something with which you are born (Zelazo & Carlson, 2020). These are skills that take years to develop, even throughout adolescence. They require practice and repetition (Shakibaie, 2022). During the first two years of life, some of these skills start to develop through environmental learning or incidental learning (Shakibaie, 2022). Within these years the development of planning, problem solving, working memory, and attentional control can be seen.
Planning is the ability to set goals, understand responsibilities, and analyze tasks to complete those goals. This skill starts to develop in infancy. When an infant starts to point to objects and grab objects, their planning skills start to develop (Shakibaie, 2022). Between eighteen months and thirty-six months, toddlers can start to enjoy simple puzzles. For example, when completing a puzzle, if puzzle piece shapes do not fit, the toddler must start to exercise planning skills for determining which piece to try next (Center on the Developing Child at Harvard University, 2014). For three to five-year-olds, during intentional imaginary play, planning skills continue to build and develop as the difficulty of play with activities also increases. In addition, Best et al. (2009) found that the ability to effectively create more complex plans develops in late childhood or adolescence.

Problem-solving is the ability to identify the problem and generate solutions. This skill encompasses multiple skills such as planning, memory, and attention. Infants and children develop problem-solving skills through play. As they age, they learn turn-taking, decision-making, and brainstorming solutions (Shakibaie, 2022). Keen states that “primitive problem-solving begins early, before one year of age,” (Keen, 2011). Between the ages of six to ten, children should be able to focus on several aspects of a problem at a time, increase their problem-solving ability (although not to the level of an adult), and think of simple plans before acting (A Parenting Program by The American Psychological Association, 2017).

Working memory is the ability to keep information “in mind” and manipulate it in some way (Zelazo and Carlson, 2020). This skill takes time to develop, but parents and caregivers can help provide opportunities for toddlers to develop this skill (Shakibaie, 2022). Working memory can be exercised between six to eighteen months old in games such as Peekaboo which challenges the baby to not only remember who is hiding but to wait for the reveal (Center on the
Developing Child at Harvard University, 2014). During this time another way that working memory can develop is through a child’s exposure to predictable rhymes. As the infant develops familiarity with the rhyme, they practice the anticipation of the surprise (Center on the Developing Child at Harvard University, 2014). For eighteen to thirty-six months, imitation games and songs like I’m a Little Teapot with movements help to continue the development of those working memory skills. During three to five years old, there is rapid growth in executive function skills. During this time, working memory can continue to be practiced during imaginary play, storytelling, and songs that repeat and add on more information such as She’ll be Coming ‘Round the Mountain. Other activities that allow a child to develop working memory skills include puzzles, strategy games, matching games, learning an instrument, and brain teasers. And again, as the difficulty of these activities increases, the working memory development needed to engage in them increases (Center on the Developing Child at Harvard University, 2014). In conclusion, the ability to hold information in the mind develops early. Even young children and infants can hold onto one or two pieces of information in their minds. However, being able to hold many things and manipulate information is far slower to develop (Diamond, 2013). To further this point, Gethercole et al., (2004) found that there is an increase in performance between ages 4 and 15 for different working memory tasks of increasing complexity (Best et al., 2009).

Attentional control develops in infancy when an infant learns to hold their gaze to focus on different objects (Shakibaie, 2022). This is an important skill to stay on task. During six to eighteen months, pointing and naming objects is when attention skills start to emerge (Center on the Developing Child at Harvard University, 2014). Between eighteen to thirty-six months, children build attentional control abilities through activities such as imitation games, rhymes,
sorting games, and simple puzzles. For three to five-year-olds, activities such as imaginary play, storytelling, and cooking provide opportunities for continued development of attentional control. For five to seven-year-olds, games like Red Light, Green Light, Slapjack, and Simon Says are all great ways for a child to improve attentional control (Center on the Developing Child at Harvard University, 2014). As mentioned above, as a child continues to age, attentional control increases with the difficulty of attentional tasks that they practice.

Shifting is the ability to switch between mental states, operations, or tasks (Best et al., 2009). The ability to shift between more complex tasks improves as you age, typically until early adolescence. Best et al. 2009 conducted a literature review and found that three and four-year-olds can reliably shift between two simple tasks if the rules or instructions are easily understood. Improved set shifting in more complex shifting tasks (shifting between responding to either lines or shapes on a computer screen) is further seen between ages five and six.

**Executive Functions in Children With TBI**

Krasny-Pacini et al. (2017) conducted a longitudinal study of children (3 months to 14 years old at the time of injury) with severe TBI who were tested with performance-based tests and questionnaires of executive functions at 3, 12, and 24 months post-injury. The four executive functions that were observed were inhibition, flexibility, attention, and planning. The authors used many different tests to determine these scores. Some of these tests include the Stroop Test, Wisconsin Card Sorting Test, Tower of London, NEPSY-1: A Developmental Neuropsychological Assessment Visual Attention and Auditory Attention subtests, and the Behavior Rating Inventory of Executive Function (BRIEF). During this study, they found that these children showed significant impairments in working memory, inhibition, attention, and
global executive functions after sustaining a severe traumatic brain injury. For flexibility and performance-based tests, they found that children were impaired at three months after injury but by twelve months their scores improved to be within normal range. There were no impairments found in planning at any time. Their findings were similar to other studies in that their results did not find any impairment in planning. The authors suggest this is because this skill typically develops later around twelve years of age. Lastly, attention was impaired during all assessment times (Krasny-Pacini et al, 2017).

Levin et al. (2004) focused on the impact that TBIs had on working memory between ages six to sixteen. Levin et al. (2004) studied 144 children, whose injuries ranged from mild to severe. The children in this study underwent magnetic resonance imaging (MRI) at three months post-injury and were tested for working memory at baseline and again at 3, 6, 12, and 24 months post-injury. To test working memory, they used the n-back task for letter identification at 3, 6, 12, and 24 months post-injury. This study found two major findings. Firstly, all patients initially exhibited improved working memory during the first year post-injury. Severity and age at injury did not affect the ability to improve working memory during the first year after the injury. Secondly, they found that working memory performance deteriorated between 12 and 24 months post-injury in those children who sustained a severe traumatic brain injury. This decline in performance was not found in the mild and moderately injured patients (Levin et al, 2004).

Keenan et al. (2021) conducted a longitudinal study to observe patterns of a child’s recovery depending on injury severity and age. They administered the BRIEF or BRIEF-P and the McMaster Family Assessment Device-General Functioning Scale. The McMaster Family Assessment Device-General Functioning Scale was used to assess family function. For the Emotional Control subscale, Keenan et al. (2021) found that severe TBI has a period of
improvement during the first year after injury. This growth then plateaued between 12 to 24 months and then accelerated again by 36 months post-injury. They also found that for working memory, scores decelerated for mild to moderate TBI and severe TBI from 12 months to 24 months. Scores accelerated again from 24 months to 36 months only in the mild TBI and severe TBI groups, but the mild to moderate TBI group continued to decelerate during this time. However, there was a step-like increase in score relative to the baseline by severity for all severities at 36 months compared to the orthopedic injury group (Keenan et al., 2021).

These studies indicate that the recovery pathway is going to change over time and that it is not going to be linear. Age and severity both have an effect on the deficits in executive function after a TBI.

**Interventions**

Recovery from a TBI is highly individualized and it depends on the severity, cause, and type of injury (Cleveland Clinic, 2021). Levin et al. (1993) concluded that age and severity of injury have a significant effect on cognitive skills including problem-solving, planning, fluency, and memory. Many of these interventions seem to be fairly recent and all conclude more research needs to be done. This section is broken down into interventions for different executive function skills: attentional control, problem-solving, working memory, and into interventions which target these skills by use of technology, or through parental and family intervention.

**Attentional Control**

Attention encompasses the processes that allow sustained and selective focus on environmental stimuli (Treble-Barna et al., 2016). Treble-Barna et al. 2016 looked at the
effectiveness of the Attention Improvement and Management Program (AIM) in improving control of attention. This program combines computerized attention tasks and instruction in metacognitive strategies in home-based sessions and clinical sessions. After each exercise, the participant would rate their level of motivation and effort. Pre and post-tests were administered. These tests included the Test of Everyday Attention For Children (TEA-Ch), the Behavior Rating Inventory of Executive Function (BRIEF), and the TEA-Ch subtests. For the BRIEF, only children ages eleven and eighteen completed the self-report portion. The Goal Attainment Scale (GAS) was also used at baseline and during the final session. At the end of the intervention, a survey and interview were conducted between the clinician, parent, and participant. They found that there were significant improvements post-intervention in neuropsychological measures of sustained attention and on parent reports of EFs. In contrast, child-reported EFs post-intervention showed no significant changes.

In the literature review by Backeljuaw and Kurowski. (2014), they researched three methods for attention intervention. These included pharmacologic interventions, cognitive therapy or attentional training studies, and mixed injury studies (which included populations of children with TBI and other acquired brain injuries). The pharmacologic intervention that was researched included the use of methylphenidate which is primarily used for ADHD. Of the three studies involving pharmacologic intervention, one out of the three showed no improvement, Williams et al. (1998); and two studies showed significant improvements compared to a placebo group, Mahalic et al (1998) and Hornyak et al. (1997). The second group of interventions that were focused on in the literature review by Backeljuaw and Kurowski. (2014) were cognitive therapy/attentional training studies. Each of these studies used the Continuous Performance Test II at baseline, completion of the intervention, and one year after training to monitor progress
In one study by Galbiati et al. (2009), they used intensive attention-specific training that targeted different areas of attention. They found significant gains in attention and IQ which were in the low to normal range after intervention. Compared to their peers who did not receive this training, participants still showed significant improvements in attention from baseline. The difference was that these improvements for the control group were still in the pathological range. In addition to this, the improvements within the treatment group were maintained at the one-year follow-up. The second study of cognitive therapy/attentional training that was reviewed was by Catroppa et al. (2009). This study had an extremely small sample size of only three participants who participated in six sessions focusing on different areas of executive functioning. One of the six sessions was an attention-specific session. No change was found pre- to post-intervention which is similar to the findings of Thomas-Stonell et al. (1994) that suggest attention needs to be trained separately. Lastly, two mixed injury studies were examined, Ho et al. (2011) and Van’t Hooft et al. (2005). Ho et al. (2011) used self-instructional training in fifteen children with mild to severe acquired brain injury. The intervention method was the Amsterdam Memory and Attention Training for Children (AMAT-C). This intervention took place over several weeks and a different skill was targeted each week. The difficulty of the tasks increased over time. After training, the scores on the Test of Everyday Attention in Children showed significant improvements. However, these improvements were only seen in one of the eleven subtests and the majority of the improvements were seen in learning and memory. Van’t Hooft et al. (2005) used the AMAT-C intervention over seventeen weeks. Immediately following intervention, they saw significant increases in sustained attention and selective attention. These gains remained six months post-intervention. The results from Van’t Hooft et al. (2005) showed contradictory results to the Sjö et al (2010) study. Sjö et al (2010) indicated that
AMAT-C training was more beneficial for learning and memory skills compared to Van’t Hooft et al. (2005) that concluded AMAT-C improves attention skills and memory.

The results of the Attention Improvement and Management Program, pharmacological interventions, cognitive or attentional training, and the Amsterdam Memory and Attention Training for Children seemed to have conflicting results. However, the Attention Improvement and Management Program and the Amsterdam Memory and Attention Training for Children seem to have the most promising results in the ability for children with TBI to improve scores on attention tasks.

**Problem-Solving**

Wade et al. (2012) examined the efficacy of teen online problem-solving (TOPS) to improve executive function deficits following a TBI. TOPS is a cognitive-behavioral skill-based intervention. This online program consisted of ten core sessions in areas such as stress management, problem-solving, planning, organization, communication, and self-regulation with a heavy focus on problem-solving. The problem-solving focus aimed to teach a sequential process or step-like process; “stop and think,” identify problems, brainstorm solutions, analyze consequences, implement a plan, and evaluate the outcome. The results of this study revealed that adolescents (ages 11-18) with severe TBI reported significant improvements in the global executive composite (GEC) following TOPS intervention. GEC provides an overall summary of executive dysfunction.

Another study that focused on problem-solving was done by Suzman et al. (1997). This study had a small sample size of only five families whose children had a moderate to severe TBI. All five children showed impairments on at least three of four standardized problem-solving
measures: Rey-Osterrieth Complex Figure Test, Porteus Maze Test, Wisconsin Card Sorting Task, and the Word Fluency Test. These families were given a multi-component cognitive behavioral treatment package which included self-instruction, self-regulation, metacognition, attribution, and reinforcement. Briefly, these pieces of training are used to help guide the child on how to problem solve, identify a problem, solve the problem, evaluate performance, and reinforce behavior with a reward. This method is very similar to the TOPS problem-solving session but has more steps. This training was three days a week for forty minutes. They found there were large and rapid improvements in problem-solving performance. Two of the four standardized tests (the Rey-Osterrieth Complex Figure Test and the Word Fluency Test) showed significant improvement in scores. The self-instruction training and self-regulation training with the reinforcement component seemed to be the most effective of the package.

The TOPS and the multi-component cognitive behavioral treatment package seemed to show promising results. Despite the relatively small sample size, the findings of Wade et al. (2012) and Suzman et al. (1997) suggest that these methods result in significant improvements in problem-solving skills.

**Working Memory**

Available articles specifically on treatment for working memory ability were focused on different populations such as adults or typically developing children. This may be due to working memory ability being indirectly targeted within other treatments for executive function. The three articles that were found and related to this topic did not provide detailed information. The first article by Cook et al. (2014) did not offer detailed information about the interventions. The second article by Weicker, Villringer, and Thöne-Otto (2015) did not offer specifics on what
trainings were offered. Lastly, the article by Sood et al. (2018) was a proposed study. However, this may be a starting point for further research in the area of working memory interventions for children with traumatic brain injury.

Cook et al. (2014) compared two forms of cognitive training, gist reasoning versus rote memory learning in 20 patients aged twelve through twenty who were six months or longer post-injury. Gist reasoning is the ability to strategically comprehend and convey generalized, core meaning from complex information. To strengthen these skills, Chapman and colleagues developed the Strategic Memory Advanced Reasoning Training (SMART). Both the SMART, gist training, and the Memory training were delivered individually and comprised of eight 45-minute sessions over one month. The SMART program was developed to train individuals to abstract gist meanings from complex information using reasoning skills. The memory training was modeled after the classroom-based training created by Gamino et al. (30) with typically developing adolescents. The findings of this study suggest gist reasoning training improved the ability to deduce abstract meanings from complex information and also resulted in generalization to specific untrained executive functions of working memory and inhibition (Cook et al., 2014).

The literature review by Weicker et al. (2015) found 103 studies (which added up to 112 independent group comparisons) that included 6,113 participants. Nine hundred and five were healthy children, 1,585 were children and adolescents with working memory deficits, and 224 patients with stroke or TBI. The authors did not indicate the ages of these individuals in the stroke or TBI group. Eighty-seven of the 112 independent group comparisons were used in analysis of the data on trained tasks. All studies except for one reported improvement from the first to the final training session. In conclusion, the literature review by Weicker et al (2015)
found that working memory training did improve significantly overall in healthy subjects as well as in patients.

The proposed study by Sood et al. (2018) will focus on the Cogmed Working Memory Training Program (Cogmed). Cogmed is a popular computerized cognitive intervention that has shown success in improving working memory in other childhood populations such as ADHD, but has received little evaluation in the TBI population. Cogmed is an online training course that is supervised by a trained coach. There are twenty-five blocks over five weeks. These blocks are interactive and adaptive exercises that target working memory and decision-making. The researchers hope to translate Cogmed into standard clinical care, schools, and community settings if they find significant outcomes.

Each of these articles concluded that more research and evidence-based interventions need to be available in this area. However, this may be a starting point for further research in the area of working memory interventions for children with traumatic brain injury. Weicker et al. (2015) concluded that improvements were seen in all patients which shows that working memory training will help for the populations included in the study, but what methods to use needs to be researched.

**Strategies.**

Some strategies can be used to help with working memory. These strategies include rehearsal training, mnemonics, imaging, and visual associations (Manasco, 2020). Rehearsal training is when the client repeats information to themselves to increase the likeliness of retaining that information (Parente & Herrman, 2003). Mnemonics is a great strategy to help enhance memory. There are different types of mnemonic devices such as the letter strategies, The
Keyword Method, and The Pegword Method (Mastropieri & Scruggs, 1998). The letter strategy is creating acronyms using the first letter to help remember. The Keyword Method can be used to teach new vocabulary words by creating pictures of the keyword and the definition. The Pegword Method can be used when numbered or ordered information needs to be used by utilizing rhyming words for numbers (Mastropieri and Scruggs, 1998). Lastly, imaging and visual associations include using pictures or writing to help remember information. It is important to note that some of these strategies are not kid-friendly. For example, having a two-year-old create and remember a mnemonic will be very challenging even for a kid without a TBI. However, these strategies would benefit teenagers and adolescents (Manasco, 2020).

**The Use of Technology for Intervention**

Over the last couple of years, there has been an influx of emerging innovative technology, specifically virtual reality (VR). VR has been marketed as a gaming console but authors such as Shen et al. (2020) looked closer at the use of VR for rehabilitation in children. Shen et al. (2020) designed a VR system for executive function among children with TBI. They built on previous research that focused on adult patients who found that VR rehab had positive outcomes. Shen et al. (2020) chose a PC-based VR system to focus on inhibitory control, working memory, and cognitive flexibility. This system consisted of three games that worked on these skills. The first game for inhibitory control was created based on the spatial Stroop task. The user battles different characters and has different tasks, and the user has to choose between options that appear to defeat the character. Game two works on working memory and this game was adapted from Visual Working Memory Task. This game uses sequences of characters that the user will have to recall. Once the user gets two sequences in a row correct, the next level gets more
difficult and adds more characters to the sequence. Similarly, if two sequences were missed in a row, the next level would be a shorter sequence. Lastly, game three was adapted by the Wisconsin Card Sorting Task which uses a matching game based on a rule that switches. For example, the rule could be to match based on color, shapes, numbers, etc. This rule changes periodically throughout the task and has to be determined by trial and error. Shen et al. (2020) compared healthy children to children with TBI and found that both groups, healthy children and children with TBI reported high levels of fun and enjoyment. Despite these positive thoughts on using VR, children with TBI had mixed attitudes towards the future use of VR in therapy. This may be due to how challenging these games are. Further results indicate that children with TBI can complete all three games, they just need more time to complete the games compared to healthy children.

The use of virtual reality is new. There are numerous studies done in adult populations, but very little research for children. Shen et al. (2020) reported mixed feelings toward the use of VR in future therapy sessions. They also ran into some problems that were addressed and solved, such as the controller and headset. The controller was too large for some of the children, so both hands were needed. The headset also proposed a challenge due to its weight and size. Since there is not a lot of research on this population, it could be expected that within the next few years, more research will be made available to conclude if VR is reliable and effective for pediatric populations.

**Parental and Family Interventions**

The second goal of this project was to provide parents with a user-friendly guide, (See Appendix A). When conducting the literature review, there were several studies identified that
conducted different interventions with parents and families. Angular et al. (2019) examined the effectiveness of the web-based parenting intervention, Internet-Based Interacting Together Everyday: Recovery After Childhood TBI (I-InTERACT), compared to the express version to reduce executive dysfunction. The I-InTERACT program has ten to fourteen modules and videoconference meetings. These sessions provided the parents with information about the behavioral and cognitive effects of early TBI. These include information on effective parenting skills, stress and anger management, and family communication strategies. The express version of the I-InTERACT had only seven sessions based on parenting skills. To measure outcomes of these interventions, they administered the BRIEF and the Center for Epidemiologic Studies Depression Scale at baseline and during the six-month follow-up. The results of the express version were primarily positive. Parents reported fewer executive dysfunction behaviors. There were also significant reductions in other problems following TBI, such as depression and anxiety. However, they did conclude that children with greater deficits pre-intervention seemed to benefit more. Despite this, these results do suggest that a brief online parental program can improve outcomes such as executive dysfunction behaviors which also is less of a time commitment for families and helps cut back costs.

Another family intervention method that was examined by Wade et al. (2006) was Online Family Problem Solving (FPS). This training included an initial meeting and fourteen sessions. During the initial meeting, the therapist conducted an interview focused on concerns and goals the family had. The therapist was able to enter these concerns and goals into the program. This intervention was designed to allow multiple family members to use it at the same time. The sessions included eight core sessions on identifying goals, problem orientation, problem-solving steps, cognitive changes, behavioral changes, communication, crisis management, and planning
for the future. The additional six sessions were issues or concerns that were relevant to the family. These options included stress, working with schools, sibling concerns, anger management, and marital communication. The results found that parents reported a greater reduction in depression, anxiety, and distress. However, the improvements in child behavior and social competence did not relate to the number of sessions completed.

Conclusion

To summarize, a traumatic brain injury (TBI) is an acquired brain injury as a result of an external force to the head (Manasco, 2020). There are two types of TBI, traumatic impact and traumatic inertial. Traumatic impact injuries are contact injuries where the head is struck by or against an object. These can be either closed-head or open-head injuries. Traumatic inertial brain injuries are non-contact injuries caused by falls, motor vehicle accidents, or sports-related accidents (Brain Injury Association of America, 2023). Symptoms and deficits following a traumatic brain injury depend on the degree, type, and severity of the injury. Additional symptoms for infants and children include crying nonstop and refusal to eat, drink, or breastfeed (Cleveland Clinic, 2021). Executive functioning (EF) skills enable us to plan, focus attention, remember instructions, and juggle multiple tasks successfully (Center on the Developing Child at Harvard University, 2014). The development of EF takes years to develop even throughout adolescence (Shakibaie, 2022). When a child has a TBI, their ability to use these executive functioning skills are hindered. There are intervention options for specific EF skills including attention, problem-solving, working memory, including some which incorporate the use of technology, or parental and family intervention. Many of these studies in this literature review had a relatively low sample size compared to the amount of these injuries that are seen each year,
however, the results of these studies are promising. Given the limited amount of research on intervention for executive functioning in children with TBI, more research needs to be done to effectively find interventions that result in improvement in the majority of patients with TBI.
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