Mild Traumatic Brain Injury Executive Function Rehabilitation Through Serious Gamification

by

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ABSTRACT

The purpose of the present study is to explore a potential rehabilitation alternative/additive, when time, insurance, finances, or lack of knowledge are limitations for mild traumatic brain injury (mTBI) executive function (EF) rehabilitation. The experimental intervention involved two sets of participants an experimental group and a control group. Participants within the experimental and control groups partook in initial (week 1) and final (week 6) EF and TBI assessments. The experimental group additionally participated in four weeks (weeks 2 - 5) of an experimental intervention in beta stage of a web-based application. The aim of the intervention was to train EF skills planning, organization, and cognitive flexibility through serious gamification. At the conclusion of the study, it was observed that participants within the experimental group achieved higher scores on the experimental executive function assessment when compared to the control group. The difference in scores can be attributed to the weekly participation in executive function training.

Keywords: Mild traumatic brain injury, executive function, cognitive flexibility, planning, organization, serious gamification.

DEDICATION

I would like to dedicate this dissertation to my late maternal and paternal grandfathers Frederick Cleghorn and Raphael Ezenyilimba.

To my grandfather Fred, although you just missed me completing this milestone in my life by only a few months, I know that you held on for as long as you could. You were my reason, and my why for completing this degree. I wanted to hurry up so you could see me walk and become the Dr. I promised you I would be, but I thank you for holding on long enough to spend your last moments with me. Even though you are no longer with me on this earthly plane I know that you are forever in my heart. I love you more than the sun has light grandpa and I hope I continue to make you proud.

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Finally, to both my grandfathers, I hope you are smiling down on the first PhD holder in the family.

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Some trust in chariots and some in horses,

but we trust in the name of the LORD our God.

– Psalm 20:7

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CHAPTER 1

INTRODUCTION

Every year more than 2.8 million traumatic brain injuries (TBI) are reported within the United States alone (Nelson, Temkin, Dikmen, Barber, Giacino, Yuh, Levin, McCrea, Stein, Mukherjee, Okonkwo, Robertson, Diaz-Arrastia, Manley, & TRACK-TBI Investigators, 2019). The majority (75 to 90%) of individuals who are diagnosed with TBIs are classified as mild, which can be defined as a change to brain function as a result of external forces (Hadanny & Efarti, 2016; Prince & Bruhns, 2017).

These external forces can fall into one of four categories: 1. the head being hit with an object, 2. the head hitting a hard object or surface, 3. the brain going through an unnatural acceleration or deceleration of movement without direct contact between the head and an object or surface, 4. and/or the head being exposed to forces from a blast or explosion (Silverberg, Iverson, Brown, Cogan, Damn-O'Connor, Delmonico, Graf, Iaccarino, Kajankova, Kamins, McCulloch, McKinney, Nagele, Panenka, Rabinowitz, Reed, Wethe, & Whitehair, 2022). In order for the classification of mild to be attributed to a TBI, according to Silverberg et al. (2022) one or more of the three components mentioned in Table 1 must accompany the TBI:

Table 1. Components necessary for mild traumatic brain injury diagnoses as per Silverberg et al. (2022)

Component A: At least two symptoms from criterion 3 are present when no other criteria is met for mTBI diagnoses		
Criterion	**Classification**	**Example**
Criterion 3 (Acute symptoms): ***Must be***: *New or worsened, onset 72 hours of injury, not improved by external*	Alteration in mental status	• Feeling confused • Disoriented • Dazed

interventions; co-existing or pre-existing		
	Physical symptoms	• Headache • Nausea • Dizziness • Balance problems • Vision problems • Sensitivity to light or noise
	Cognitive symptoms	• Feeling slowed down • Mental fog • Difficulty concentrating • Memory problems
	Emotional symptoms	• Uncharacteristic emotional liability or irritability
Component B: Two signs of criterion 4 (clinical or laboratory findings) are present and no other criterion is met for mTBI diagnoses		
Criterion	**Classification**	**Examples**
Criterion 4 (Clinical or laboratory symptoms): ***At clinical examination***	Cognitive impairment	• Rambling • Difficulty with word retrieval • Difficulty communicating
	Balance impairment	• Difficulty keeping body centered • Issues with coordination
	Oculomotor impairment	• Reacting to visual stimuli • Engaging in vision related tasks
	Elevated blood biomarkers	• Related to intercranial injury
Component C: Unclear if criterion 2 (clinical signs), criterion 3 (acute symptoms), and criterion 4 (clinical or laboratory findings) signs are present, and no pre-existing or co-occurring health issues		
Criterion	**Classification**	**Examples**
Criterion 2 (clinical signs): ***Immediately following injury***	Loss of consciousness	• No protective movement taken from affected individual after impact • Lying motionless

		• Unresponsive
	Alteration of mental status ***Can occur after regaining consciousness***	• Reduced responsiveness • Inappropriate responses to external stimuli • Slowed responses • Agitated • Inability to follow two-part commands • Disoriented
	Complete or partial amnesia ***Can occur after regaining consciousness***	• Gap in memory related to events before injury
	Other neurological signs	• Motor incoordination when standing • Seizure • Tonic posturing
Criterion 3:	******see Component A******	
Criterion 4	******see Component B******	

Even with the majority of TBIs that occur within the United States being classified as mild, there still continues to be a disconnect and a lack of knowledge related to standardization of care post-TBI and rehabilitation options. One of the common links for this potential disconnect is the lack of streamline communication between first line and next line health care workers (Knollman-Porter, Brown, Wallace, & Spitz, 2021). In addition to this non-standardization of care between first and next line health care workers, many individuals who have experienced a mild traumatic brain injury (mTBI) can remain undiagnosed, due to the fact that in many cultures a mTBI is simply perceived as just a ‘bump on the head.’

CHAPTER 2

BACKGROUND

Mild Traumatic Brain Injury Executive Function Deficits

In addition to limitations related to PPCS treatment for mTBI there are also limitations in research related to EF and mTBIs. Research does not consistently highlight the potential deficits that may exist for individuals who are actively returning back to regular activities also known as activities of daily living following a mTBI. A vast majority of research related to mTBI is heavily centered around military and athletics and does not necessarily pertain to everyday civilians. As seen in developed countries such as Canada, at least 65% of traumatic brain injury (TBI) patients are discharged to return home without any sort of rehabilitation plan or checkups (O'Neil et al., 2019). During the acute stage of a mTBI injury substantial evidence points to altered cognitive functioning.

This altered state as a result of a mTBI then leads to ED. When ED related impairments do not resolve within three months of the initial injury, PPCS begins to come into play (Bottari, Gosselin, Chen, & Ptito, 2017). The post-TBI stage is a crucial point in one's recovery. Research would suggest that individuals who have acquired a mTBI would be able to return back to their cognitive baseline within 90 days, but that is not the norm for about 5-20% of mTBI individuals with reported PPCS (Bouix et al., 2013; Hadanny & Efrati, 2016; Prince & Bruhns, 2017; Pang, 2015).

The impact of a TBI can have devastating consequences at any point in life, but especially during adolescents. But often times adolescent head injuries are overlooked or minimized (Yu, Sea, Reyes, Godfrey, Anderson, Adamson, Ryan, Hearps, & Catroppa, 2017). This passive perception of adolescent TBIs has proven to be detrimental due to the

long lasting effects that can extend far into adulthood, resulting in EF decrements related to planning, goal setting, organization, inhibition, attention, and even behavior. These decrements can be linked to changes in the brain's cortical white matter (Yu et al., 2017). Not only can these capabilities that are typically enacted by the execution of EF become impaired, but individuals can struggle when engaging in activities and tasks that require the initiation of these superior skills (Kennedy et al., 2008).

It has been noted in adolescents with a history of mTBI, that parents typically describe their children as having significant difficulties related to behavior and emotional adjustment. These finding have also been apparent in adults with a history of mTBI as well (Jones, Starkey, Barker-Collo, Ameratunga, Theadom, Pocock, Borotkanics, Feigin, and the BIONIC Study Group, 2021). Furthermore, when TBI trauma has occurred during childhood, even years after the initially injury, EF decrements can persist, hindering the ability to engage in cognitive flexibility and regulate inhibition (Yu et al., 2017).

EF decrements of this magnitude are especially apparent when they occur during adolescents as a result of a TBI, due to the fact that the brain is still maturing. Disruptions related to head trauma ultimately interfere with the developmental process and necessary EF skills are not able to reach their full potential, especially in the absence of rehabilitation (Yu et al., 2017). Research has suggested in order to overcome these challenges related to behavior, emotional regulation, and attention, specific and targeted training may prove to be useful. More specifically EF related treatments that pinpoint and focus on attentional control, cognitive flexibility, planning, and organization (Jones et al., 2021).

Typically, the impact from a mTBI takes place in the frontal and/or temporal lobes (Pang, 2015). When impairment within this realm occurs, it can result in dysfunction in the ability to plan, organize, reason, set shift, and even monitor (Pang, 2015). When addressing mTBIs it is important highlight issues that may persist due to ED. By pinpointing certain areas of EF i.e., prioritizing, planning, or even problem-solving, TBI rehabilitation for individuals could improve overall executive skills by having specific and direct approaches (Prince & Bruhns, 2017).

Planning

Many TBI patients have displayed issues with the ability to effectively plan, engage in productive reasoning, and complete tasks that require problem solving skills (Said**,** Ghosh**,** Pal**,** Poli**,** Moscote-Salazar**,** Agrawal, 2018). When an individuals is not capable of utilizing their EF skills related to planning setbacks can trickle over into their everyday routine, impeding their ability to engage in daily activities that are reliant on this ability (Said et al., 2018).

In an exploratory case study, Bottari and colleagues (2015) found that when observing three mTBI individuals in comparison to individuals without a history of TBI there were apparent deficits in planning everyday activities. Within this study a potential link was identified between deficits in planning and observed abnormality in the prefrontal cortex, frontal lobe, and parietal components via an fMRI. Bottari et al. also noted that mTBI individuals were unable to engage in effective planning strategies and took longer to recognize errors in strategy (Bottari et al., 2015).

As a result of ineffective ability to plan, participants within this study demonstrated reduced levels of independence when in comparison to non-TBI

individuals. This reduction in independence was even more notable when evaluating participants ability to partake in complex everyday activities (i.e., dealing with demands of family members, routine domestic activities, and maintenance of standard workload; Bottari et al., 2015). When faced with complex everyday activities Bottari noted that participants were only able to cope with the demands placed upon them by having to engage in strategies that allowed them to compensate for their shortcomings (Bottari et al., 2015).

Organization

In addition to mTBI individuals facing difficulties related to planning, there also are notable decrements related to their ability to partake in activities that require organization. For TBI individuals their ability to subjectively organize visual information can be undermined. Even with the known association of TBI leading to problems being able to organize, there have only been a few studies that explore the link between the two when it comes to processing visual information (Finley and Parente, 2020).

Bottari et al. (2015), also noted that mTBI individuals struggle staying organized with tasks that are related to the utilization of financial information such as budgeting (Bottari et al., 2015). In order for the mTBI participants to complete the financial tasks they needed to take additional steps. The delay in the promptness of mTBI individuals responses potentially could be explained by a decrease in brain activation in the prefrontal cortex due to injury. This potential decrease in brain activation ultimately leads to delay or slowed reaction times and ability to process information in a timely manner. Not only does this decrease in brain activation hinder EF related tasks but overall has a

negative impact on an individual's ability to engage in activities of daily living (Bottari et al., 2015).

In another study focused on collegiate athletes with multiple self-reported mTBIs in comparison to non-TBI non-collegiate athletes, student athletes with a history of mTBI struggled subjectively organizing unfamiliar symbols (Finley and Parente, 2020). When comparing the mTBI group to the non-TBI group, the mTBI group did not associate complex rules with the way the presented symbols were organized, while the non-TBI group was fully capable of this. Additionally, the mTBI group's inability to enact high level structure when asked to organize various symbols demonstrates that even a minor injury to the brain can disrupt EF (Finlet & Parente, 2020).

Cognitive Flexibility

Individuals who are diagnosed with mTBI typically do not receive or seek additional treatment post diagnoses, resulting in cognitive deficits often going unnoticed or underreported (Lucas, Killgore, & Dailey, 2020). One of the main EDs that occur after a mTBI is difficulty adapting to new stimuli, also known as cognitive flexibility (Lucas, Killgore, & Dailey, 2020)

Lucas and colleagues (2020) found that when assessing mTBI with the PEBL Wisconsin Berg Card Sorting Test (pWCST), individuals showed apparent decrements related to cognitive flexibility. For mTBI individuals the intake of new information and processing how to integrate said information can be difficult and unreported (Lucas, Killgore, & Dailey, 2020). Deficits of this nature continue to demonstrate the apparent need for earlier targeted interventions related to rehabilitation in an attempt to rectify cognitive deficits that are unreported (Lucas, Killgore, & Dailey, 2020).

Individuals who have experienced a mTBI have been shown to take a longer time to process information. Latency of this nature requires those with mTBI to be reliant on connectivity to or activation within other regions of the brain to accomplish a desired task resulting in higher levels of effort in comparison to non-TBI counterparts (Pang, 2015). Decrements as a result of cognitive inflexibility when studied in mTBI individuals show that cognitive processing is heavily impacted by reduction in brain activation in necessary regions of the brain, and overactivation in other areas, resulting in apparent disorganization (Pang, 2015). Deficits of this nature suggest a need for improvement in TBI rehabilitation that cater to specific areas of dysfunction leading to long-term benefits (Pang, 2015).

When it comes to cognitive flexibility training it is important to ensure that the intended path of training is beneficial to the participant and does not have negative associated costs. A common mode of cognitive flexibility training is reliant on stimulus response-mapping: *training that is contingent on participants solely responding to a presented stimulus in an effort to evoke cognitive flexibility, rather than having to actively account for unpredictability through rule changes*. Allowing individuals to engage solely in this type of training especially after a mTBI may not be beneficial to individuals with a history of mTBI especially if that damage has occurred in the prefrontal cortex (Friedman & Robbins, 2021).

Training solely based on stimulus-response mapping may result in individuals relying on predictability through a potential pattern, rather than individuals being fully engaged in the tasks, limiting the true potential benefits of the intended training. With the prefrontal cortex being one of the fundamental areas impacted by mTBI, cognitive

flexibility training that is reliant on set-shifting may be more beneficial due to its nature of incorporating feedback (Friedman & Robbins, 2021). Through the incorporation of feedback participants will be less likely to be reliant on identifying a potential pattern, and more likely to engage in the desired task through the implementation of ongoing rule changes.

Executive Function Deficits and Awareness Challenges

Planning, problem, solving, reasoning, organization, and goal setting can all be linked to EF skills that correlate to one's self-awareness, but when a TBI occurs that impairs EF, an individual's level of self-awareness can be negatively impacted (Kennedy et al, 2008). Being readily self-aware of our action, and why we are engaging in an activity of daily living is an essential part of being able to self-regulate. This innate affordance in many TBI cases is ultimately compromised therefore taking a toll on one's ability to elicit individual autonomy in activities of daily living.

Challenges with utilizing individual autonomy are problematic due to EF decrements that can occur as a result of a TBI. Impairment to EF skills can ultimately make it challenging to engage in activities that are reliant on higher levels of cognitive functions (Bar-Haim Erez, Rothschild, Katz, Tuchner, & Hartman-Maeir, 2009). When a good sense of awareness is not available to mTBI individuals, it can make it difficult to see progress in rehabilitation efforts (Bar-Haim Erez et al., 2009). For many mTBI individuals it has been noted that issues can persist with maintaining employment as a result of ED (Bar-Haim Erez et al., 2009). Diminished levels of awareness after a TBI create byproducts such as irritability that make an already difficult situation even more unbearable for TBI individuals.

When observing 160 participants, 80 with a history of TBI and 80 with no history of TBI, mTBI participants were more irritable when they could not complete tasks that were reliant on cognitive functions (Yang Huang, Lin, Tsai, & Hua, 2013). Discrepancy in perception of awareness can be especially limiting for mTBI individuals when having to engage in tasks that require the processing of incoming information (Yang et al., 2013). Yang and colleagues attributed this to potential limitations within rehabilitation efforts that do not actively monitor, train, or asses how participants process information (Yang et al., 2013).

There continues to be discrepancies related to how impacted awareness is amongst TBI individuals. Yang and colleagues also found that mTBI individuals in comparison to moderate or severe TBI patients have a better sense of awareness in regard to irritability. Although there may not be absolute certainty, mTBI individuals are capable of being aware that potential decrements exist, sometimes hyper aware (Yang et al., 2013). In order for rehabilitation to be a beneficial tool participants awareness is something that must be managed and align with their present challenges and future goals (Prince & Bruhns, 2017).

A pivotal component to awareness for mTBIs is the acceptance of the disability. With the often negative connotation that is associated with mTBI, individuals can be aware that an issue is present but still in denial that they have acquired a disability that now puts them at a disadvantage in comparison to non-TBI individuals (Yehene, Lictenstern, Harel, Druckman, & Sacher, 2019). Without full acceptance of the impact of a mTBI, individuals allow themselves to adopt ineffective coping mechanisms that are not beneficial to the longevity of their quality of life and are only capable of resolving

challenges momentarily (Yehene et al., 2019). Not only are mTBI individuals hindered by ED related decrements and non-standardization of care, but individual autonomy, re-acclimation post-injury, and financial constraints continue to be impacted, exacerbating the recovery process.

Diminished Individual Autonomy

The post-TBI stage enamors individuals with a multitude of challenges and changes that are out of their control. The lack of available proactive and inclusive plans not only inhibit TBI individuals' re-acclimation to society, but significantly diminish their overall quality of life (O'Neil et al., 2019). A fundamental component that is essential to establishing quality of life is being able to have a semblance of individual autonomy. For individuals who have experienced a TBI this inalienable right is hindered. Simple everyday tasks become altered in the blink of an eye. Although mTBI individuals 3 months post-injury typically report a reduction in issues related to confusion, attention, and memory loss, ongoing decrements with EF can remain an ongoing issue (Said et al., 2018).F

The ongoing impact of a TBI more often than not stems far beyond the reach of routine in a person's physical therapy initiatives. Often times doctors and therapist only get a glimpse of the decrement's that their patients face on a daily basis within their sessions. With many patients wanting to regain their individual autonomy as soon as possible, pertinent information about their injury is often not shared, minimized, or even overlooked. Of the reported mTBIs that occur each year more than a third actively report still experiencing challenges related to EF one year post-injury. When cognitive

dysfunction remains an ongoing issue, individuals struggle returning to various aspect of everyday life such academics and socially related events (Said et al., 2018).

In a study that asked parents and teachers of children with a history of mTBI aged 7 – 17, to conduct follow up assessments related to the children's ability to engage in certain tasks, it was noted that EF decrements were present seven years post injury. These EF decrements that persisted seven years post injury adversely impacted the overall quality of life (Jones et al., 2021). It is important to note that perception of children's abilities varied when coming from parents vs. teachers. With this in mind, upon further evaluation it was apparent that children with a history of mTBI faced difficulties with tasks that require them to engage in EF skills pertaining to cognitive flexibility, planning, and inhibition when evaluated seven years post injury (Jones et al., 2021).

Need for Rehabilitation Alternatives

For those who are diagnosed with a TBI, especially when that diagnosis is mild, patients are generally met with one of three options: 1. first line health care only 2. prescribed medication and rest, or 3. no treatment plan at all. These three paths that individuals are offered when impacted by a TBI lead to improper access to appropriate treatment, underdiagnosis, and misdiagnosis of mTBIs (Prince & Bruhns, 2017). Limitations of this nature are extremely regressive due to the fact some of the leading causes for mTBIs stem from occurrences of everyday life such as motor vehicle accidents, falls, sports related injury, or even military incidents. For many individuals, a TBI diagnosis is not a matter of if, but when (Hadanny & Efrati, 2016).

Following a TBI diagnoses, only 2 to 36% of individuals received referrals to appropriate next line care specialists i.e., speech language pathologists (SLP; Knollman-

Porter et al., 2021). Of those who received a referral, treatment or services were less likely to be rendered for those who were classified as having a mild traumatic brain injury diagnoses (Knollman-Porter et al., 2021). In addition to non-standardization of care persistent post-concussive syndrome (PPCS) is one of the leading issues facing individuals with mTBIs, resulting in nearly 20% of diagnosed mTBI individuals reporting PPCS symptoms that are still present 6 months post injury (Hadanny & Efrati, 2016).

These PPCS symptoms typically persist as a result of issues related to executive dysfunction. When executive dysfunction related impairments do not resolve within three months of the initial injury, PPCS begins to come into play (Bottari, Gosselin, Chen, & Ptito, 2017). The post-TBI stage is a crucial point in one's recovery.

Research would suggest that individuals who have acquired a mTBI would be able to return back to their cognitive baseline within 90 days, but that is not the norm for about 5-20% of mTBI individuals with reported PPCS (Bouix, Pasternak, Rathi, Pelavin, Zafonte, & Shenton, 2013; Hadanny & Efrati, 2016; Prince & Bruhns, 2017; Pang, 2015). Therefore, more needs to be done to advocate for better initial diagnosis, treatment plans, and follow-ups related to these types of injuries (Nelson et al., 2019). In addition to limitations that are related to PPCS treatment for mTBI, there are also limitations in research related to executive function (EF) and mTBIs.

Necessary Components Needed to Better Address mTBI Rehabilitation

Many mTBI patients face issues with EF skills that are dependent on the ability to engage in planning, organizing, and cognitive flexibility. Continuous issues related to EF amongst mTBI individuals highlights the fact that there is an apparent need to address these decrements during the recovery process. For executive function rehabilitation to be

effective, it is pertinent that the skills learned are applicable and transferrable to activities of daily living (Prince & Bruhns, 2017). In addition to skills being applicable, it is also important to allow participants to be able to build a sense of awareness, monitor their progress while they are engaging in the desired tasks, anticipate through a set routine, and incorporate a mechanism geared toward self-evaluation (Prince & Bruhns, 2017).

When attempting to address potential EF skills it is pertinent to realize that although EF has different individuals facets (i.e., organization, multi-tasking, planning, etc.) proper utilization of EF is reliant on a set of skills to make daily activities attainable (Kennedy, Coelho, Turkstra, Ylvisaker, M., Moore Sohlberg, Yorkston, Chiou, & Kan, 2008). Some of the most common challenges related to executive dysfunction are not linked to a singular issue. For many TBI individuals with apparent EF decrements it is not uncommon that they struggle with predicting potential problems or conflicts, prioritizing and organizing, or even maintaining pertinent information to achieve a future goal (Kennedy et al., 2008).

TBI rehabilitation has proven to benefit from the incorporation of asynchronous and synchronous remote efforts (O'Neil, Ierssel, & Sveistrup, 2019). The need for continued rehabilitation outside the confines of in person, physical or clinical appointments, has been deemed necessary to the rehabilitation process for individuals with TBIs. Currently there is a need to focus on further improving rehabilitation through the incorporation of assistive technology to further patient's progress at home (Parrington, Jehu, Fino, Stuart, Wilhelm, Pettigrew, & King, 2020). Incorporation of technology of this nature (1) potentially enables patients to further their progress at their own leisure, (2) enable therapist to be aware of progress if any made by patients outside

of scheduled visits, and (3) creates a standard that both patients and therapist can adhere to (Parrington et al., 2020).

How to Implement Components

***Goal setting*.** An essential part of EF rehabilitation is allowing the participant to engage in goal setting. In setting these goals it is important to ensure they are realistic and can be measured (Prince & Bruhns, 2017). Through goal setting participants are able to be and feel like they have a say in the rehabilitation process. Without goals it can be hard to garner the intended direction of the rehabilitation process and pinpoint when it is necessary to step in and redirect (Brown, Ackley, Knollman-Porter, 2021).

***Routine*.** Additionally, the ability to anticipate a daily routine allows for individuals to have a sense of reliability that is familiar. Through anticipation individuals are allowed to set their expectations and create realistic goals (Sharifian, 2020). This same approach is also necessary for TBI rehabilitation. Through routines TBI individuals are able to hone in on their cognitive skills and focus on EF related skills specifically. When designing a rehabilitation program for TBI individuals it is important to incorporate a routine that is capable of being flexible and adapting to the needs of the patient, while managing to not be overwhelming (Sharifian, 2020). This can be done by ensuring the program includes training that pinpoints relevant EF skills that are applicable to activities of daily living that will allow participants to overcome present challenges that they are facing when it comes to executive dysfunction (Sharifian, 2020).

***Self-awareness*.** Decrements in executive function can impede an individual's ability to be fully aware of their present condition and limitations, meaning individuals can be hyper or under aware of the true nature of their decrements (Prince & Bruhns,

2017). To overcome this challenge rehabilitation measures must be capable of incorporating self-regulation and enable participants to be aware of their thought processes (Prince & Bruhns, 2017). To further ensure mild traumatic brain injury individuals are self-aware throughout their rehabilitation process, a metacognitive aspect needs to be reinforced within the process. This can be done through allowing the individual to set goals, be able to compare performance and self-monitor, make necessary adjustments to reach the desired goal, and implement the intended change (Kennedy et al., 2008).

***Self-efficacy and self-evaluation*.** Incorporating self-efficacy as a mechanism within the rehabilitation process encourages awareness of goals but also improves the quality of life post-TBI (Yehene, Lichtenstern, Harel, Druckman, & Sacher, 2019). The bias view of mTBIs being a minor injury can leave individuals impacted by the injury in a constant state of longing what once was, rather than being able to create attainable goals for the future. Therefore, low self-efficacy allows for the streamlining of emotional turmoil that does not allow individuals to accept their injury (Yehene et al., 2019).

Additionally, when acceptance of disability is low, self-efficacy is diminished as well (Yehene et al., 2019). When mTBI individuals self-efficacy is low, it tends to lead the adoption of avoidant behavior. This newfound behavior then leads to individuals subconsciously not engaging in complex cognitive activities. By avoiding these complex tasks, mTBI individuals are less likely to actively work on their shortcomings, thereby impeding their awareness of decrements (Yehene et al., 2019).

CHAPTER 3

CURRENT STUDY

In order for individuals to have the most beneficial outcomes from rehabilitation it is pertinent to incorporate aspects of self-awareness, self-efficacy, routine, and goal setting. By actively incorporating these components, participants will be involved throughout the entirety of their program and will be more likely to accept their disability and not be defined by it. Furthermore, mTBI individuals will be able to better manage physical symptoms that tend to manifest as a result of heightened levels of stress and will be more inclined to create an opportunity that leads to more positive outcomes throughout their rehabilitation program (see Figure 1; Yehene et al., 2019).

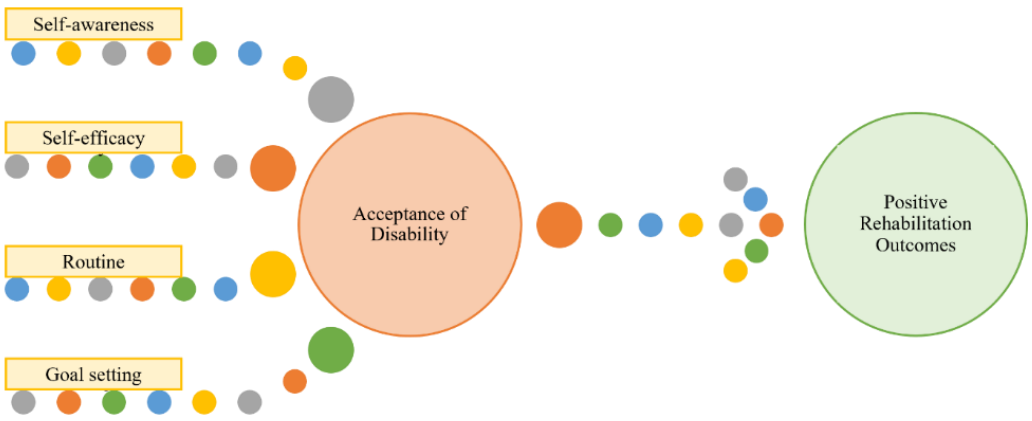


Figure 1. Components for positive mTBI rehabilitation outcomes

The following proposed study aims to further explore and build upon these necessary questions to address executive function rehabilitation amongst mTBI individuals. To further explore the needs of mTBI the goal of this study is to introduce a new mode of intervention when finance, time, and insurance serve as potential

constraints. In conducting this study, in no way does is this proposed intervention meant to serve as a tool for medical diagnoses related to mTBI, but rather an assistive tool along an individual's rehabilitation journey.

Research Questions and Hypothesis

The focus of this study is executive function rehabilitation through serious gamification. The primary EF skills within this study will be organization, planning, and cognitive flexibility. To further explore how to best implement EF rehabilitation through serious gamification the first research question that the study will address is ***(R1) how has previous research addressed the rehabilitation needs of individuals with a history of mild traumatic brain injury?*** To address this a control group has been implemented within this study. The control group will take both the initial and final assessments like the experimental group but will not partake in the experimental intervention. Additionally, the use of a validated clinical assessment will be implemented within this study as well. The following hypotheses will address this research question within the confines of this study.

H1. Participants within the experimental group will have higher final assessment scores in comparison to those in the control group.

Due to the experimental group regularly training their EF skills via the experimental intervention, they will be exposed to more opportunities to train the EF decrements than the control group who will not have any type of intervention weeks 2 – 5.

H2. There will be a positive correlation between participants' game levels and participants' recorded times.

Participants who are able to progress to higher game levels weekly will demonstrate that they are benefiting from the serious gamification. Therefore, by having the opportunity to advance to higher levels participants will be able to also improve their overall response time in comparison to participants who do not advance to higher game levels.

Research has shown that specific and targeted training can be beneficial for mTBI individuals, especially when that training is executive function based. Furthermore, individuals have shown to benefit most when executive function training is applicable to everyday activities of daily living, which leads to the second research question, ***(R2) can mild traumatic brain injury individuals with executive dysfunction see improvements after executive function rehabilitation?*** The following hypothesis will explore this research question. The study will also explore if after a certain period of time if the possibility of improvements to executive function skills becomes obsolete.

H3. Participant's within the experimental group, will see the most improvement in their initial assessment primary executive function focus.

By increasing participants self-awareness and bringing awareness to potential decrements at the start of the study, participants will be more aware of potential decrements and motivated to address said decrements.

The third and final research question for this study is, ***(R3) how can rehabilitation best attempt to help mild traumatic brain injury executive dysfunction individuals with activities of daily living?*** The proposed study will be delivered to participants via a remote setting. The study aims to encourage self-monitoring and self-awareness through goal setting.

H4. Experimental group participants will have a more positive outlook on their ability to accomplish tasks that require executive function skills.

With participants actively engaging in weekly executive function training participants will be actively aware of ongoing shortcomings as well as areas in which they are prevailing. Due to positive reinforcement from encourage goal setting after each game participants will have a more positive outlook on their ability to achieve various activities of daily living in comparison to the control group.

CHAPTER 4

METHODS

For this study participants piloted a new mTBI rehabilitation alternative application entitled Ụbụrụ. This study was conducted in the beta stage of the applications development. During the beta stage of this study, the weekly games and surveys will be delivered to the experimental group participants via Talent LMS (Learning Management System). The games and weekly surveys were created using iSpring Quiz Maker software. Both the experimental and control group will also take the Ụbụrụ assessment via Talent LMS as well. Upon completion of the beta stage of testing the application will then move to its gamma stage which consists of a fully functioning web-based application.

The focus of this application is to assist in EF rehabilitation through a serious games approach. The goal of Ụbụrụ is to assist individuals in EF related tasks that require planning, organizing, and cognitive flexibility skills. Ụbụrụ is not intended to be a mTBI diagnosis application, but instead an alternative intervention that will assist those who have limitations related to finances, time, or insurance as well as be source of information for those who are uncertain about the severity of their injury.

Design

The study was a 2 x 2 (Group – between x Test – within) mixed experimental design. Both the experimental and control group took the initial and final assessments, which consisted of both a clinical (CNS Vital Signs) and experimental assessments (derived from the application Ụbụrụ). Only the experimental group partook in the weekly Ụbụrụ experimental intervention, see Figure 2.

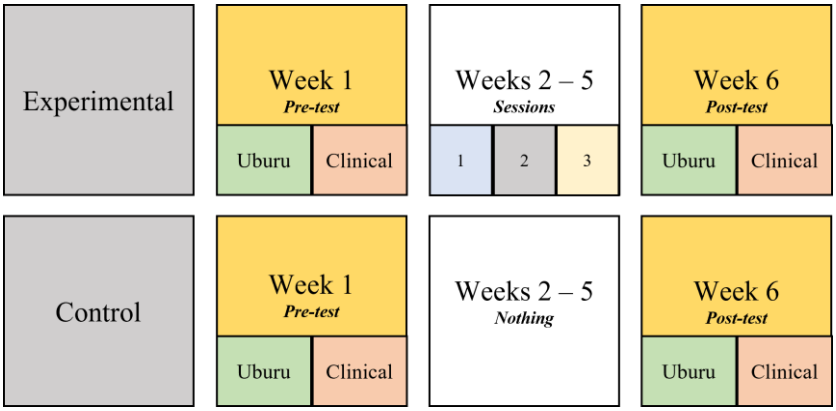


Figure 2. Experimental sequence

Participants

To determine the necessary number of participants for this study, an a priori power analysis was conducted using G*Power3 (Faul, Erdfelder, Lang, & Buchner, 2007) to evaluate the difference between the means of 2-group by 2-test (pre and post-test) using an *F*-test, a medium effect size (η_p^2 = 0.06), and an alpha of 0.05. Based on the results, a total sample of 34 participants with two equal-sized groups of n = 17 is required to achieve a power of 0.80. At the conclusion of the study a total of 27 participants successfully completed the study with n = 13 for the control group, and n = 14 for the experimental group.

To be eligible for this study, participants had to be at least 18 years of age, 6-months post mTBI, with normal to corrective vision. All participants within this study experienced a mTBI one of four ways, motor vehicle accident, physical altercation, fall, or sports related. Participants were grouped into six age categories (18 – 25, 26 – 30, 31 – 40, 41 – 50, 51 – 60, and 61+).

The average age group of the experimental group was 31 – 40, and the average age group of the control group was 26 – 30. The study included a total of 14 females, and

13 males. Twenty-five participants reported experiencing a mTBI more than a year ago, and two participants reported experiencing a mTBI less than a year ago (see Table 2).

Table 2. Demographics of experimental and control group

Group:	***Experimental***	***Control***
Average age group:	31 – 40	26 – 30
Gender:	6 Females 8 Males	8 Females 5 males
When TBI occurred:	13; < a year ago 1; > a year ago	12; < a year ago 1; > a year ago
Average age at injury:	26.57 years of age	20.53 years of age
Average number of TBIs:	3.28 TBIs / person	1.77 TBIs / person
How TBI occurred:	4 Motor vehicle 1 Physical altercation 9 Sports related	3 Motor vehicle 1 Physical altercation 7 Sports related 2 Fall
Medical treatment:	Yes: 11 No: 3	Yes: 4 No: 9

Participants were each given a participant ID number that was used for all participant data. Participant data for the study was stored on a secure google drive, which was not associated with any identifiable information. Participants were also randomly assigned to the experimental and control groups. A random number generator was utilized to assist in the random assignment of participants.

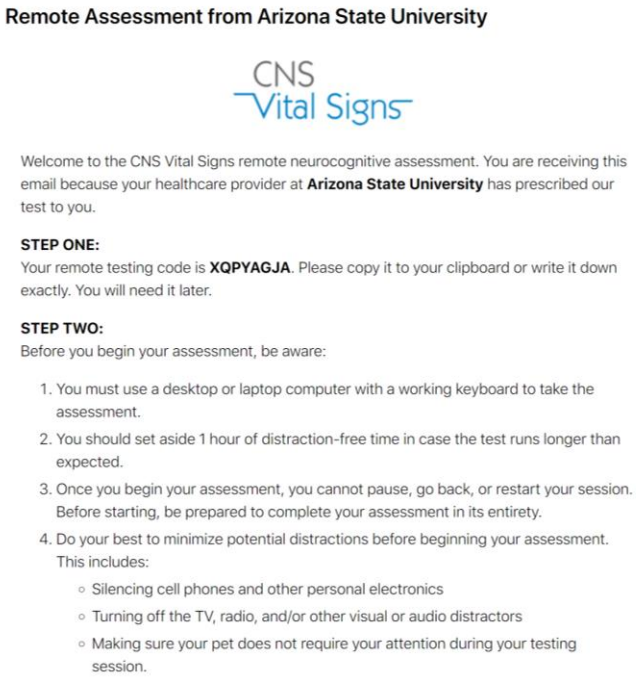
A list of thirty-four slots was created and a random number between 1 and 50 was then associated with each slot. If the number slot was filled with the number 25 or less that slot was then assigned to the experimental group; if the number slot was filled with a number greater than twenty-five that slot was then assigned to the control group. Participants in both groups were all recruited via three methods using a recruitment flyer

(see appendix L): 1. Arizona State University Polytechnic Campus E-mail Listserv 2. Word of mouth via clinical contact 3. Participant referrals.

After the initial flyer was circulated participants completed a pre-screening study questionnaire. Upon completion of the pre-screening questionnaire eligible participants were contacted via e-mail and asked to select a time for a pre-study information session. During the information session participants were informed of which group they were randomly assigned to, study requirements, and completed their consent forms. At the conclusion of each informational session participants were sent their initial assessments. Participants were not made aware of the treatment conditions for the group they were not assigned to.

Initial and Final Assessments

The initial and final assessments (see Appendices A – E) consisted of two parts: validated clinical assessment and experimental executive function assessment (Ụbụrụ). The clinical assessment was delivered to participants from the database CNS (Computerized Neurocognitive Assessment) Vital Signs (see Figure 3).



Remote Assessment from Arizona State University

CNS Vital Signs

Welcome to the CNS Vital Signs remote neurocognitive assessment. You are receiving this email because your healthcare provider at **Arizona State University** has prescribed our test to you.

STEP ONE:
Your remote testing code is **XQPYAGJA**. Please copy it to your clipboard or write it down exactly. You will need it later.

STEP TWO:
Before you begin your assessment, be aware:

1. You must use a desktop or laptop computer with a working keyboard to take the assessment.
2. You should set aside 1 hour of distraction-free time in case the test runs longer than expected.
3. Once you begin your assessment, you cannot pause, go back, or restart your session. Before starting, be prepared to complete your assessment in its entirety.
4. Do your best to minimize potential distractions before beginning your assessment. This includes:
   - Silencing cell phones and other personal electronics
   - Turning off the TV, radio, and/or other visual or audio distractors
   - Making sure your pet does not require your attention during your testing session.

Figure 3. CNS vital signs access email

The experimental executive function assessment was delivered to participants via Talent LMS (Learning Management System) using iSpring Quizmaker SCORM (Shareable Content Object Reference Model; see Figure 4). The initial experimental executive function assessment consisted of three parts: demographics, self-report survey, and executive function assessments. The experimental executive function assessment is intended to gauge an individuals' ability to engage in tasks that require the ability to plan, organize, and engage in cognitive flexibility. Participants overall scores for the experimental executive function assessment were calculated by averaging the participant's scores on the in the aforementioned three sections, planning, organization, and cognitive flexibility.

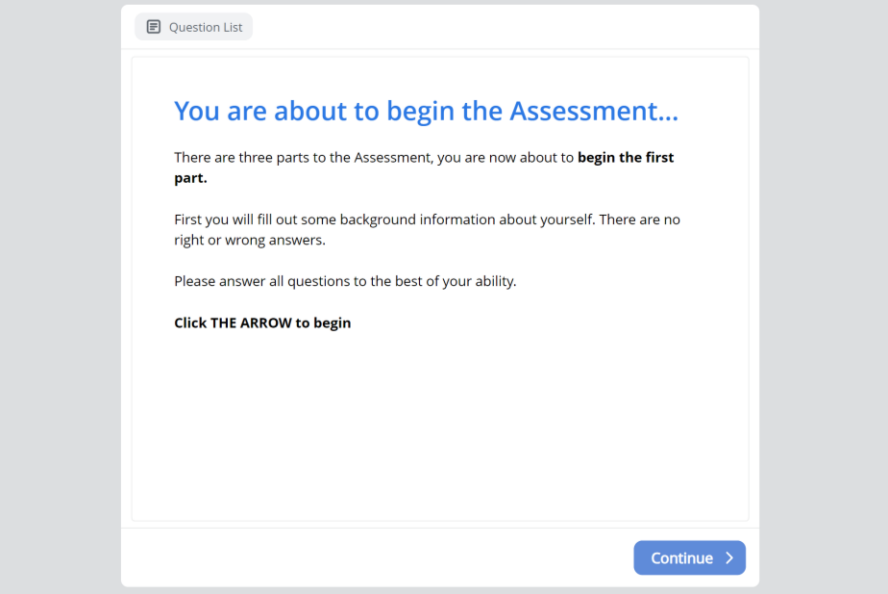


Figure 4. Initial assessment via talent LMS

At the conclusion of the initial assessment, experimental group participants received three scores that were then ranked based on primary, secondary, and tertiary focuses related to planning, organizing, and cognitive flexibility, see Table 3. At the conclusion of the six-week study all participants in both the experimental and control group retook both assessments. For the purposes of this study, the experimental executive function assessment focuses (primary, secondary, and tertiary) were used for participant knowledge solely.

Table 3. Experimental steps

Step	Component	Description
STEP 1: Week 1	Complete Initial Assessment	• Clinical Assessment: CNS Vital Signs • Ụbụrụ Assessment
STEP 2: Week 1	Experimental group receives Executive Function Focus; primary, secondary, and tertiary	Focuses will be planning, organization, and cognitive flexibility
STEP 3: Weeks 2 – 5 ***Experimental group only***	Participate in weekly tasks	5 games x 3 sessions per week

STEP 4: Week 6	Complete Final Assessment	• Clinical Assessment: CNS Vital Signs • Ụbụrụ Assessment

Sessions

For six-weeks participants within the experimental group had three sessions per week in which they participate in five different games (three cognitive flexibility, one planning, and one organization) during each session, see Table 4. Participants were also reminded to complete these weekly sessions via email or text depending on the participants preference.

Table 4. Ụbụrụ session components

EF Skill	Game	Description
Cognitive Flexibility	Beat the Value	Designed to help participants sharpen their problem-solving skills through math, while engaging in task switching. As levels continue to progress users will be responsible for maintaining instructions while completing the task.
	Keeping Track	Focuses on training participants ability to differentiate between items while paying attention to detail. Through the game of Keeping Track participants will be responsible for task switching during a subordinate task in order to acquire information for a superior task.
	This or That	Builds on task switching with an emphasis on paying attention to instruction detail. The focus of this game is to allow participants to maintain relevant information to achieve an overarching goal. As users continue to progress through the levels of This or That
Planning	Train of Thoughts	Provides real world scenarios that allow participants to see the end result of their decisions. During the Train of Thoughts game users are responsible for helping a civilian determine the necessary sequence of events (i.e., making it to a doctor's appointment on time) in order for the 'train to leave the station' while utilizing aspects of working memory and prioritization.

		These scenarios are designed to resemble activities of daily living so knowledge and skills can be applied to the participant's life.
Organization	Rank Order	Focuses on teaching users how to break down an overarching event or goal into smaller tasks. The game of Rank Order has participants look at a list of items and then determine where to start first and order events logically. As levels progress, users will also be responsible for deciphering which events are most urgent, flexible, and/or are able to be rescheduled.
Weekly Surveys		
Will be made available at the end of the week for all participants once all tasks and sessions are completed. The survey will consist of three types of questions: Likert scale, multiple choice, and open-ended questions. The self-report nature of the survey serves as a check in for user feedback, keeps users aware of progress, and keeps users accountable of their program.		

As participants progressed throughout the week, game level difficulty either increased, decreased, or remained the same depending on the participants scores from the previous week. At the conclusion of each week participants also completed a weekly self-report survey (see Figure 5).

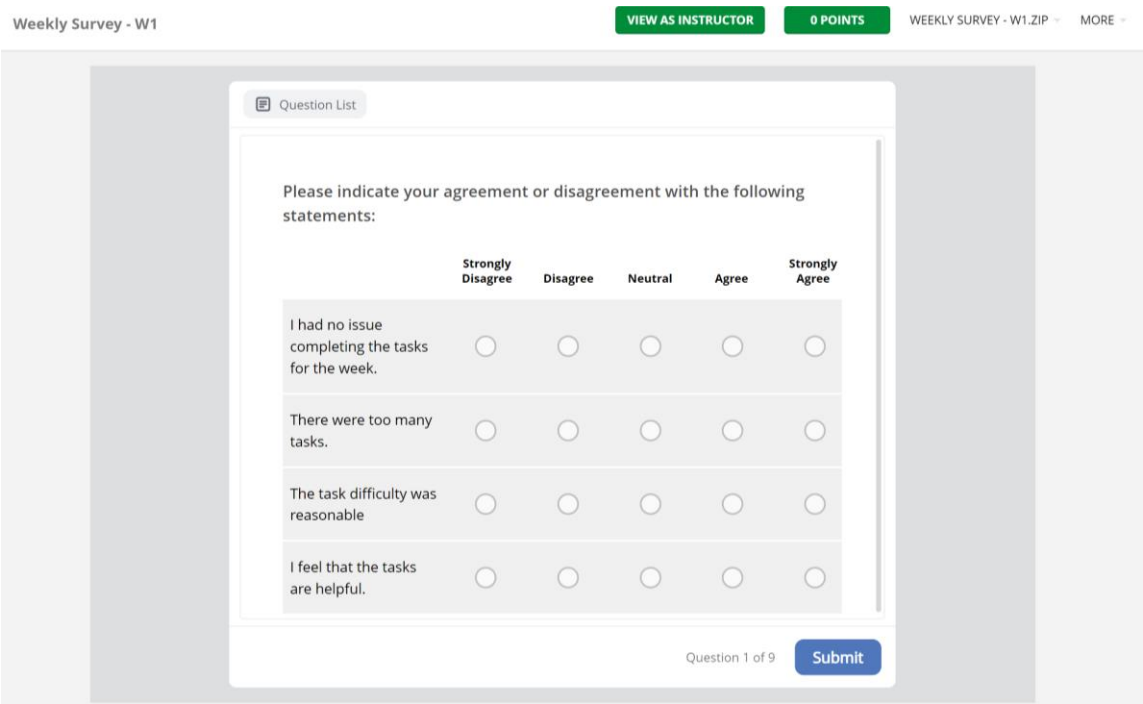


Figure 5. Weekly survey

Session rules. During weeks 2 – 5 all participants within the experimental group participated in three sessions per week. To start off the study all participants began at level one for all five executive function games, there were a total of eight potential levels for each game (see Figure 6). In order for participants to advance to the next level participants had to receive a score of 80 percent or higher. With the beta stage of the application being an accelerated version of the application's intended purpose, participants were capable of playing all five games at various levels depending on their individual progression on each game,

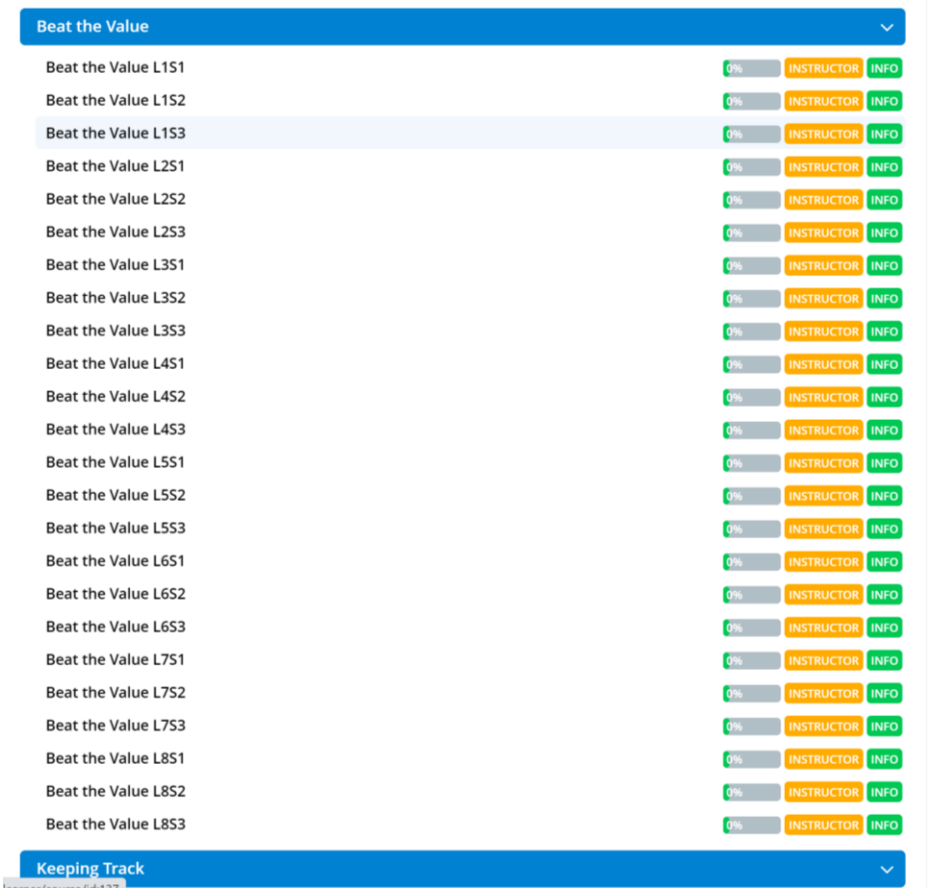


Figure 6. Talent LMS beat the value various levels and sessions example

During participant's first attempt at level one and two, if the participant did not receive a passing score of 80% they would continue to remain at the level they were at until they were capable of reaching a passing score, rather than being limited to the standard three attempt rule that was present in levels 3 – 8. During level's one and two participants also received corrective feedback, and participants were made aware of their running score (see Figure 7).

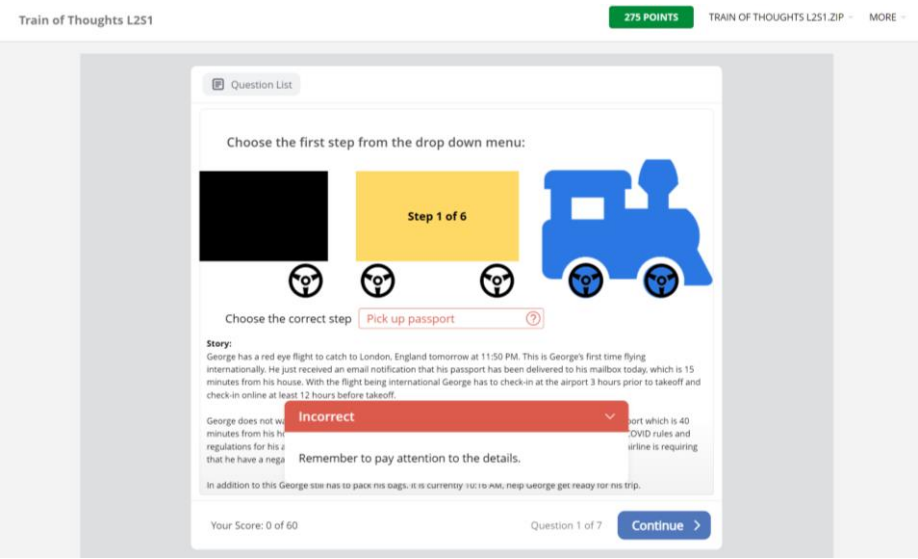


Figure 7. Corrective feedback level two train of thoughts

After participants reached level 3 they were then only allowed three attempts at each level to pass before being moved back down a level. During levels 3 – 8 corrective feedback was removed, and participants did not see their scores until the end each game. At the end of each game levels 1 – 8, all participants were encouraged but not forced to set goals related to target time and score for their next session of each game.

If participants were capable of completing all eight levels of a game before the conclusion of the study they were then exempt from the game for the remainder of the week (see Figure 8a and 8b). At the beginning of each week participants were then reassigned the games the leveled out of, and if they received a passing score again of 80% or better they were then again exempt from that game for the remainder of the week.

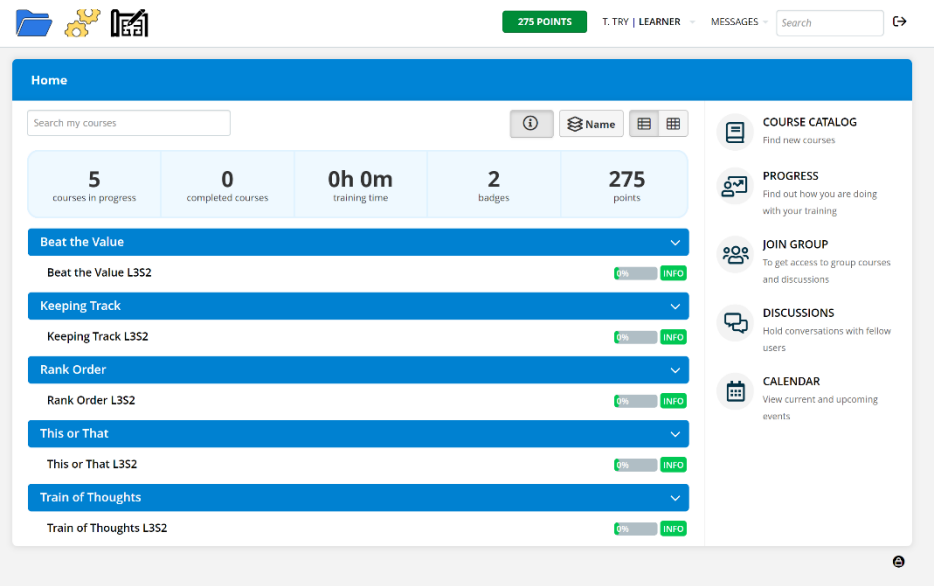


Figure 8a. Weekly tasks – all games no exemption

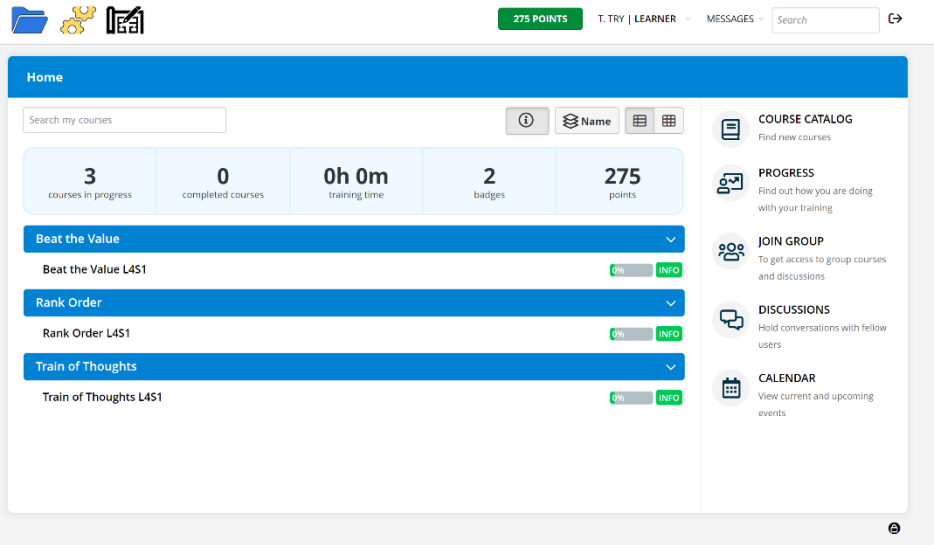


Figure 8b. Weekly tasks – game exemption due to all levels passed

CHAPTER 5

RESULTS

Hypothesis 1 Analysis: Participants within the experimental group will have higher final assessment scores in comparison to those in the control group

Experimental Executive Function Assessment (Ụbụrụ)

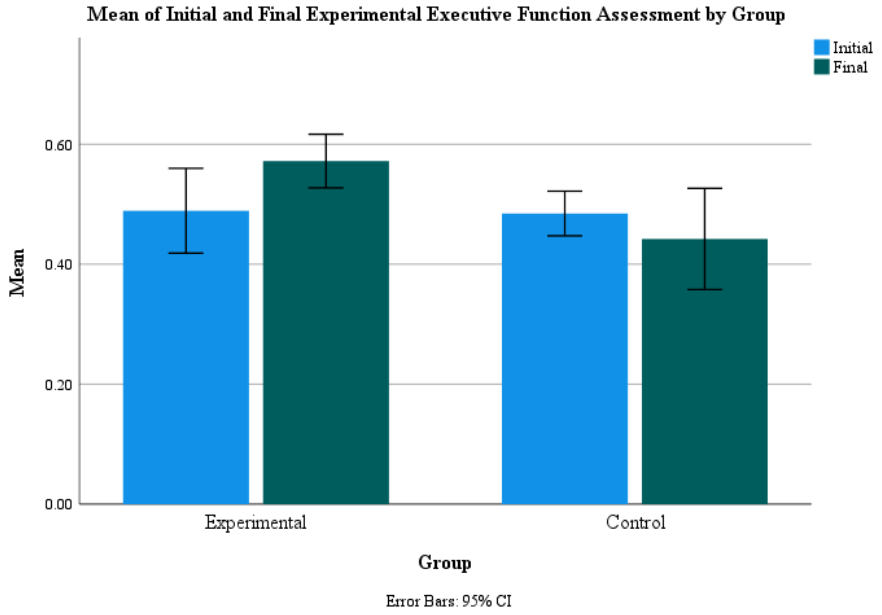


Figure 9a. Initial and final experimental executive function assessment score average by group

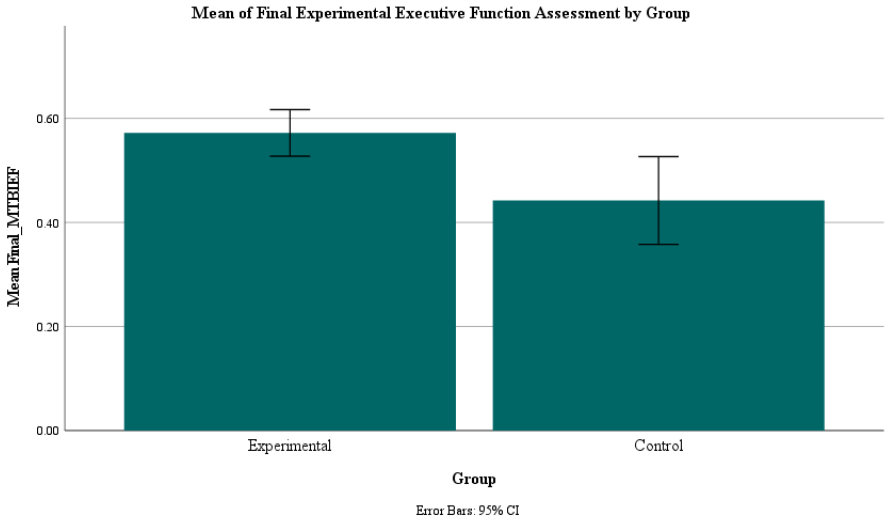


Figure 9b. Final experimental executive function assessment score average by group

As per Hypothesis 1 the experimental group's average score on the experimental executive function assessment was higher than the control group (see Figure 9a – b). To analyze the difference a one-way ANOVA was conducted to compare the means of the control and experimental groups final experimental executive function assessment scores. As a result, there was statistical significance between the groups resulting in, $F(1,25) = 9.109$, $p = 0.006 < 0.05$ (see Table 5).

Table 5. Experimental executive function assessment scores one-way ANOVA

ANOVA

Final_MTBIEF

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.114	1	.114	9.109	.006
Within Groups	.312	25	.012		
Total	.425	26			

Clinical Assessment (CNS Vital Signs)

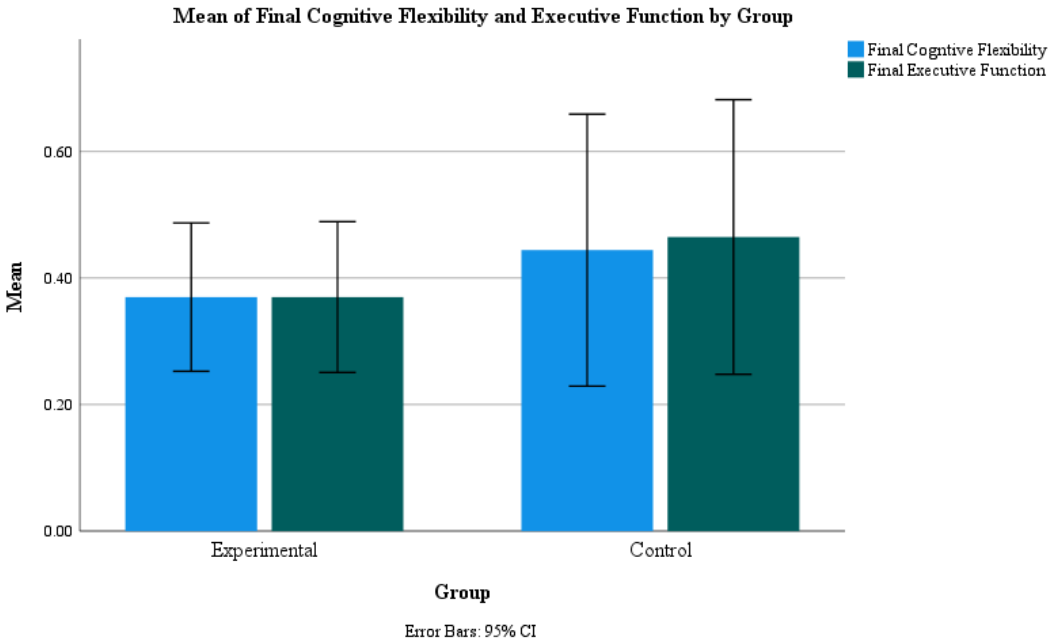


Figure 10. Clinical assessment: Cognitive flexibility and executive function means by group

In analyzing the final clinical assessment scores between the experimental and control group, participants executive function and cognitive flexibility scores were assessed (see Figure 10). To analyze if there was a difference between the group a one-way ANOVA was conducted to compare the means of the control and experimental groups final executive function and cognitive flexibility scores from the clinical assessment (see Table 6).

Table 6. Clinical assessment: Cognitive flexibility and executive function scores one-way ANOVA

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Final_CF	Between Groups	.036	1	.036	.475	.497
	Within Groups	1.796	24	.075		
	Total	1.831	25			
Final_EF	Between Groups	.058	1	.058	.762	.392
	Within Groups	1.838	24	.077		
	Total	1.896	25			

The results yielded for the cognitive flexibility portion of the clinical assessment were $F(1,24) = 0.475$, $p = 0.497 > 0.05$. and the results for the executive function portion of the clinical assessment were $F(1,24) = 0.762$, $p = 0.392 > 0.05$. Unlike the experimental executive function assessment there was no statistical significance for the clinical assessment when it came to executive function and cognitive flexibility scores.

Hypothesis 2 Analysis: There will be a positive correlation between participants' game levels and participants' recorded times.

The next hypothesis for this study looks at the potential relationship between participant level progression and the participant's recorded time for each game within the experimental group. The aim of this hypothesis was to assess if there was any

relationship of significance between participant's recorded time and level. To conduct this analysis a Pearson correlation was conducted.

Participants weekly level average (see Figures 11a – e) and weekly time average was initially calculated for each of the five games on a weekly basis. With participants participating in each game three times a week for four weeks, the average weekly score was used for each game by participant, resulting in five average game scores (This or That, Train of Thoughts, Keeping Track, Rank Order, and Beat the Value) for four weeks.

This or That

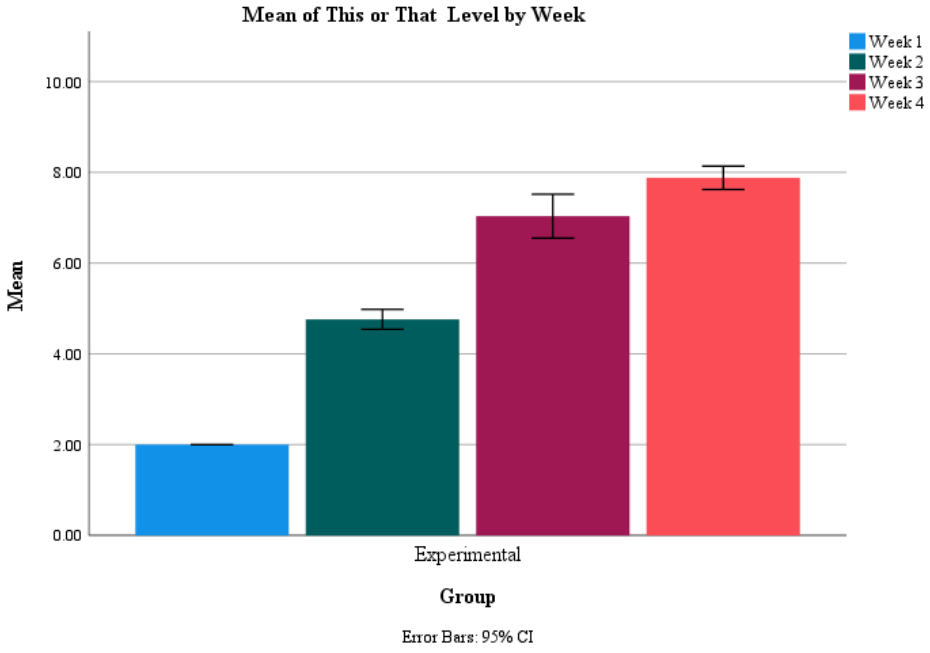


Figure 11a. Experimental group this or that experimental group weekly game level

The first weekly game that was analyzed is This or That, a cognitive flexibility game. There was no significant correlation when it came to observing significance between participant's recorded time and level during week 1 – 4 of This or That.

However, during weeks 2 – 4 there was an observed significant correlation between participant score and game level (see Tables 7a – 7c).

Table 7a. This or that week two correlation: score x level

Correlations

		Week 2 Score	Week 2 Level	Week 2 Time
Week 2 Score	Pearson Correlation	1	.587*	.198
	Sig. (2-tailed)		.027	.497
	N	14	14	14
Week 2 Level	Pearson Correlation	.587*	1	.394
	Sig. (2-tailed)	.027		.164
	N	14	14	14
Week 2 Time	Pearson Correlation	.198	.394	1
	Sig. (2-tailed)	.497	.164	
	N	14	14	14

*. Correlation is significant at the 0.05 level (2-tailed).

During Week 2 of This or That the average level for experimental group participants was 4.7 and the average score was 89.86%. During this week, the observed correlation between participant score and game level was [r(14) = 0.587, p = 0.027].

Table 7b. This or that week three correlation: score x level

Correlations

		Week 3 Score	Week 3 Level	Week 3 Time
Week 3 Score	Pearson Correlation	1	.918**	.157
	Sig. (2-tailed)		<.001	.593
	N	14	14	14
Week 3 Level	Pearson Correlation	.918**	1	.024
	Sig. (2-tailed)	<.001		.936
	N	14	14	14
Week 3 Time	Pearson Correlation	.157	.024	1
	Sig. (2-tailed)	.593	.936	
	N	14	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

During Week 3 of This or That the average level for experimental group participants was 7.04 and the average score was 95.50%. During this week, the observed correlation between participant score and game level was [r(14) = 0.918, p < 0.001].

Table 7c. This or that week four correlation: score x level

Correlations

		Week 4 Score	Week 4 Level	Week 4 Time
Week 4 Score	Pearson Correlation	1	.762**	.214
	Sig. (2-tailed)		.002	.463
	N	14	14	14
Week 4 Level	Pearson Correlation	.762**	1	.290
	Sig. (2-tailed)	.002		.315
	N	14	14	14
Week 4 Time	Pearson Correlation	.214	.290	1
	Sig. (2-tailed)	.463	.315	
	N	14	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

During Week 4 of This or That the average level for experimental group participants was 7.88 and the average score was 96.71%. During this week, the observed correlation between participant score and game level was [r(14) = 0.762, p = 0.002].

Train of Thoughts

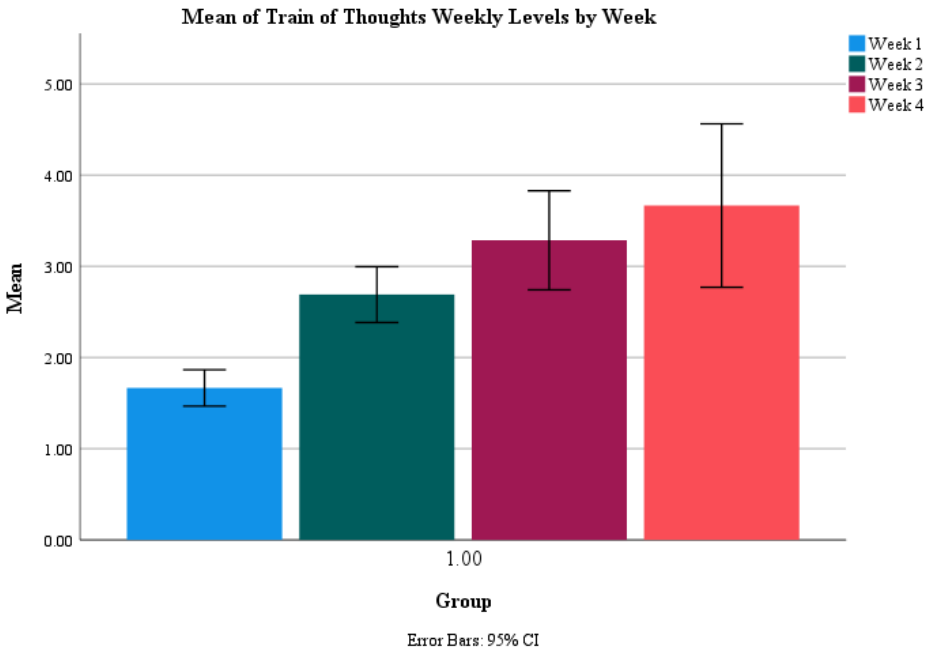


Figure 11b . Experimental group train of thoughts experimental group weekly game level

The next weekly game that was analyzed is Train of Thoughts, a planning game. The null hypothesis proved to be true again when it came to observing significance between participant's recorded time and level during week 1 – 4 of Train of Thoughts. During weeks one there was an observed significant correlation between participant score and game level (see Table 8).

Table 8. Train of thoughts week one correlation: score x level

Correlations

		Week 1 Score	Week 1 Level	Week 1 Time
Week 1 Score	Pearson Correlation	1	.545*	.167
	Sig. (2-tailed)		.044	.568
	N	14	14	14
Week 1 Level	Pearson Correlation	.545*	1	.377
	Sig. (2-tailed)	.044		.184
	N	14	14	14

Week 1 Time	Pearson Correlation	.167	.377	1
	Sig. (2-tailed)	.568	.184	
	N	14	14	14

*. Correlation is significant at the 0.05 level (2-tailed).

During Week 1 of Train of Thoughts the average level for experimental group participants was 1.67 and the average score was 66.14%. During this week, the observed correlation between participant score and game level was [r(14) = 0.545, p = 0.044].

Keeping Track

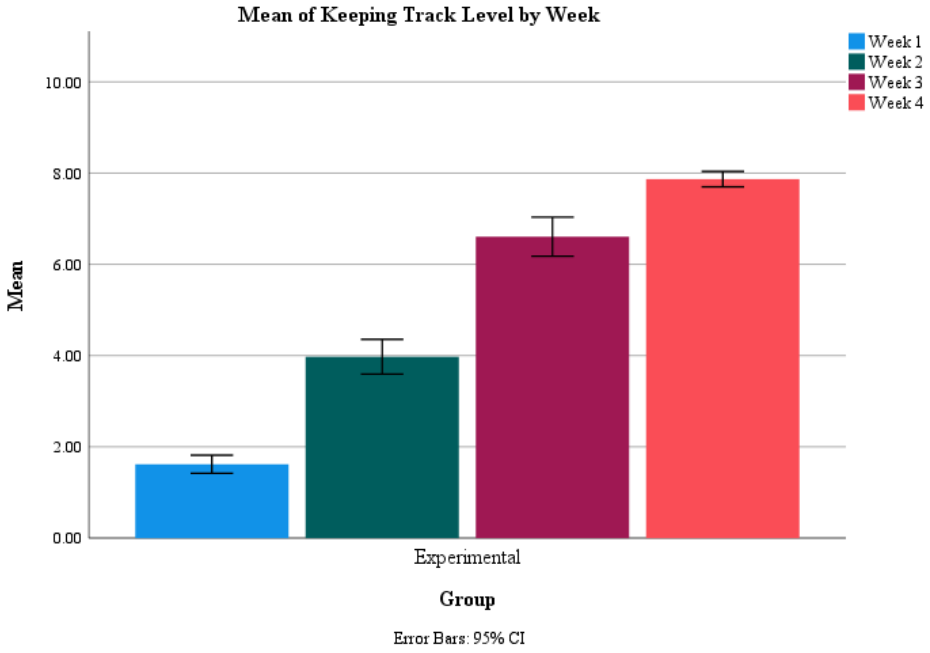


Figure 11c. Experimental group keeping track experimental group weekly game level

Next Keeping Track, another cognitive flexibility game was analyzed. Hypothesis 2 was supported when it came to observing the significance between participant's level and recorded time during week 2 (see Table 9b). Another correlation was observed when it came to participant scores and recorded time during week one of Keeping Track (see Table 9a).

Table 9a. Keeping track week one correlation: score x time

Correlations

		Week 1 Score	Week 1 Level	Week 1 Time
Week 1 Score	Pearson Correlation	1	.478	.637*
	Sig. (2-tailed)		.084	.014
	N	14	14	14
Week 1 Level	Pearson Correlation	.478	1	.489
	Sig. (2-tailed)	.084		.076
	N	14	14	14
Week 1 Time	Pearson Correlation	.637*	.489	1
	Sig. (2-tailed)	.014	.076	
	N	14	14	14

*. Correlation is significant at the 0.05 level (2-tailed).

During Week 1 of Keeping Track the average level for experimental group participants was 1.62, the average score was 86.64%, and the average time was 2 minutes and 15 seconds. During this week, the observed correlation between participant score and recorded time was [r(14) = 0.637, p = 0.014].

Table 9b. Keeping track week two correlation: level x time

Correlations

		Week 2 Score	Week 2 Level	Week 2 Time
Week 2 Score	Pearson Correlation	1	.367	-.004
	Sig. (2-tailed)		.196	.989
	N	14	14	14
Week 2 Level	Pearson Correlation	.367	1	.593*
	Sig. (2-tailed)	.196		.025
	N	14	14	14
Week 2 Time	Pearson Correlation	-.004	.593*	1
	Sig. (2-tailed)	.989	.025	
	N	14	14	14

*. Correlation is significant at the 0.05 level (2-tailed).

During Week 2 of Keeping Track the average level for experimental group participants was 3.97, the average score was 94.21%, and the average time was 3 minutes and 10 seconds. During this week, the observed correlation between participant recorded time and game level was [r(14) = 0.593, p = 0.025].

Rank Order

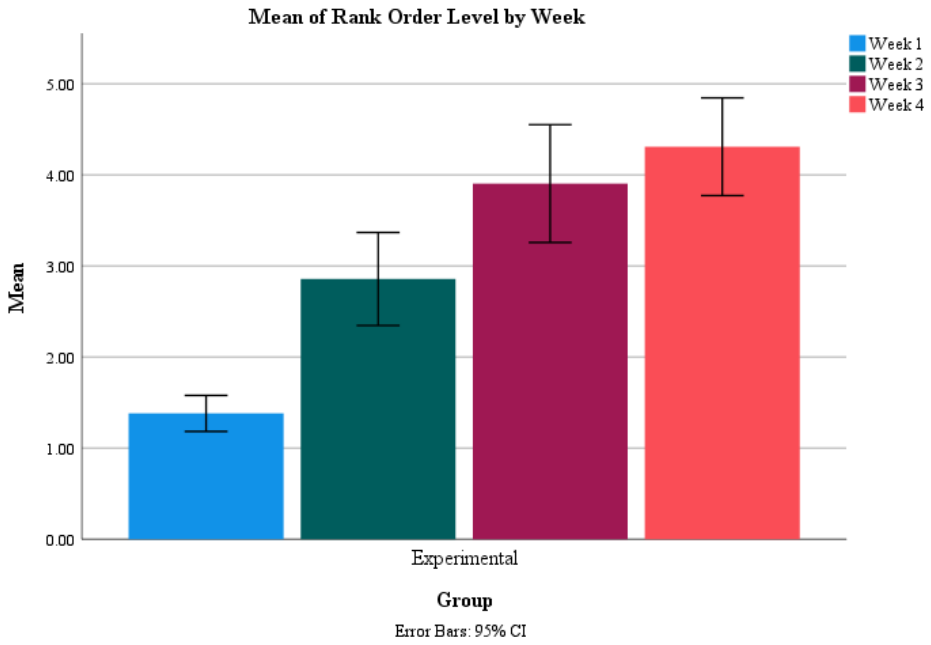


Figure 11d. Experimental group rank order experimental group weekly game level

The next weekly game that was analyzed is Rank Order, an organization game. Hypothesis 2 proved to be true again when it came to observing significance between participant's recorded time and level during week two of Rank Order (see Table 10b). During week one there was another observed significant correlation between participant score and game level (see Table 10a).

Table 10a. Rank order week one correlation: score x level

Correlations

		Week 1 Score	Week 1 Level	Week 1 Time
=Week 1 Score	Pearson Correlation	1	.683**	.192
	Sig. (2-tailed)		.007	.510
	N	14	14	14
Week 1 Level	Pearson Correlation	.683**	1	.373
	Sig. (2-tailed)	.007		.190
	N	14	14	14
Week 1 Time	Pearson Correlation	.192	.373	1
	Sig. (2-tailed)	.510	.190	
	N	14	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

During Week 1 of Rank Order the average level for experimental group participants was 1.38 and the average score was 72.07%. During this week, the observed correlation between participant score and game level was [r(14) = 0.683, p = 0.007].

Table 10b. Rank order week two correlation: level x time

Correlations

		Week 2 Score	Week 2 Level	Week 2 Time
Week 2 Score	Pearson Correlation	1	-.029	-.239
	Sig. (2-tailed)		.922	.410
	N	14	14	14
Week 2 Level	Pearson Correlation	-.029	1	.576*
	Sig. (2-tailed)	.922		.031
	N	14	14	14
Week 2 Time	Pearson Correlation	-.239	.576*	1
	Sig. (2-tailed)	.410	.031	
	N	14	14	14

*. Correlation is significant at the 0.05 level (2-tailed).

During Week 2 of Rank Order the average level for experimental group participants was 2.86, the average score was 66.14%, and the average time was 1 minute and 34 seconds. During this week, the observed correlation between participant recorded time and game level was [r(14) = 0.576, p = 0.031].

Beat the Value

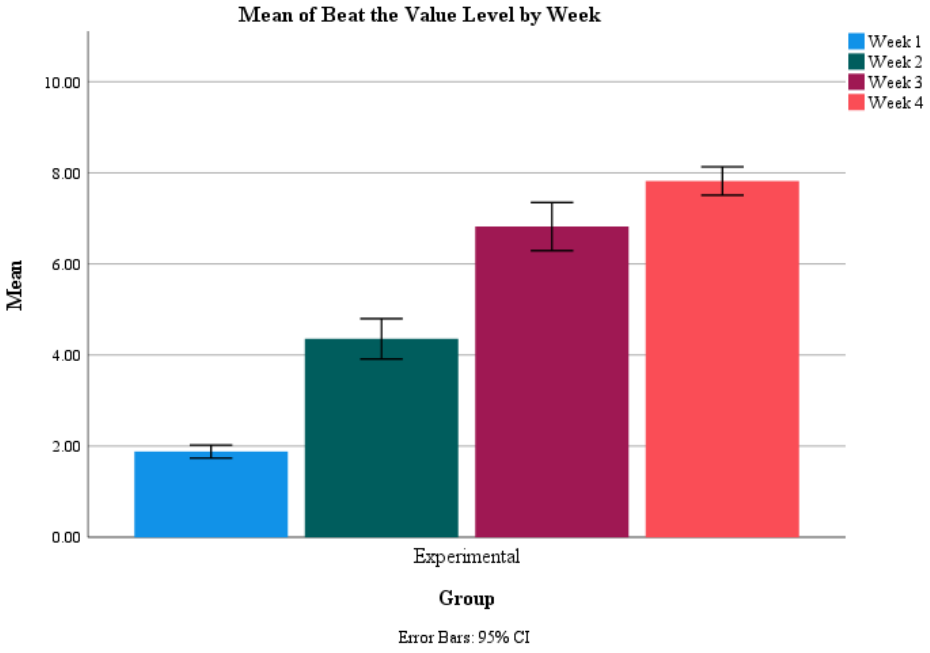


Figure 11e. Experimental group beat the value experimental group weekly game level

The next weekly game that was analyzed is Beat the Value, a problem solving cognitive flexibility game. There was no significant correlation between participants' recorded time and level during weeks 1 – 4 of Beat the Value. However, during week three there was an observed significant correlation between participant score and game level (see Table 11).

Table 11. Beat the value week three correlation: score x level

Correlations

		Week 3 Score	Week 3 Level	Week 3 Time
Week 3 Score	Pearson Correlation	1	.750**	-.439
	Sig. (2-tailed)		.002	.116
	N	14	14	14
Week 3 Level	Pearson Correlation	.750**	1	-.347
	Sig. (2-tailed)	.002		.224
	N	14	14	14
Week 3 Time	Pearson Correlation	-.439	-.347	1
	Sig. (2-tailed)	.116	.224	
	N	14	14	14

**. Correlation is significant at the 0.01 level (2-tailed).

During Week 3 of Beat the Value the average level for experimental group participants was 6.82 and the average score was 88.79%. During this week, the observed correlation between participant score and game level was [r(14) = 0.750, p = 0.002].

Hypothesis 3 Analysis: Participant's within the experimental group, will see the most improvement in their initial assessment primary executive function focus.

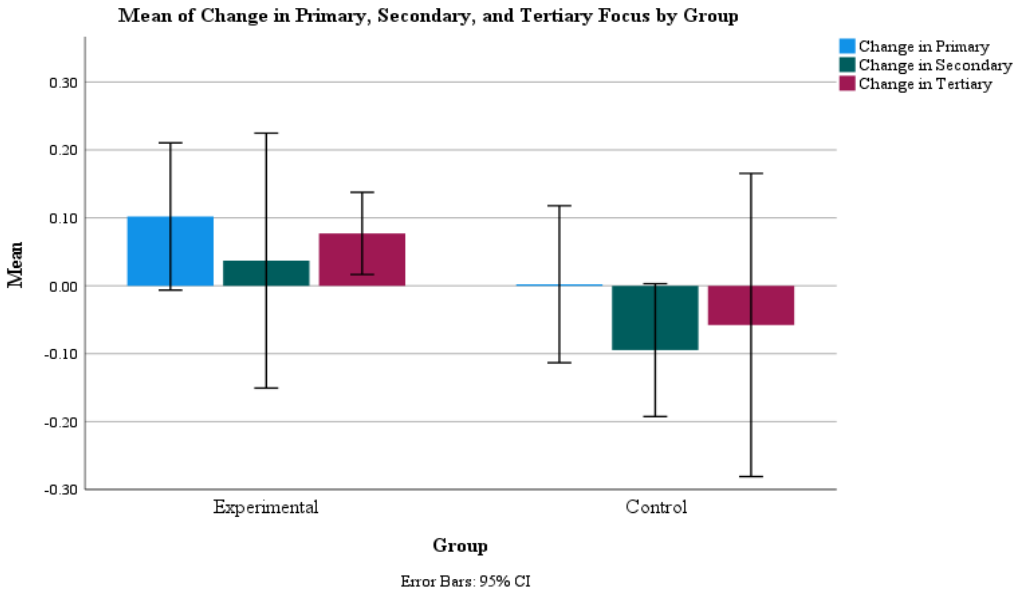


Figure 12. Mean of change for executive function assessment primary, secondary, and tertiary focus

To analyze Hypothesis 3 a one-way ANOVA was conducted. Prior to conducting the ANOVA, the change in scores was calculated for each participants primary, secondary, and tertiary executive function focus (see Figure 12).

Table 12. Final and initial primary executive function focus one-way ANOVA

ANOVA

Change_Prim

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.067	1	.067	1.872	.183
Within Groups	.897	25	.036		
Total	.964	26			

After observing the data there was no observed statistical significance for participants primary focus ($F(1,25) = 1.872$, $p = 0.183 > 0.05$; see Table 12). There also was no statistical significance for participants secondary or tertiary focus scores (see Table 13).

Table 13. Final and initial secondary and tertiary executive function focus one-way ANOVA

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Change_sec	Between Groups	.117	1	.117	1.733	.200
	Within Groups	1.688	25	.068		
	Total	1.805	26			
Change_ter	Between Groups	.123	1	.123	1.722	.201
	Within Groups	1.780	25	.071		
	Total	1.902	26			

Hypothesis 4 Analysis: Experimental group participants will have a more positive outlook on their ability to accomplish tasks that require executive function skills.

Hypothesis 4 explores the qualitative data from the experimental executive function assessment self-report survey. In looking at the results from the 16 item survey, one statement, ‘it is difficult for me to plan out my day,’ highlighted a difference between groups in the final assessment self-report (see Figure 13).

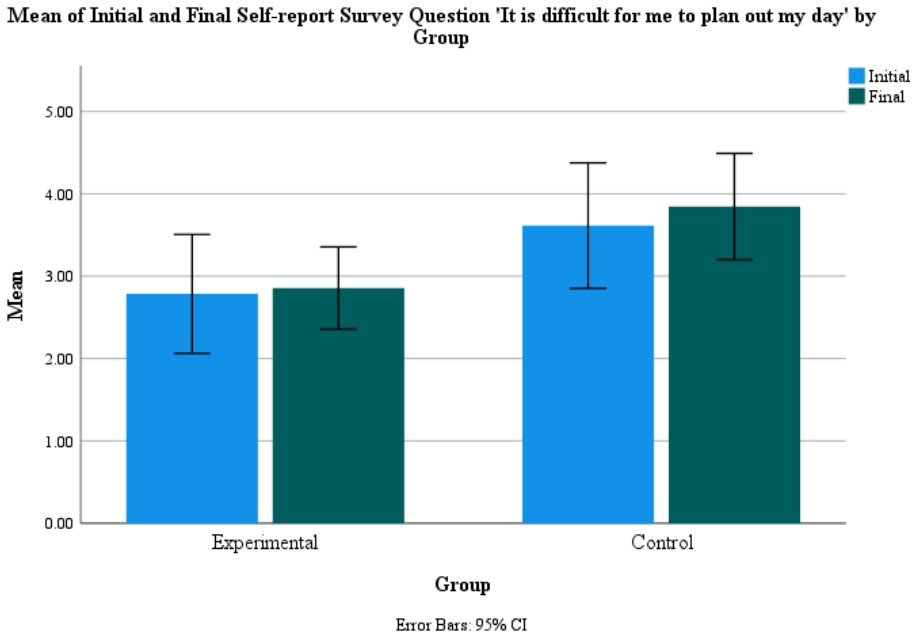


Figure 13. Mean of participant initial and final response scores to 'it is difficult for me to plan out my day'

Although the experimental group did not demonstrate a more positive outlook than the control group, there still was an observed difference in perception between the groups when it came to opinions related to the question 'it is difficult for me to plan out my day.' As a result, there was statistical significance between the groups from the final assessment self-report resulting in, $F(1,25) = 7.042$, $p = 0.014 < 0.05$ (see Table 14).

Table 14. Initial and final self-report survey (it is difficult for me to plan out my day) one-way ANOVA

ANOVA

		Sum of Squares	Df	Mean Square	F	Sig.
ini_diff_plan outday	Between Groups	4.640	1	4.640	2.942	.099
	Within Groups	39.434	25	1.577		
	Total	44.074	26			
fin_diff_plan outday	Between Groups	6.593	1	6.593	7.042	.014
	Within Groups	23.407	25	.936		
	Total	30.000	26			

CHAPTER 6

DISCUSSION

Summary

The goal of this research was to further explore how to better aid in mild traumatic brain injury rehabilitation. The study aimed to further explore TBI rehabilitation by specifically focusing on the role executive function can play in rehabilitation for mTBI individuals. By further exploring the role that executive dysfunction plays amongst mTBI individuals, a novel approach to rehabilitation was able to be taken. This was done through attempting to pinpoint activities of daily living in an experimental setting. Participants in the experimental group of this study were able to test out a new experimental intervention.

The efforts of this dissertation also aimed to implement the National Science Foundation Research Traineeship Smart Cities initiative, by exploring the needs of its members who belong to the mild traumatic brain injury community. By specifically focusing on a special population, this dissertation aimed to identify a customizable solution rather than a one size fits all approach. The intent of the experimental application was to encapsulate executive function in activities of daily living in the form of five games. The weekly games that participants played focused on planning, organization, and cognitive flexibility, and were used to help train participants to adapt or improve various skills used to complete these tasks.

By incorporating a control group within this study, comparisons were able to be made to fellow mTBI individuals who did not partake in any experimental intervention other than the initial and final assessments. Although the application in this study is in its

beta stage, the experimental group when in comparison to the control group displayed significance when looking at both the quantitative and qualitative (self-report) data as well.

Discussion Findings

Hypothesis 1 Analysis: *Participants within the experimental group will have higher final assessment scores in comparison to those in the control group*

The experimental group not only showed statistical significance in regard to their final experimental executive function assessment scores, but also in comparison to the control group there was improvement in score from the initial to final experimental executive function assessment. Whereas although not statistically significant, the control group demonstrated a decrease in scores from the initial to the final experimental executive function assessment.

Hypothesis 2 Analysis: *There will be a positive correlation between participant's game levels and participant's recorded times.*

In looking at Hypothesis 2 for each of the five individuals games significant correlation was detected. When looking at the cognitive flexibility games that focused on adapting to new rules (This or That and Beat the Value) a positive correlation was found between either level or time and score later on in the study when participants were reaching higher levels in the intervention. On the other hand, when looking at the planning (Train of Thoughts), organization game (Rank Order), and cognitive flexibility game that require maintaining and storing new information for a future goal (Keeping Track) the correlation was only apparent during the earlier weeks of the study when participants were at lower levels in the intervention.

Cognitive flexibility (adaptation). The aim of the cognitive flexibility tasks was to train individuals ability to integrate new information and adapt present behavior to achieve a desired task (Pang, Dunkley, Doesburg, de Costa, & Taylor, 2016). For the majority of the participants cognitive flexibility was deemed their tertiary focus, due to their initial scores on the initial experimental executive function assessment; and for the majority of the participants their cognitive flexibility score improved on the final experimental executive function assessment.

With participants' cognitive flexibility scores improving in the final assessment as well as there being a positive correlation between scores and higher levels in later weeks (weeks 3 and 4) indicates that the application does align with intended purposes of the training. Within this study participants demonstrated that they were capable of adapting their behavior when it comes to cognitive flexibility tasks on both a weekly basis as well as on the initial and final assessments. Participants also demonstrated on a weekly basis that they were capable of progressing to higher levels of cognitive flexibility games focused on adaptation.

Planning and Organization. For planning and organization games, a positive correlation between level and score was only observed during the earlier weeks of the study (weeks 1 and 2) when participants were at easier levels. As participants' levels increased for planning and organization games, participants displayed lower scores. With this study being an accelerated version of the intended purpose of the application, by the conclusion of the study ideally participants who engaged in three sessions per week should be at level four for all games, but that was not the case for Train of Thoughts.

Although participants were capable of reaching level four at the conclusion of the study for Rank Order, participants were also still more likely to decrease in level for Train of Thoughts and Rank Order than with the cognitive flexibility games. The fact that participants decreased levels for these two games may suggest that the level difficulty for these two games may be too difficult and need to be readjusted.

Although the experimental group scores improved when it came to the final experimental assessment for planning and organization, the overall scores were still lower when compared to cognitive flexibility. Therefore, another possibility is that with planning and organization having lower final experimental executive function scores more training needs to be incorporated in the application for planning and organization tasks, for participants to see substantial improvements in planning and organization executive function skills.

Cognitive flexibility (maintenance). Unlike the cognitive flexibility games that were reliant on adaptation participants did not show a strong correlation in later weeks (week 3 and 4) between levels, scores, or time for Keeping Track, which was focused on maintaining information. The only time a correlation was detected between score and time, and level and time was during the earlier weeks (week 1 and 2) of the study. Despite the lack of correlation participants still demonstrated an ability to perform successfully at higher levels for Keeping Track.

Hypothesis 3 Analysis: *Participant's within the experimental group, will see the most improvement in their initial assessment primary executive function focus.*

Although there was no statistical significance in terms of improvement, the experimental group did see the most improvement in terms of score when it came to their

primary focus. The experimental group also saw improvements in scores for both their secondary and tertiary focus. Whereas the control group who did not partake in the intervention saw a decline in score in their primary, secondary, and tertiary focus.

Hypothesis 4 Analysis: *Experimental group participants will have a more positive outlook on their ability to accomplish tasks that require executive function skills.*

The intention of encouraging participants to engage in goal setting on a regular basis was to encourage awareness amongst participants (Brown et al., 2021). Additionally, by having participants set goals and achieve them on a regular basis the idea was that participant's confidence would increase as well, especially in comparison to the control group. However, in analyzing the data from the self-report survey participants within the experimental group seemed to be more pessimistic about their ability to plan out their day.

The experimental groups average response via a Likert scale (1 = strongly agree – 5 =strongly disagree) was 2.84 (neutral) while the control groups average response was 3.83 (disagree). Although the experimental group was not in complete agreement with the statement the intended outcome of increasing confidence was not observed. Instead, the results may suggest that participants within the experimental group may be hyper aware or overly cautious when it comes to self-report.

Limitations

With this study being conducted only in the beta phase it was important to keep in mind potential limitations. A potential limitation to consider for this study is the retention rate of participants within this study. The final number of participants who completed the study was 27. In total there were 70 participants who were enrolled in the study, and 44

participants in total who started the study. The fluctuation in participation can be attributed to the amount of compensation for participating in this study.

Another limitation for this study was interval differences in the experimental group. The study was intended to last a total of six weeks from start to finish. Due to the intermittent responsiveness of some participants, some individuals took a total of nine weeks to complete the study from start to finish. This discrepancy in enrollment time may have negatively impacted participant motivation and hindered the integrity of the three weekly sessions.

Last, with the study being in the beta stage the delivery method of the study is not the final intended mode. With participants accessing the components for this study via a learning management system the serious gamification concept may have been hindered. The intended fluidity of an inclusive web-based application was not able to be achieved for this phase of the study.

Future Work

There still continues to be much to learn about mTBI rehabilitation especially as it relates to executive function. This study began to explore the role of executive function especially as it relates to activities of daily living for mTBI individuals. Although this study was able to find some significance in regard to the role of an experimental intervention versus no intervention, the study had its apparent limitations.

More work needs to be done to further address the disconnect between first line and next line care medical professionals. By expanding research in this realm, issues related to misdiagnoses and underdiagnosis can potentially be better addressed. mTBI rehabilitation as a whole has made progress and continues to still have even more room

for progression to better address the needs of the mTBI community. In order for progress to continue to be made it is important to start from the roots up.

Another area for future work related to mTBI rehabilitation is further expanding into the role that artificial intelligence (AI) can play. Although AI and TBI research is fairly new the potential work and discoveries could be groundbreaking. This is especially so when it comes to implementing AI into TBI detection, prevention, and identifying potential patterns for future health risks related to TBIs (Man, Poon, & Lam, 2013).

Going forward with this application, the next step will be to advance from the prototype (beta stage) to having a fully functioning web based application. During this next stage of the projects development new features will be implemented through the incorporation of resource recommendations, resources page, and in app notifications. In addition to these features participants within the next phase of the study will move up and down game levels on a weekly basis rather than per session.

Additionally, future work related to this application, would potentially be beneficial to individuals without a history of traumatic brain injury. Due to the increase in the experimental groups experimental executive function scores as well as primary, secondary, and tertiary focus, this application may prove to be beneficial in helping with executive function training for the general public.

Conclusion

Mild traumatic brain injury rehabilitation research has come a long way. Advances have been made in terms of diagnosis, rehabilitation, and detection, but there still is so much that we do not know. The findings of this dissertation illustrate that further research can be beneficial and is still needed to better understand the needs of the

mTBI community. As seen in this study, though cognitive flexibility is a prominent area of executive function, mTBI individuals do not appear to struggle with tasks that require cognitive flexibility as much as they do tasks that are dependent on planning and organization. In looking at the results from this study it is even more apparent that more research is needed as it is related to executive function training for planning and organization. This dissertation also demonstrated that despite being out of the acute stage mTBI individuals are still able to benefit from executive function training, even when it is implemented more than a year post-injury.

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APPENDIX A

ỤBỤRỤ ASSESSMENT: DEMOGRAPHICS

Traumatic Brain Injury / Concussion History

1. What age group do you fall in?
    a. 18-25
    b. 26-30
    c. 31-35
    d. 35-40
2. Please select your gender.
    a. Male
    b. Female
    c. Male, born female
    d. Female, born male
3. When did your traumatic brain injury/concussion occur?
    a. Less than 3 months ago
    b. Less than 6 months ago
    c. Less than a year ago
    d. More than a year ago
4. How old were you at the time of injury? ***Type answer***
5. How many traumatic brain injury/concussions have you had?
    a. 1
    b. 2
    c. 3
    d. 4
6. How did your traumatic brain injury/ concussion occur?
    a. Sports Related
    b. Motor Vehicle Accident
    c. Fall
    d. Physical Altercation
7. Have you received any medical treatment for your traumatic brain injury/concussion?
    a. Yes
    b. No
    c. Unsure

APPENDIX B

ỤBỤRỤ ASSESSMENT: ASSESSMENT SURVEY

You are now about to begin the second part of the Uburu Assessment. You will be asked to complete a survey.

There are no right or wrong answers. The survey is solely based on your opinion.
Once you start you won't be able to go back.
Take your time. Relax. Answer all questions to the best of your ability.

To answer the questions in the survey you will select a number between 1 and 5

1 = Strongly Disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly Agree

Negative language

1. I have a hard time switching between different tasks.
2. It is difficult for me to get done everything I want to in a day.
3. I usually don't remember appointments meetings, or events.
4. I am not the most organized person.
5. It is difficult for me to find more than one solution to a problem.
6. I usually don't remember to follow through with plans.
7. I have a hard time retaining more than one piece of information at a time.
8. It is difficult for me to plan out my day

Positive language

1. It is easy for me to switch between different tasks
2. I have no problem getting done what I want to in a day
3. I usually remember appointments, meetings, or events.
4. I am an organized person.
5. I can find more than one solution to a problem
6. I usually follow through with plans
7. I can retain more than one piece of information at a time
8. It is easy for me to plan out my day

APPENDIX C

ỤBỤRỤ ASSESSMENT: ASSESMENT TASKS: PLANNING

Part 1

Please read the story below and answer the questions:

It is the weekend before Johnathan's finals week. Johnathan currently has an 89 in Policy Informatics, 79 in Biochemistry, 84 in Psychology, and an 85 in Geometry.
In all four of Johnathan's classes his final exams are worth 15% of his final grade.
Johnathan exam schedule for the week is as follows:

- Psychology: Wednesday at 9 AM
- Policy Informatics: Wednesday at 10 AM
- Biochemistry: Thursday at 9 AM
- Geometry: Tuesday at 9 AM

1. Which exam should Johnathan study for first?
    a. Psychology
    b. Policy Informatics
    c. Biochemistry
    d. Geometry

2. Which exam should Johnathan study for last?
    a. Psychology
    b. Policy Informatics
    c. Biochemistry
    d. Geometry

3. Which exam on Wednesday should be Johnathan’s priority?
    a. Psychology
    b. Policy Informatics
    c. Biochemistry
    d. Geometry

Part 2

Please read the story below and answer the questions:

Kimberly is registering for next semester classes. She needs 11 more credits to graduate (1 psychology course, 1 science course and lab, and an elective course). Her boss just informed her that he needs her to switch to the 10 AM - 2 PM shift on Mondays, Tuesdays, and Fridays at the campus Bookstore.

Below is a list of classes Kimberly is considering for this semester:

Class	Days	Time	Credits
Bio-Chem	T, Th	8 AM - 9:30 AM	3
Child Psych	M, W	3 PM - 4:30 PM	3
Life Psych	T	2:20 PM - 5: 20 PM	3
Bio-Chem Lab	F	8 AM - 10 AM	2
Anthropology	M, W, F	2:30 PM - 3:20 PM	3
Bio-Chem Lab	W	4:45 PM - 6: 45 PM	2
UX Design	T	5:30 PM - 7:30 PM	2

Help Kimberly decide which courses she should take this semester

APPENDIX D

ỤBỤRỤ ASSESSMENT: ASSESSMENT TASKS: ORGANIZATION

Part 1

You have one day to complete all the items listed below, organize the events into a logical schedule:

- Flight to Denver at 10:15 AM
- Pack driver's license and wallet
- Check in to flight 24 hours before takeoff
- Set up apple pay for Lyft
- Inform airline about nut allergy
- Catch Lyft to airplane
- Pack suitcase
- Pick up EpiPen and inhaler from pharmacy
- Check bags at airline counter
- Check Denver forecast

Part 2

Select all urgent events:

- Project proposal meeting at 8 AM
- Oil change at 5:15 PM
- Hair appointment at 12 PM
- Mammogram appointment at 8 AM
- Watch Real Housewives at 5:30 PM
- Dinner with friends at 6:15 PM
- Submit finance spreadsheet by 6:30 PM
- Submit grant funding application by 12 PM

1. How many events need to be rescheduled?
2. How many events are flexible?

APPENDIX E

ỤBỤRỤ ASSESSMENT: ASSESSMENT TASKS: COGNITIVE FLEXIBILITY

ASSESSMENT TASKS EXAMPLE

Part 1

When the OBJECT appears in BLACK CLICK THE CATEGORY
When the OBJECT appears in COLOR CLICK THE COLOR

Click NEXT to begin

Sport Black

Part 2

When the WORD appears in BLACK CLICK THE CATEGORY
When the WORD appears in COLOR CLICK THE COLOR

Click NEXT to begin

Part 3

When the WORD appears CLICK THE COLOR of the word
When the OBJECT appears CLICK THE CATEGORY it belongs to

Click NEXT to begin

Sport Blue

APPENDIX F

ỤBỤRỤ WEEKLY TASKS: THIS OR THAT EXAMPLE

When the WORD appears CLICK THE COLOR of the word to the RIGHT
When the OBJECT appears CLICK THE CATEGORY it belongs to on the LEFT

Please click the NEXT button to BEGIN THE LEVEL

Shape Red

APPENDIX G

ỤBỤRỤ WEEKLY TASKS: TRAIN OF THOUGHTS EXAMPLE

You are now about to begin the 'Train of Thoughts.'
The train has entered the station! Throughout the game if you are unsure of anything please feel free to click the question icons for further explanation.
Click Next and please read the story. Remember to pay attention to the details.

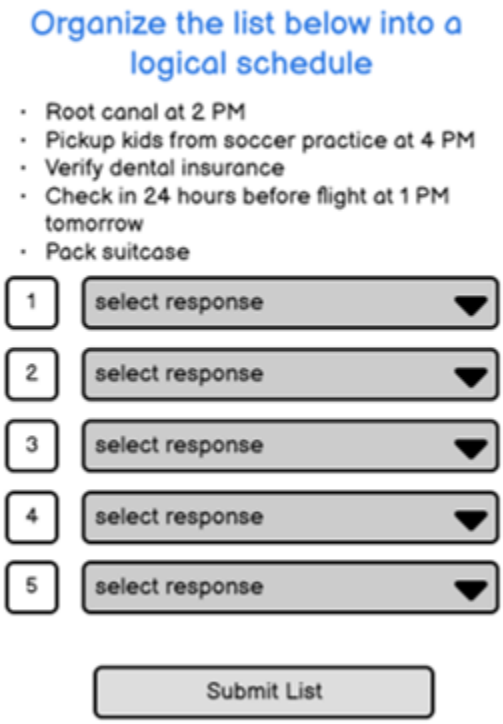
Story

Clayton has his second round interview for his dream job today at 9:15 AM in New York City. The train ride from Stamford to New York City takes 1 hour and 5 minutes.
It is a 10 minute walk from the train station to the office in New York City, and in Stamford it takes Clayton 5 minutes to walk from his apartment building to the Stamford Station.
It is currently 7:07 AM, Clayton is not dressed yet and has a history of low blood sugar when he doesn't eat. The next train leaves at 7: 40 AM. Clayton also has to take his dog to his neighbor for the day.
Click 'Next' to begin the tutorial.

APPENDIX H

ỤBỤRỤ WEEKLY TASKS: RANK ORDER EXAMPLE

You are now about to begin 'Rank Order.' You will be given lists of appointments, events, and meetings.
It is up to you to determine order to put each item based on importance.

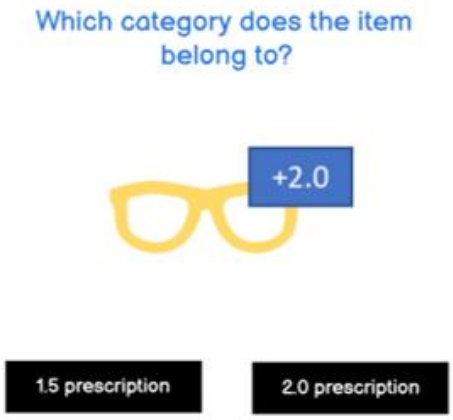


APPENDIX I

ỤBỤRỤ WEEKLY TASKS: KEEPING TRACK EXAMPLE

You are now about to begin 'Keeping Track.' You will be presented with an item. It is up to you to determine which category the item fits best and keep track of the amount in each category. At the conclusion of the level, you will input the total for each category.

Part 1

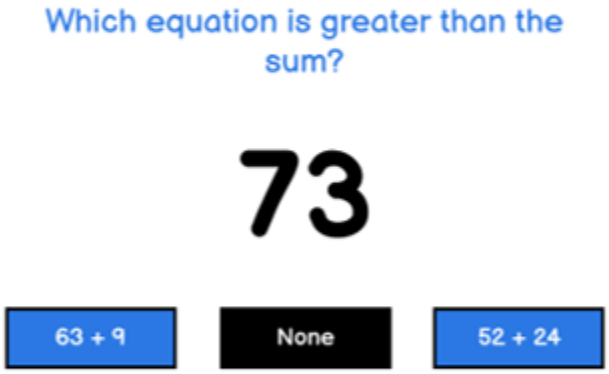


Part 2

APPENDIX J

ỤBỤRỤ WEEKLY TASKS: BEAT THE VALUE EXAMPLE

You are now about to begin 'Beat the Value.' You will be presented with a value. It is up to you to determine which of the presented math problems are higher than the sum.



APPENDIX K

ỤBỤRỤ WEEKLY TASKS: WEEKLY SURVEY

Likert Scale Response

To answer the questions in the survey you will select a number between 1 and 5:

1 = Strongly Disagree
2 = Disagree
3 = Neutral
4 = Agree
5 = Strongly Agree

1. I had no issue completing the tasks for the week
2. There were too many tasks
3. The task difficulty was reasonable
4. I feel that the tasks are helpful

Select Answer Response

1. Select the task you enjoyed the most:
    a. Train of Thoughts
    b. Keeping Track
    c. This or That
    d. Beat the Value
    e. Rank Order
2. Select the task you enjoyed the least:
    a. Train of Thoughts
    b. Keeping Track
    c. This or That
    d. Beat the Value
    e. Rank Order
3. Select the task that was most difficult for you:
    a. Train of Thoughts
    b. Keeping Track
    c. This or That
    d. Beat the Value
    e. Rank Order
4. Select the task that was easiest for you:
    a. Train of Thoughts
    b. Keeping Track
    c. This or That
    d. Beat the Value
    e. Rank Order

Open Response

1. Please use the space below to discuss how you feel your progress went this week. (If nothing to type put N/A).
2. Please use the space below to provide any other relevant feedback. (If nothing to type put N/A).
3. Please use the space below to discuss how you applied the skills learned in your weekly tasks to everyday life this week. (If nothing to type put N/A).
4. Please list any resources that you looked into this week

APPENDIX L

RECRUITMENT FLYER

MILD TRAUMATIC BRAIN INJURY (CONCUSSION) STUDY

EXECUTIVE FUNCTION REHABILITATION

PAID ONLINE PARTICIPATION STUDY

Do you or someone you know have a history of **mild traumatic brain injury (concussion)**?

You may be eligible for a 6-week **paid online study** that is exploring how to better address the needs of those with a history of a mild traumatic brain injury (concussion).

Participants will be randomly assigned to one of two groups:

- Control (2 weeks of participation)
- Experimental (6 weeks of participation).

Participation is completely voluntary.

YOU MAY QUALIFY IF YOU…

- Are 18 years or older
- Have a history of Mild Traumatic Brain Injury (Concussion)
- Have access to a computer
- Have the ability to work in a quiet uninterrupted environment
- Are fluent in English

To see if you are eligible for this study follow the link to complete the questionnaire: https://forms.gle/tSp6vjZ5hwTxJSN66

Potential benefits:

- Gaining experience in psychological research and having a better understanding of the role executive function plays in cognition
- Further research related to Mild Traumatic Brain Injuries (Concussions)

Arizona State University

Citizen-Centered Smart Cities & Smart Living NSF-NRT Project

For More Information Contact
Akuadasuo Ezenyilimba
(aezenyi1@asu.edu)

APPENDIX M

EXPERIMENTAL GROUP CONSENT FORM

CONSENT FORM
Mild Traumatic Brain Injury Executive Function Rehabilitation through Serious Gamification

INTRODUCTION

I am a graduate student under the direction of Dr. Nancy Cooke (Nancy.Cooke@asu.edu) in the Human Systems Engineering Department in the Ira A. Fulton Schools of Engineering at Arizona State University. I am conducting a research study to examine executive function amongst individuals with a history of mild traumatic brain injury (concussion).

DESCRIPTION OF RESEARCH STUDY

I am inviting your participation, which will span over the course of 6 weeks. As a participant in this study during week 1, you will complete a demographics questionnaire and executive function assessments during week 1. During week 6, you will retake the executive function assessments. Your participation during both week 1 and week 6 will take between 30 minutes – 1 hour.

In addition to the initial and final assessments you will participate in 3 weekly sessions during weeks 2 – 5 in which you will engage in weekly executive function games. Your participation during each session will take between 20 minutes – 1 hour. There will be a total of five games focused on planning, organization, and cognitive flexibility. At the conclusion of each week, you will then complete a weekly survey that will take approximately 5 – 10 minutes to complete. Individual results will not be reported back to participants.

WITHDRAWAL PRIVILEGE

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty.

COMPENSATION

The compensation for the present study will be a $10.00 gift card for every week of study completion that will be dispersed at the end of the 6 week study. You must be 18 years of age or older, have a history of mild traumatic brain injury (concussion), be fluent in English, have normal color vision, and have normal or corrected-to-normal vision to be eligible for participation.

BENEFITS & RISKS

Although there is no direct benefit to you, the possible benefits of your participation are gaining experience in psychological research and having a better understanding of the role executive function plays in cognition. There are no foreseeable risks or discomforts to your participation.

CONFIDENTIALITY

Participants will be assigned a participant ID that will be connected to any data or information connected in this study. All responses will be confidential and linked to your participant ID. Data will only be used in the aggregate form, and no de-identified data will be shared for future research purposes or other uses. All data collected will be stored on a password protected computer accessible only by members of the research team. The results of this study may be used in reports, presentations, or publications but your name will not be used.

VOLUNTARY CONSENT

If you have any questions concerning the research study, please contact the research team at: **aezenyi1@asu.edu**. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be a part of the study.

By signing the box below, you are agreeing to be part of the study.

Name_____

Signature_____ Date_____

APPENDIX N

CONTROL GROUP CONSENT FORM

CONSENT FORM
Mild Traumatic Brain Injury Executive Function Rehabilitation through Serious Gamification

INTRODUCTION

I am a graduate student under the direction of Dr. Nancy Cooke (Nancy.Cooke@asu.edu) in the Human Systems Engineering Department in the Ira A. Fulton Schools of Engineering at Arizona State University. I am conducting a research study to examine executive function amongst individuals with a history of mild traumatic brain injury (concussion).

DESCRIPTION OF RESEARCH STUDY

I am inviting your participation, which will span over the course of 6 weeks. As a participant in this study, you will complete a demographics questionnaires and executive function assessments during week 1. During week 6 you will retake the executive function assessments. Your participation during both week 1 and week 6 will take between 30 minutes – 1 hour. Individual results will not be reported back to participants

WITHDRAWAL PRIVILEGE

Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, there will be no penalty.

COMPENSATION

The compensation for the present study will be a $20.00 gift card that will be dispersed at the end of the 6 week study. You must be 18 years of age or older, have a history of mild traumatic brain injury (concussion), be fluent in English, have normal color vision, and have normal or corrected-to-normal vision to be eligible for participation.

BENEFITS & RISKS

Although there is no direct be-nefit to you, the possible benefits of your participation are gaining experience in psychological research and having a better understanding of the role executive function plays in cognition. There are no foreseeable risks or discomforts to your participation.

CONFIDENTIALITY

Participants will be assigned a participant ID that will be connected to any data or information connected in this study. All responses will be confidential and linked to your participant ID. Data will only be used in the aggregate form, and no de-identified data will be shared for future research purposes or other uses. All data collected will be stored on a password protected computer accessible only by members of the research team. The results of this study may be used in reports, presentations, or publications but your name will not be used.

VOLUNTARY CONSENT

If you have any questions concerning the research study, please contact the research team at: **aezenyi1@asu.edu**. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788. Please let me know if you wish to be a part of the study.

By signing the box below, you are agreeing to be part of the study.

Name_____

Signature_____ Date_____

APPENDIX O

PREFERRED METHOD OF CONTACT QUESTIONNAIRE

Preferred Method of Contact

1. Please type your participant ID

2. What is your preferred method of contact
    a. E-mail
    b. Call
    c. Text

3. Please type your number or email in the space below

APPENDIX P

RECRUITMENT SURVEY

Recruitment Survey

1. Are you at least 18 years of age?
    - Yes
    - No

2. Are you fluent in English?
    - Yes
    - No

3. Have you ever had a concussion / mild traumatic brain injury?
    - Yes
    - No

4. If yes, how long ago did your concussion / mild traumatic brain injury happen? ***Type answer below***

5. If yes, are you currently being treated for your concussion / mild traumatic brain injury?
    - Yes
    - No

APPENDIX Q

IRB APPOVAL

APPROVAL: EXPEDITED REVIEW

Nancy Cooke
IAFSE-PS: Human Systems Engineering (HSE)
-
Nancy.Cooke@asu.edu
Dear Nancy Cooke:

On 4/11/2023 the ASU IRB reviewed the following protocol:

Type of Review:	Initial Study
Title:	Mild Traumatic Brain Injury Executive Function Rehabilitation through Serious Gamification
Investigator:	Nancy Cooke
IRB ID:	STUDY00017779
Category of review:	(7)(a) Behavioral research
Funding:	None
Grant Title:	None
Grant ID:	None
Documents Reviewed:	• Dr. Potts_Email Correspondence.pdf, Category: Off-site authorizations (school permission, other IRB approvals, Tribal permission etc); • IRB Social Behavioral_mild traumatic brain injury executive function rehabilitation through serious gamification.docx, Category: IRB Protocol; • iSpring Quiz Maker_Email Correspondence.pdf, Category: Measures (Survey questions/Interview questions /interview guides/focus group questions); • Mild TBI EF Rehab_ Consent Form_Control Group.pdf, Category: Consent Form; • Mild TBI EF Rehab_ Consent Form_Experimental Group.pdf, Category: Consent Form; • Recruitment Flyer.pdf, Category: Recruitment Materials; • Recruitment Materials.pdf, Category: Recruitment Materials; • Surveys and Materials.pdf, Category: Measures

The IRB approved the protocol from 4/11/2023 to 4/10/2024 inclusive. Three weeks before 4/10/2024 you are to submit a completed Continuing Review application and required attachments to request continuing approval or closure.

If

	(Survey questions/Interview questions /interview guides/focus group questions);

continuing review approval is not granted before the expiration date of 4/10/2024 approval of this protocol expires on that date. When consent is appropriate, you must use final, watermarked versions available under the "Documents" tab in ERA-IRB.
In conducting this protocol you are required to follow the requirements listed in the INVESTIGATOR MANUAL (HRP-103).
This is a clinical trial and hence it is PI's responsibility to register this study on www.clinicaltrials.gov within 21 days of enrollment of first participant and follow reporting requirements to clinicaltrials.gov as required. Some journals such as the International Committee of Medical Journal Editors and other journals require registration of clinical trials prior to enrollment of first participant. See ASU Clinical Trials Guidance.
Instructions on how to register with clinicaltrials.gov, upload documents and reporting results are available in the link below https://clinicaltrials.gov/ct2/manage-recs

Sincerely,

IRB Administrator

cc:
Akuadasuo Ezenyilimba