THESIS

MEASURING EXECUTIVE FUNCTION AFTER YOGA FOR ADULTS WITH ACQUIRED BRAIN INJURY: A PILOT STUDY

Submitted by

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ABSTRACT

MEASURING EXECUTIVE FUNCTION AFTER YOGA FOR ADULTS WITH ACQUIRED BRAIN INJURY: A PILOT STUDY

Background: Acquired brain injury (ABI) may result in cognitive impairments, particularly deficits in executive function (EF), which may impact engagement in everyday activities. Yoga has been shown to improve various health outcomes for individuals with ABI. This study aims to explore the impact of group yoga on EF for individuals with ABI.

Methods and Materials: This was a single-arm pilot study that involved eight weeks of therapeutic group yoga led by a registered yoga teacher. Nine participants attended hour-long, in-person yoga classes once a week. Sessions included seated, standing, and floor postures combined with breathwork and meditation. EF was assessed pre- and post-intervention using the Behavior Rating Inventory of Executive Function for Adults (BRIEF-A) self-report form.

Results: The behavioral regulation index improved significantly pre to post yoga. No significant improvements were found on the EF scales, metacognition index, or global executive composite. However, measurable improvements (>5%) were found in the following EF scales: Emotional Control, Plan/Organize, and Organization of Materials.

Conclusion: Group-based yoga may improve behavioral regulation for adults with chronic ABI, however further research is needed.

Keywords: Yoga, executive function, cognition, acquired brain injury, traumatic brain injury, stroke

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CHAPTER 1: INTRODUCTION, LITERATURE REVIEW, METHODS

Introduction

Acquired brain injury (ABI), defined as any type of brain damage occurring after birth, is one of the leading causes of lifelong disability (Greenwald et al., 2003). ABI may result in cognitive, physical, and psychological impairments. One cognitive impairment often occurring after brain injury is deficits in executive function (EF), which may disrupt participation in everyday activities. Yoga, in the modern-day western world, combines mind and body practices and has been studied as a treatment option for variety of populations, including individuals with brain injury. While some research exists on the impact of group-based yoga on EF, few studies have examined the impact of group yoga intervention on EFs for individuals with ABI. The purpose of this study was to explore the impact of an eight-week group yoga intervention on EF for individuals with ABI.

Acquired Brain Injury

Definition, Incidence, Prevalence

The Brain Injury Association of America (2014) defines acquired brain injury (ABI) as "an injury to the brain that is not hereditary, congenital, degenerative, or induced by birth" (para 1). Thus, ABI encompasses both traumatic brain injuries (TBIs) as well as brain injuries with 'nontraumatic' etiologies (Teasell et al., 2007). The most common mechanisms of diagnosed TBIs include unintentional falls, being unintentionally struck by or against an object and motor vehicle accidents (Centers for Disease Control and Prevention, 2019). Non-traumatic brain injuries are not caused by an external physical force. This includes stroke, infections of the brain (e.g., meningitis, encephalitis), anoxic injury, focal brain lesions, and tumors (Menon & Bryant,

2019). Regardless of etiology, consequences of ABI may result in significant difficulties in everyday functioning across physical, cognitive, vocational, emotional, and social domains (Braden et al., 2010; Mozaffarian et al., 2015).

Due to the varying definitions of ABI, there is considerable uncertainty about the prevalence and incidence of ABI globally. However, statistics are reported for stroke and TBI individually. Dewan et al. (2019) estimated the global incidence of all-severity TBI at 939 cases per 100,000 people, meaning an estimated 69 million people worldwide will experience TBI each year. In the United States alone, it is estimated that about 1.7 million Americans suffer from a TBI each year and 3.2 million-5.3 million persons are living with a TBI-related disability (Frieden et al., 2015; Taylor et al., 2017). In 2019, the global prevalence of stroke was 101.5 million people (AHA, 2021). Furthermore, every year, about 800,000 people in the United States have a stroke and it is estimated that 6.6 million Americans over the age of twenty have sustained a stroke (Mozaffarian et al., 2015; Virani et al., 2020).

ABI-related Impairments

ABI may result in long-term impairments in psychological, physical, and cognitive functioning (Corrigan & Hammond, 2013; Frieden et al., 2015). Specifically, deficits in cognition are a significant cause of disability after ABI (Cicerone et al., 2000). Individuals with ABI may continue to experience impairments in cognitive domains and have reduced cognitive performance long after the initial injury (Ballard et al., 2003; Dean & Sterr, 2013; McInnes et al., 2017). Possible cognitive impairments after ABI include deficits in attention, working memory, information-processing, long-term memory, social cognition, self-awareness, and executive functioning (Azouvi et al., 2017; McAllister et al., 2001; Stocchetti & Zanier, 2016). Collectively these impairments, resulting from ABI, are strongly associated with functional

outcomes and may disrupt an individual's participation in everyday activities, including social and leisure activities, resulting in reduced quality of life (Andelic et al., 2009; Häggström & Lund, 2008; Morton & Wehman, 1995; Yousefzadeh-Chabok et al., 2021).

Executive Function

Definition

Various definitions of executive function(s) exist and thus, it is challenging to define (Jurado & Rosselli, 2007). Generally, the umbrella term "executive function(s)" refers to a set of higher-level cognitive processes or self-regulatory functions that impact the ability to effectively engage in purposeful and goal-directed behavior (Cicerone et al., 2000; Gilbert & Burgess, 2008; Gioia et al., 2000; Waid-Ebbs et al., 2012). EFs, linked to the pre-frontal cortex of the brain, are necessary for regulating thoughts, emotions, and behaviors/actions (Miyake & Friedman, 2012). EFs are effortful; for example, they influence one's ability to adapt to situations, inhibit inappropriate behaviors, create and execute a plan, and continue with a task until it is completed (Jurado & Rosselli, 2007). Consequently, EFs are essential for leading productive lives, interacting appropriately with the environment, and responding to novel situations (Chung et al., 2013; Waid-Ebbs et al., 2012).

The cognitive processes that comprise EF have varied across research and within theoretical models (Lehto et al., 2003). Some scholars have proposed EFs as distinct cognitive processes, while others have described these cognitive processes as interrelated, with some EFs allowing for higher-level EFs (Diamond, 2013; Gioia et al., 2000). Despite this, there is some agreement three core EFs, including: inhibition (inhibitory control, self-control), working memory, and cognitive flexibility (shifting, mental flexibility) (Miyake et al., 2000). Inhibition or inhibitory control refers to the ability to "control one's attention, behavior, thoughts, and/or

emotions, to override a strong internal predisposition or external lure" (Diamond, 2013, p. 137). This allows individuals to resist impulses and respond in an appropriate way (Diamond & Ling, 2019). Working memory involves storing information in the mind and then utilizing or manipulating that information when that information is no longer present (Baddeley & Hitch, 1994; Smith & Jonides,1999). Differing from short-term memory, working memory uses stored information for things like problem-solving, reasoning, and language processing (Diamond, 2013). Cognitive flexibility or shift(ing) involves being able to change perspectives both spatially and interpersonally and adjust accordingly to changing demands of the circumstance (Diamond, 2013). This includes one being about to change how they think about something and being able to consider something from another person's point of view.

Despite EFs being elusive to define, they are essential to performance in everyday activities and impact areas like physical and mental health, interpersonal relationships, job success, and overall quality of life (Diamond, 2013).

ABI's Impact on EF

The frontal lobes are thought to be primarily responsible for EFs and many brain injury cases involve some level of disruption in frontal-subcortical systems (Funahashi & Andreau, 2013; McDonald et al., 2002). Such disruptions may be caused by not only direct injury to the frontal lobes, but also indirect damage from disruption of neuronal connections, or lesions in regions with afferent or efferent frontal connections (McDonald et al., 2002). Thus, deficits in EF are common after ABI and may persist years after injury (Marsh et al., 2016). For example, Pettemeridou et al. (2020) found that individuals with moderate to severe TBI underperformed on executive functioning tasks and demonstrated deficits in self-awareness several years post

injury. Additionally, it is estimated that about 75% of stroke survivors experience impairments in EF (Chung et al., 2013; Riepe et al., 2004).

Impairment in EF, often referred to as 'executive dysfunction,' is associated with difficulties in everyday decision making (Cicerone et al., 2000). For instance, individuals with executive dysfunction may have difficulty learning new ways of completing tasks, further impacting their ability to problem solve challenges with movement that may have also resulted from brain injury (Chung et al., 2013). Executive dysfunction may lead to functional impairments, restrictions in participation in daily life activities including employment and social participation, and reduced quality of life for individuals with ABI (Mazaux et al., 1997; McDowd et al., 2003; Nybo & Koskiniemi, 1999; Pohjasvaara et al., 2002; Viscogliosi et al., 2011; Yousefzadeh-Chabok et al., 2021). Therefore, addressing EF should be a focus of rehabilitation efforts for individuals with ABI (Häggström & Lund, 2008).

Treatment Options for Executive Dysfunction Resulting from ABI

A variety of rehabilitation professionals provide treatment for individuals with ABI, such as: neuropsychologists, speech language pathologists, occupational therapists, special education instructors, and vocational rehabilitation counselors (Kennedy et al., 2008). Cognitive rehabilitation is a type of therapy used to restore EFs or compensate for EFs to help improve independence in daily activities (Chung et al., 2013; Stephens et al., 2015). More specifically, cognitive rehabilitation treatment approaches for EF in ABI may include: metacognitive strategy training (problem-solving, planning, organization, multi-tasking), EF/attention training, group training, goal management training, self-awareness training, working memory training and/or compensatory and adaptive methods (Poulin et al., 2012; Raymer et al., 2018). Overall findings for these intervention methods for individuals with TBI have indicated that they may be effective

in improving EF, however more research is needed (Raymer et al., 2018). Similarly, in a systematic review on the efficacy of EF interventions after stroke, Poulin et al. (2012) found limited, but promising evidence, that EF interventions may improve components of EF when compared to no treatment. Perhaps other treatment methods, such as yoga, may be considered when working addressing EF.

Yoga

Definition

Yoga is an ancient Hindu practice for physical, spiritual, and mental development with the initial aim of fostering attainment of self-awareness and achieving tranquility of the mind (Field, 2011; Riley, 2004). The Yoga Journal (2016) reports that 28% of Americans have participated in yoga at some time in their lives and 34% of Americans (equal to about 80 million Americans) report they are likely to practice yoga within the next 12 months. While there are many different traditions of yoga, *Hatha* yoga is of specific interest to the western world. Yoga includes eight limbs of yoga, three of which tend to be utilized in Hatha yoga: physical postures (*asanas*), breathing exercises (*pranayama*), and meditation (*dhyana*) (Büssing et al., 2012; Field, 2011).

In the western world, yoga has been clinically adapted and increasingly utilized as a treatment modality or therapeutic intervention for neurological, psychological, and medical disorders (Silveira & Smart, 2020). The goal of yoga, from a treatment perspective, is to optimize health, reduce stress and increase self-regulation (Schmalzl et al., 2015). Schmalzl et al. (2015) defines yoga-based practice, as "modern psychophysiological therapeutic practices that employ a series of movement-, breath- and attention-based techniques inspired by a variety of yogic traditions" (p. 2). Yoga is a feasible option to be included in rehabilitation as an alternative

or complementary to traditional rehabilitation, as it does not need to be prescribed by a physician or approved by insurance (Schmid et al., 2016). Furthermore, yoga can be modified or adapted accordingly (i.e., seated poses) to accommodate different conditions and abilities such as balance deficits, chronic pain, or general weakness (Schmid et al., 2016; Silveira & Smart, 2020).

Therapeutic Yoga and ABI

Yoga may be beneficial in improving chronic symptoms for individuals with ABI (Silveira & Smart, 2020; Thayabaranathan et al., 2017). Emerging evidence, though limited in scope, has shown yoga is a holistic approach that can improve physical and psychological outcomes such as physical functioning (range of motion, strength, endurance), balance, self-reported pain, mental health (anxiety, depression), and quality of life in individuals with ABI (Chan et al., 2012; Combs et al., 2018; Donnelly et al., 2017; Garrett et al., 2011; Immink et al., 2014; Montgomery et al., 2015; Schmid et al., 2012, 2016; Silverthorne et al., 2012; Stephens et al., 2020; Yeates et al., 2015). Findings have indicated yoga intervention, delivered 1-2 times a week for 6-10 weeks, is a feasible intervention for ABI and may improve chronic symptoms of ABI (Silveira & Smart, 2020). However, it should be noted that many of the studies on yoga and ABI included small sample sizes, focused specifically on persons with stroke or TBI, and lacked statistical rigor (Silveira & Smart, 2020). Therefore, it is difficult to draw definitive conclusions on the efficacy of yoga in ABI.

Yoga and EF

A growing body of research suggests that yoga, particularly Hatha yoga, may improve EF for a variety of populations. For healthy adults, findings suggest acute bouts of Hatha yoga may improve working memory, inhibitory control, and selective attention (Gothe et al., 2013; Telles et al., 2012). Likewise, Gothe et al. (2014) found that eight weeks of Hatha yoga significantly

improved working memory and mental flexibility for healthy older adults (n=58) as compared to a stretching control group (n=50). In addition, Bilderbeck et al. (2013) found inhibitory control for 'impulsive prisoners' improved significantly after 10 weeks of Hatha yoga compared to the control group. In contrast, Luu & Hall (2016) revealed mixed findings for the effect of yoga in improving EF for people with multiple sclerosis, which tends to be a progressive condition. Overall, based on a systematic literature review on Hatha yoga and EF, conducted by Luu & Hall (2016), Hatha yoga shows promise of benefit for EF in various populations, indicating it may be an option for intervention for individuals with ABI.

Theorized Mechanisms of Yoga-EF Relationship

Although it is not completely understood how yoga may improve cognition/EF, there have been some theorized mechanisms. Conceptually speaking, the mind-body properties of yoga may have potential benefits on cognition (Rocha et al., 2012). Yoga involves active attention exercises; this requires concentration to coordinate movement and breath through a series of postures (Froeliger et al., 2012; Rocha et al., 2012). This, in turn, may improve attentional abilities that may translate to other areas of daily activity (Luu & Hall, 2016; Oken et al., 2006)

Some researchers have speculated that stress reduction and improved psychological outcomes (anxiety, depression, mood) may be moderators of the yoga-EF relationship (Gothe et al., 2016; Rocha et al., 2012). Stress, anxiety, and depression have been associated with cognitive deficits and yoga has been shown to improve these outcomes (Hammar & Årdal, 2009; Kirkwood et al., 2005; Lupien et al., 2009; Maloney et al., 2014; Moran, 2016; Sliwinski et al., 2006; Uebelacker et al., 2010; West et al., 2004). Furthermore, in response to stress, yoga has a down-regulatory effect on the sympathetic nervous system (SNS) and hypothalamus-pituitary-

adrenal (HPA) axis (Ross & Thomas, 2010a). Thus, it is possible that cognitive improvement after yoga is achieved by the quieting of the SNS/HPA axis along with the attenuation of stress and emotional intensity (Rocha et al., 2012). To further this hypothesis, Gothe et al. (2016) completed a randomized controlled trial and found that eight weeks of yoga practice, compared to a stretching-strengthening control group, resulted in improved working memory performance, mediated by an attenuated response to stress.

Yoga as an Intervention for Executive Dysfunction Resulting from ABI

There is limited research regarding the effects of yoga intervention on EF for persons with ABI. To our knowledge, three studies have examined this relationship; one of these studies was a mixed-methods case study, one was a mixed-methods pilot study, and the other was a mixed-methods, pre-post, retrospective study (Donnelly et al., 2021; Grimm et al., 2017; Wen et al., 2021). Two of the studies reported on emotional regulation, the self-perceived ability to regulate emotions, which is synonymous with emotional control, a cognitive process involved in executive functioning. Grimm et al. (2017) found that an eight-week individualized yoga intervention improved emotional regulation for three adults with chronic TBI. On the other hand, Donnelly et al. (2021) did not find improvement in emotional and behavioral dysregulation after a 6-week group yoga intervention for participants with TBI (n =1563), however significant improvement was found in cognition. Cognition was defined in this study as the application of cognitive abilities (memory, attention, decision making) in everyday tasks (planning, organizing, calculating, remembering, and learning), which is closely related to the processes involved in EF (Donnelly et al., 2021). Additionally, in this study by Donnelly et al. (2021), content analysis of open text responses revealed improved ability to regulate impulsivity, anger, stress, and anxiety, which also relates to emotional regulation. Lastly a recent study by Wen et al. (2021) examined

changes in EF for two participants with severe TBI after a 6-week, twice a week group yoga intervention and found mixed results: one participant's EF improved while the other participant's EF worsened. Additionally, slight improvements in emotional control, memory, and attention were noted in semi structured interviews (Wen et al., 2021).

These three studies, though restricted to individuals with TBI, and limited in their generalizability due to sample size, indicate that yoga could potentially be beneficial in EF for individuals with ABI. More research is needed to explore the relationship between these variables. Likewise, future studies may include persons with other forms of ABI, particularly stroke participants, as no studies were found that look at the impact of yoga intervention on EF for individuals after stroke.

Conclusion

ABI can result in significant long-term cognitive effects, including deficits in EF, which affects daily functioning and participation in meaningful activities, in turn impacting overall quality of life. Yoga has been utilized as a treatment modality and has been shown to improve physical, psychological, and cognitive outcomes for individuals with ABI. Few studies have indicated promising improvements in executive functioning following yoga intervention for individuals with TBI. More research is needed to further explore the efficacy of yoga on EF for individuals with ABI. Thus, this pilot study aims to investigate the impact of yoga on EFs for individuals with ABI.

Research Question

1. What is the impact of group yoga on executive function for individuals with ABI?

Methods

Study Design

This was a single-arm pilot study that included pre and post assessments. This study was one part of a larger study. The intervention included eight weeks of therapeutic group yoga, delivered in person once a week, with the option to attend virtual classes up to three times a week.

Recruitment

Participants were recruited through word of mouth, prior related research studies, social media, newsletters in the local community, email list servers, and stroke and brain injury support groups. All study participants were ≥18 years old with chronic ABI (>6 months) with self-reported balance issues, ability to stand with or without a device, able to read and understand English. Institutional Research Board approval was obtained; all participants consented to the study. Participants that completed both pre and post written assessments received $20 and yoga materials (mat and yoga blocks).

Data Collection

Data were collected face-to-face by trained researchers at baseline and after eight weeks of the yoga intervention. Data were collected on self-reported demographics, which included age, sex, education, and ethnicity. Information related to basic ABI characteristics included: time since ABI, type of injury, time since injury, participation in rehabilitation, limitation in activities, and participation in yoga prior to the study.

Executive function was assessed using the Behavior Rating Inventory of Executive Function – Adult Version (BRIEF-A). The BRIEF-A is a standardized measure used to capture adults' "perspective" of their EFs in their everyday behaviors (Roth et al., 2005). The BRIEF-A

is designed for adults ages 18 to 90 years with a variety of disorders such as: traumatic brain injury, depression, mild cognitive impairments, attention disorders, and learning disabilities (Roth et al., 2005). The BRIEF-A includes a self-report and informant form; only self-report forms were utilized. The BRIEF-A consists of 75-items that comprise nine nonoverlapping clinical scales used to measure nine scales of EF: Inhibit, Shift, Emotional Control, Self-Monitor, Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials. See Table 1 for definitions of each scale. The nine clinical scales form two broad indices: the Behavioral Regulation Index (*BRI*) and the Metacognition Index (*MI*). The *BRI* includes Inhibit, Shift, Emotional Control and Self-Monitor. The MI is comprised of the Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials scales. The *BRI* and *MI* are combined for a total summary score, the Global Executive Composite (*GEC*).

The 75-items were self-rated using a three-point frequency scale (1=never, 2=sometimes, 3=often). Raw scores were transformed into T-scores for each of the nine clinical scales and the *BRI*, *MI*, and *GEC*. Higher T scores reflect more reported problems and T scores at or above 65 are considered clinically significant. The BRIEF-A also contains three validity scales: negativity, infrequency, and inconsistency, which evaluate if questions were answered in an inconsistent, atypical, or negative way. If deemed “elevated”, “infrequent” or “inconsistent”, data was examined further. The BRIEF-A has demonstrated validity, reliability, and clinical utility for assessment of EF for adults with a range of abilities, particularly adults with traumatic brain injury (Roth et al., 2005; Waid-Ebbs et al., 2012).

Intervention

The therapeutic yoga intervention included 1-hour in-person sessions, once a week for eight weeks, along with the option to attend 90 minute live online yoga sessions three times per

week. In-person and online yoga was delivered in a group format by a certified yoga instructor, who specializes in adaptive yoga. The yoga program was based on our prior research and further refined by the yoga instructor who strives to combine yogic philosophy and modern science to be especially beneficial for individuals living with movement disorders (Grimm et al., 2017; Stephens et al., 2020). All sessions included breath work, postures, meditation/mindfulness. See table 2 for yoga protocol. While yoga was delivered in a standardized approach and was appropriate for beginner-level participants, postures were modified or adapted as needed to meet individuals' needs and abilities. Postures were completed seated, standing (with or without support), and on the floor with props. Props were used during yoga to enhance successful completion of yoga postures. Props included: yoga mat, wall, chair, bolsters, blankets, or yoga block. Supervision for safety and minimal physical assistance for adaptive poses was provided by volunteer adaptive yoga assistants during in-person classes. Over the eight-week period, yoga sessions were designed to build on one another and were progressively difficult. Attendance for both in-person and virtual sessions was recorded.

Online sessions were offered three times a week to increase the dose of yoga without the increased risk of exposure to the Coronavirus Disease 2019 (COVID-19), as this study was completed in the fall of 2021. Live online yoga sessions were provided as a group intervention focused on delivering a similar yoga protocol as the in-person classes. However, the online sessions included an additional 15 minutes before yoga began to provide time for connecting online and problem solving as needed. It is noted that the attendees often used this time for conversation and connecting with others. Additionally, some sessions included 15-20 minutes of music and rhythm mindful activities. Adaptive yoga assistants attended live sessions and provided one-on-one assistance in breakout rooms if needed.

Data Analyses

Data were entered into a database, uploaded to, and analyzed with SPSS Version 28 (IBM Corp, New York). Descriptive statistics, including mean, standard deviation, proportions, and frequencies, were used to describe demographics and ABI characteristics of the sample. Normality of the data was assessed with the Shapiro-Wilks test. Paired t-tests were used to assess change between baseline and eight-week score for normally distributed data. For data that was not normally distributed, Wilcoxon signed-rank test were used to assess change between baseline and eight-week variables. Percent changes calculation was performed for the total score using the following equation: (Time 1-Time2/Time 1 * 100).

CHAPTER 2: MANUSCRIPT

Introduction

Acquired brain injury (ABI), or any brain damage occurring after birth, is an umbrella term encompassing both traumatic brain injuries (TBIs) and brain injuries with 'nontraumatic' etiologies such as stroke, infections of the brain, and tumors (Teasell et al., 2007). Regardless of etiology, ABI may result in significant difficulties in everyday functioning across physical, cognitive, vocational, emotional, and social domains (Braden et al., 2010; Mozaffarian et al., 2015). Difficulties in cognitive domains following ABI, may include deficits in executive function (EF). EF refers to a set of higher-level cognitive processes that impact the ability to effectively engage in purposeful and goal-directed behavior; EFs are effortful and enable control over behavior, thought, and emotions (Cicerone et al., 2000; Gilbert & Burgess, 2008; Gioia et al., 2000; Miyake & Friedman, 2012; Waid-Ebbs et al., 2012).

Deficits in EF are common after ABI and may persist years after injury (Chung et al., 2013; Marsh et al., 2016; Pettemeridou et al., 2020; Riepe et al., 2004). Impairment in EF, often referred to as 'executive dysfunction,' is associated with difficulties in everyday decision making (Cicerone et al., 2000). Furthermore, executive dysfunction may lead to functional impairments, restrictions in participation in daily life activities, and reduced quality of life for persons with ABI (Mazaux et al., 1997; McDowd et al., 2003; Nybo & Koskiniemi, 1999; Pohjasvaara et al., 2002; Viscogliosi et al., 2011; Yousefzadeh-Chabok et al., 2021). Therefore, addressing EF should be a focus of rehabilitation efforts for individuals with ABI (Häggström & Lund, 2008).

Cognitive rehabilitation is a commonly used treatment approach in ABI rehabilitation. Cognitive rehabilitation aims to restore EFs or compensate for EFs by evaluating and training

cognitive capacities using computer-based or pencil-paper tasks, or through everyday activities that require cognitive skills (i.e., paying bills, managing medications, weekly schedule planning) (Chung et al., 2013; Stephens et al., 2015). Overall findings for cognitive rehabilitation methods for individuals with ABI indicate that it may be effective for improving EFs, however more high-quality evidence is needed (Poulin et al., 2012; Raymer et al., 2018). Perhaps other interventions may be more effective for improving EF. In a recent systematic review of EF interventions for non-brain injury populations, Diamond & Ling (2019) concluded that mindfulness practices involving movement, such as yoga, show the best result for improvements in EF.

Yoga is an ancient Hindu practice for physical, spiritual, and mental development with the initial aim of fostering attainment of self-awareness and achieving tranquility of the mind (Field, 2011; Riley, 2004). In Western society, yoga has been clinically adapted and utilized as a treatment modality or therapeutic intervention for neurological, psychological, and medical conditions (Silveira & Smart, 2020). This style of practice typically aligns with *Hatha* yoga, which involves physical postures (asana), breathing exercises (pranayama), and meditation (dhyana) (Büssing et al., 2012; Field, 2011). Yoga is a feasible option to be included in rehabilitation as an alternative or complementary to traditional rehabilitation, as it does not need to be prescribed by a physician or approved by insurance (Schmid et al., 2016).

Emerging evidence, though limited in scope, has shown yoga is a holistic approach that can improve physical and psychological outcomes for individuals with ABI (Chan et al., 2012; Combs et al., 2018; Donnelly et al., 2017; Garrett et al., 2011; Immink et al., 2014; Montgomery et al., 2015; Schmid et al., 2012, 2016; Silverthorne et al., 2012; Stephens et al., 2020; Yeates et al., 2015). A growing body of research suggests that yoga, particularly Hatha yoga, may improve EF for a variety of population; however, few studies have explored the impact of yoga on EF for

adults with ABI (Gothe et al., 2013). To our knowledge, three studies have examined this relationship (Donnelly et al., 2021; Grimm et al., 2017; Wen et al., 2021). Findings from these studies indicate possible improvements in cognitive processes involved in EF for adults with TBI. Underlying mechanisms of the yoga-cognition relationship are continuing to be explored; some researchers have proposed that the attenuation of stress, along with the quieting of the sympathetic nervous system, and hypothalamic pituitary adrenal (HPA) axis seen after yoga, may serve as potential mechanisms (Gothe et al., 2016; Ross & Thomas, 2010b; West et al., 2004). More research is needed to explore the relationship between yoga and EF, including persons with other types of ABI. Thus, the purpose of this study is to explore the impact of group yoga on executive functioning for individuals with ABI.

Methods

Design

This study is one part of a larger study involving brain imaging and yoga. This was a single-arm pilot study studying the impact of eight weeks of group therapeutic yoga. Yoga was delivered in-person once a week, with the option to attend up to three live virtual yoga sessions each week. Data were collected pre- and post-yoga intervention.

Participants

Participants were recruited through word of mouth, prior related research studies, social media, newsletters in the local community, email list serves, and stroke and brain injury support groups. Inclusion criteria included: chronic acquired brain injury (>6 months post injury), self-reported balance issues, ability to stand with or without an assistive device, and the ability to read and understand English. Institutional Research Board approval was obtained, and all

participants provided written consent to participate. Participants that completed both pre and post written assessments received $20 and yoga materials (mat and yoga blocks).

Assessments

Data were collected face-to-face by trained researchers. Demographic data were collected, which included: age, sex, education, and ethnicity. Information related to basic ABI characteristics included: time since ABI, ABI etiology, participation in rehabilitation, and limitation in activities.

EF in everyday functioning was assessed at baseline and after eight weeks of the yoga intervention using the Behavior Rating Inventory of Executive Function – Adult Version (BRIEF-A). The BRIEF-A is a self-report measure which consists of 75-items that comprise nine scales of EF: Inhibit, Shift, Emotional Control, Self-Monitor, Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials. The nine clinical scales form two summary indices: the Behavioral Regulation Index (*BRI*) and the Metacognition Index (*MI*). Inhibit, Shift, Emotional Control, and Self-Monitor combine to yield the *BRI*. Initiate, Working Memory, Plan/Organize, Task Monitor, and Organization of Materials combine to yield the Metacognition Index. The *BRI* and *MI* are combined for an overall total or summary score, the Global Executive Composite (*GEC*). Higher T scores reflect more reported problems and T scores at or above 65 are generally considered clinically significant. The BRIEF-A has demonstrated validity, reliability, and clinical utility for assessment of EF for adults with a range of abilities, particularly adults with TBI (Roth et al., 2005; Waid-Ebbs et al., 2012).

Intervention

The therapeutic yoga intervention included one-hour in-person sessions, once a week for eight weeks, along with the option to attend 90-minute live online yoga sessions three times per

week. In-person and online yoga was delivered in a group format by a registered yoga instructor, who specializes in adaptive yoga. All sessions included breath work, postures, and meditation/mindfulness (Table 2). While yoga was delivered in a standardized approach and was appropriate for beginner-level participants, postures were modified or adapted as needed to meet individuals' needs and abilities. Postures were completed seated, standing (with or without support), and on the floor with props. Props were used during yoga to enhance successful completion of yoga postures, props included: yoga mat, wall, chair, bolsters, blankets, or yoga block. Supervision for safety and minimal physical assistance for adaptive poses was provided by volunteer adaptive yoga assistants during in-person classes. Over the eight-week period, yoga sessions were designed to build on one another and were progressively difficult. Attendance for both in-person and virtual sessions was recorded.

Online sessions were offered three times a week by the same yoga teacher to increase the dose of yoga without the increased risk of exposure to COVID-19, as this study was completed in the fall of 2021. Live online yoga sessions were provided as a group intervention focused on delivering a similar yoga protocol as the in-person classes. Adaptive yoga assistants attended live sessions and provided one-on-one assistance in breakout rooms if needed.

Data Analysis

Data were analyzed using SPSS Version 28 (IBM Corp, New York). Descriptive statistics, including mean, standard deviation, proportions, and frequencies, were used to describe demographics and ABI characteristics of the sample. Normality of the data was assessed with the Shapiro-Wilks test. For data that was normally distributed, paired t-tests were used to assess change between baseline and eight-week score. Additionally, a percent change calculation was performed for each subscale and summary scores (Time 1-Time2/Time 1 * 100).

Results

Twelve people completed baseline assessments. An overview of patient demographics and ABI characteristics are reported in Table 3 (n=12). Most participants were white (92%), female (58%), with a baccalaureate degree or greater (50%). Etiologies of brain injuries included stroke (n=3), TBI (n=4), mild TBI/multiple concussions (n=3), anoxic brain injury (n=1), and hydrocephalus (n=1). Of the 12 people who began the study, nine people completed the intervention and follow-up assessments. Study withdrawal was due to the following reasons: scheduling issues (n=2) and unrelated illness (n=1).

We assessed normality of data. Paired t-test were used to evaluate changes pre to post yoga as all EF scales, indices, and overall summary score, were normally distributed. The behavioral regulation index (*BRI* 56.3±11.8 vs 53.7± 11.2; *P*=.046) improved significantly between baseline and after eight weeks of yoga (n=9) (Table 4). There were no statistically significant changes (p values > .05) between pre- and post-assessments on the EF scales, metacognition index, or global executive composite. A decrease in scores indicates improved executive functioning in daily living (See Figure 1). Improvements in EF (>5%) were noted for the following scales: Emotional Control, Plan/Organize, and Organization of Materials.

Discussion

We assessed normality of data. Paired t-test were used to evaluate changes pre to post yoga as all EF scales, indices, and overall summary score, were normally distributed. Results indicated there was a significant improvement on the behavioral regulation index between post-yoga scores (M = 56.3, SD = 11.8) and pre-yoga scores (M = 53.7, SD = 11.2), p = .046, d = .226. There were no statistically significant changes (p values > .05) between pre- and post-assessments on the EF scales, metacognition index, or global executive composite. A decrease in

scores indicates improved executive functioning in daily living (See Figure 1). Measurable improvements (percent change >5%) were noted between mean scores pre to post yoga for the following scales: Emotional Control, Plan/Organize, and Organization of Materials.

The findings of our study align with previous studies on the effects of yoga on EF in non-brain injury populations. Luu and Hall (2016) completed a systematic review on Hatha yoga and EF and concluded that varying doses of Hatha yoga show promise of benefit for EF in healthy adults, healthy children and adolescents, healthy older adult populations, prisoners, and individuals with diabetes. Most commonly, the studies highlighted in the Luu and Hall (2016) review utilized computer-based tasks (e.g., Stroop task, Flanker task, n-back task) to measure changes in EF. In contrast, our current study utilized a paper and pencil assessment, the BRIEF-A self-report form. While the BRIEF-A is valid and reliable for TBI populations, the self-report form alone may not have accurately gathered information about EF as individuals with ABI may experience deficits in self-awareness (Prigatano, 2005). Likewise, the BRIEF-A consists of 75-items, and participants may have been challenged to complete the entire form. Thus, although the chosen assessment was appropriate for the study population, it is unknown whether the study participants were able to accurately complete the BRIEF-A self-report form (Prigatano, 2005; Roth et al., 2005). Perhaps, including the BRIEF-A informant report, completed by an informant (i.e., spouse, caregiver, adult child, friend, etc.), would provide more accurate information or demonstrate differences between informant ratings and participant ratings, when assessing EF for individuals with ABI (Roth et al., 2005).

An additional consideration is that at pre-yoga, the average summary score (*GEC*) on the BRIEF-A was a T-score of 56. T-scores of 65 or greater are typically considered clinically significant (Roth et al., 2005). Thus, participants in this study may not have been experiencing

high deficits in EF in their everyday environment, and consequentially significant improvements in EF were not seen on all areas of this measure. Likewise, the BRIEF-A may not have been sensitive enough to detect changes in EF due to the 3-point Likert scale of "never", "sometimes", and "often".

Our study adds to the existing literature on cognitive/EF benefits for individuals with ABI following yoga. The *BRI* is comprised of the Inhibit, Shift, Emotional Control, and Self-Monitor scales; it represents the ability to maintain control of emotional responses and behavior (Roth et al., 2005). It is likely changes in emotional control led to significant improvements in the *BRI*. Improvements in behavioral regulation, as seen in our study, align with previous findings from Grimm and colleagues (2017) who found improvements in emotional regulation for three participants with TBI after an eight-week yoga program. Though in our study, yoga was delivered as a group intervention, which differs from Grimm et al. (2017), where yoga was delivered in a one-to-one format. In contrast to our findings on behavioral regulation, Donnelly et al. (2021) found no improvements in emotional and behavioral dysregulation (disinhibition, emotional ability, irritability, impatience, and impulsiveness) in a mixed-methods, pre-post study on yoga for people with TBI (n=705); however, content analysis in their study revealed better ability to regulate impulsivity, anger, stress, and anxiety.

In studies of non-brain injury populations, yoga has been shown to have a downregulatory effect on the sympathetic nervous system (SNS) and hypothalamic pituitary adrenal (HPA) axis in response to stress (Menezes et al., 2015; Ross & Thomas, 2010b). This quieting effect on the SNS/HPA axis, potentially allows for improved emotional and behavioral regulation (Menezes et al., 2015). It is unknown if this response is also seen after brain injury, but it is likely the reason for changes in behavioral regulation, as reported in our study. On the

other hand, this mechanism may also explain the nonsignificant changes in some areas of EF in our study, as stress and anxiety may relate to poorer performance on cognitive tasks, and stress may be potential mediator of the yoga-EF relationship (Gothe et al., 2016; Menezes et al., 2015; Moran, 2016; Sliwinski et al., 2006). Our study was conducted in-person in the fall of 2021, following COVID-19 vaccinations, and prior to the omicron variant wave. Recent studies have indicated higher levels of stress and anxiety during the COVID-19 pandemic (Kar et al., 2021; Lakhan et al., 2020). While we did not collect data about stress or anxiety, participants may have experienced ongoing stress/anxiety due to COVID-19, and the associated risk of in-person yoga sessions during this time. Thus, this may account for some of the nonsignificant improvements in all EF scales from pre- to post-yoga intervention.

Limitations

One limitation of this study is that there was a small sample size, and therefore, there was likely not enough participants to see significance on all EF scales. Likewise, due to the sample size and lack of representation of the larger population, the results are not generalizable. This study was conducted in a smaller city in the western United States that includes a highly educated population, who may have been more likely to participate in complementary and integrative therapies. Furthermore, included participants may not have been yoga naïve as they may have participated in yoga or been exposed to the benefits of yoga, prior to this study. An additional limitation may have been the inclusion of individuals of varying abilities and ages in the same yoga class, as the yoga intervention may not have been challenging enough for all participants. Perhaps separating into multiple classes, based on skill level, would have been more beneficial for participants.

As mentioned, this study was completed during COVID-19, which impacted the planned dose of in-person yoga. The planned dose of yoga for our research trials is typically 16 in-person sessions, delivered twice per week over eight weeks (Grimm et al., 2017; Schmid et al., 2012; Stephens et al., 2020). In our study, in-person classes were only offered once a week to minimize the risk of COVID-19. To increase dose, there was an option of online live classes, however most participants (n=6) only attended in-person classes. Although doses of yoga vary amongst previous brain injury studies, yoga once a week for eight weeks may not have been enough to see significant improvements in the individual EF scales.

Future Research

There is limited research on the impact of yoga on EF for ABI populations and thus more research is needed in this area. Future research may consider utilizing the informant-report version of the BRIEF-A, in addition to the self-report form, to gain a better understanding of EF deficits and subsequent improvements. Additionally, direct observation, or task-based measures evaluating EF may be utilized in conjunction with the BRIEF-A (Roth et al., 2005). Future researchers may consider incorporating an anxiety or stress measure, to examine these factors as potential mediators of the yoga-EF relationship. Lastly, although yoga delivered via telehealth is feasible for some populations, we recommend future research continue in-person yoga intervention for the ABI population, due to safety concerns and potential difficulties accessing online classes (Engström et al., 2010; Schmid et al., 2016; Schulz-Heik et al., 2017).

Conclusion

In conclusion, our findings suggest a group yoga intervention for individuals with ABI may improve behavioral regulation. Overall, more research is warranted to examine the impact of

yoga on EF/cognition for individuals with ABI, including studies with larger samples sizes, randomized controlled trials, and different types of EF assessments.

CHAPTER 3: IMPLICATIONS FOR OCCUPATIONAL THERAPY PRACTICE

Individuals who have sustained an ABI often experience declines in cognitive function, including EF, which impacts participation and performance in meaningful activities (Draper et al., 2007; Wortzel & Arciniegas, 2012). Occupational therapy (OT) plays a key role in ABI rehabilitation; occupational therapists (OTs) often utilize remedial and/or compensatory treatment approaches, based in cognitive rehabilitation, to address cognitive impairments (Radomski et al., 2016; Wheeler et al., 2016). Due to mixed findings regarding the efficacy of cognitive rehabilitation on outcomes of EF for persons with ABI, other interventions approaches, such as yoga, may be considered (Boelen et al., 2011; Chung et al., 2013; Cicerone et al., 2005; Radomski et al., 2016; Raymer et al., 2018).

Emerging evidence has revealed the benefits of yoga for the ABI population with few studies investigating cognition and EF (Silverthorne et al., 2012; Thayabaranathan et al., 2017). Furthermore, previous studies involving non-brain injury populations have shown that yoga can improve EF (Luu & Hall, 2016). Our findings revealed yoga may improve behavioral regulation, and thus may be a potential treatment option

Additionally, this study adds to the existing literature that group yoga is likely a feasible intervention for a group of individuals with ABI of varying etiologies (Schmid et al., 2012; Stephens et al., 2020). While more research is required to determine the feasibility and efficacy of yoga on EF for individuals with ABI, yoga may be utilized as a complementary approach to current treatment options for individuals with ABI.

The American Occupational Therapy Association supports the use of complementary health approach and integrative health (CHAIH) in occupational therapy practice (Bradshaw,

2017) . Yoga, classified as a CHAIH, may be incorporated into OT practice as a preparatory method, occupation, or activity to address health outcomes, ultimately enhancing participation in other meaningful occupations and roles (Boop et al., 2020; Bradshaw, 2017). Furthermore, yoga is a holistic mind-body approach that may be modified to meet the needs of the client, adhering to client-centered care.

TABLES AND FIGURES

Table 1

Description of the Nine BRIEF-A Scales

Scale	Definition*
Inhibit	Control impulses; appropriately stop verbal, attentional, physical behavior at the proper time
Shift	Move freely from one situation, activity, or aspect of a problem to another as the situation demands; think flexibly to aid problem-solving
Emotional Control	Modulate one's emotional responses appropriately
Self-Monitor	Recognize the effect of one's own behavior on others
Initiate	Begin a task or activity without external prompting; independently generate ideas
Working Memory	Hold information in mind in order to complete a task; stay with, or stick to, an activity
Plan/organize	Anticipate future events; set goals; develop steps ahead of time to carry out a task; organize information and behavior to achieve and objective; carry out tasks in a systematic manner
Task Monitor	Assess performance during or after finishing a task for mistakes
Organization of Materials	Keep workspace and living areas in an orderly manner; keep track of materials needed for tasks

*Defined verbatim from Roth et al. (2013).

Table 2

Yoga Protocol

Yoga component	Examples
Breath work (prayanama)	Breath awareness
	Breath with sound on exhale (e.g., noun sounds)
	Extended inhale/exhale
	Belly Breathing (Dirga Swasam)
Yoga Poses (asanas) while seated	Face yoga exercises
	Eye movements (mindful blinking)
	Neck movements
	Hand yoga
	Open/closed fists, finger to thumb
	Knees raised and bent, abdomen towards spine (boat pose)
	Spinal flexion/extension (seated cat/cow)
	Deep core strengthening (i.e. rock forward and back with block between knees)
	Crossing midline with upper body reaching
	Chest towards leg (forward fold)
	Hip openers; internal/external rotations
	Arm/shoulder joint rotations
	Calf raises, plantar and dorsiflexion

	Leg lifts, stepping/stomping
	Side body stretches
	Wide open lunge (seated warrior II)
Yoga poses (asanas) while standing	Standing feet width apart (mountain pose)
	Lunge with hips squared forward (warrior I)
	Chest and hip opener in side-lunge (warrior II)
	Standing forward bend from the hips (forward fold)
	Single leg balance poses with various leg positions (i.e. tree pose)
	Calf Raises
	Flow series (Modified sun salutation)
Yoga poses (asanas) while supine on floor	Chest openers
	Spinal twists
	Knees into chest (happy baby)
	Seated cross legged (modified lotus pose)
	Supine relaxation (savasana)
	Mindfulness body scan

Table 3

Demographics and Acquired Brain Injury (ABI) Characteristics (n=12)

Variable	N, (%)
Age, years (mean ± SD)	45.0 ± 15.8
Age Range	29-74
Gender (female)	7 (58%)
Race (white)	11 (92%)
Education	
< College degree	5 (42%)
> College degree	6 (50%)
ABI Etiologies	
Stroke	3 (25%)
Moderate/Severe TBI	4 (33%)
Mild TBI/Multiple Concussions	3 (25%)
Anoxic Brain Injury	1 (8%)
Hydrocephalus	1 (8%)
Time since ABI	
1.5 to 6 years	6 (50%)
6 – 10 years	3 (25%)
> 10 years	3 (25%)
Participation in Rehabilitation (yes)	10 (83%)
Limited in activities (yes)	9 (75%)

Moderate Limitation	7 (58%)
Severe Limitation	2 (17%)
Practiced Yoga Prior to Study (yes)	2 (17%)

TBI = Traumatic Brain Injury

Table 4

Changes in Executive Functioning Scales and Summary Scores on BRIEF-A after Yoga (n=9)

EF Scales, Indices, Summary Score	Pre Yoga (Mean ± SD)	Post Yoga (Mean ± SD)	P value	Percent change
Inhibit	54.9 ± 10.7	53.2 ± 11.0	.340	3.10%
Shift	59.1 ± 11.0	57.4 ± 8.3	.432	2.88%
Emotional Control	54.0 ± 10.6	50.3 ± 9.9	.134	6.85%
Self-Monitor	53.7 ± 13.5	52.9 ± 12.3	.775	1.49%
Initiate	54.7 ± 6.8	54.9 ± 8.6	.902	-.366%
Working Memory	65.6 ± 11.3	63.8 ± 10.4	.459	2.74%
Plan/Organize	59.1 ± 7.2	55.2 ± 8.7	.090	6.60%
Task Monitor	55.1 ± 12.0	54.1 ± 10.7	1.00	0%
Organization of Materials	51.0 ± 11.1	47.9 ± 9.7	.184	6.08%
BRI	56.3 ± 11.8	53.7 ± 11.2	.046	4.62%
MI	60.1 ± 10.2	57.6 ± 9.9	.193	4.16%
GEC	57.7 ± 10.3	55.3 ± 10.6	.147	4.16%

BRIEF-A = Behavior Rating Inventory of Executive Function for Adults

BRI = The Behavioral Regulation Index

MI = The Metacognition Index

GEC = Global Executive Composite

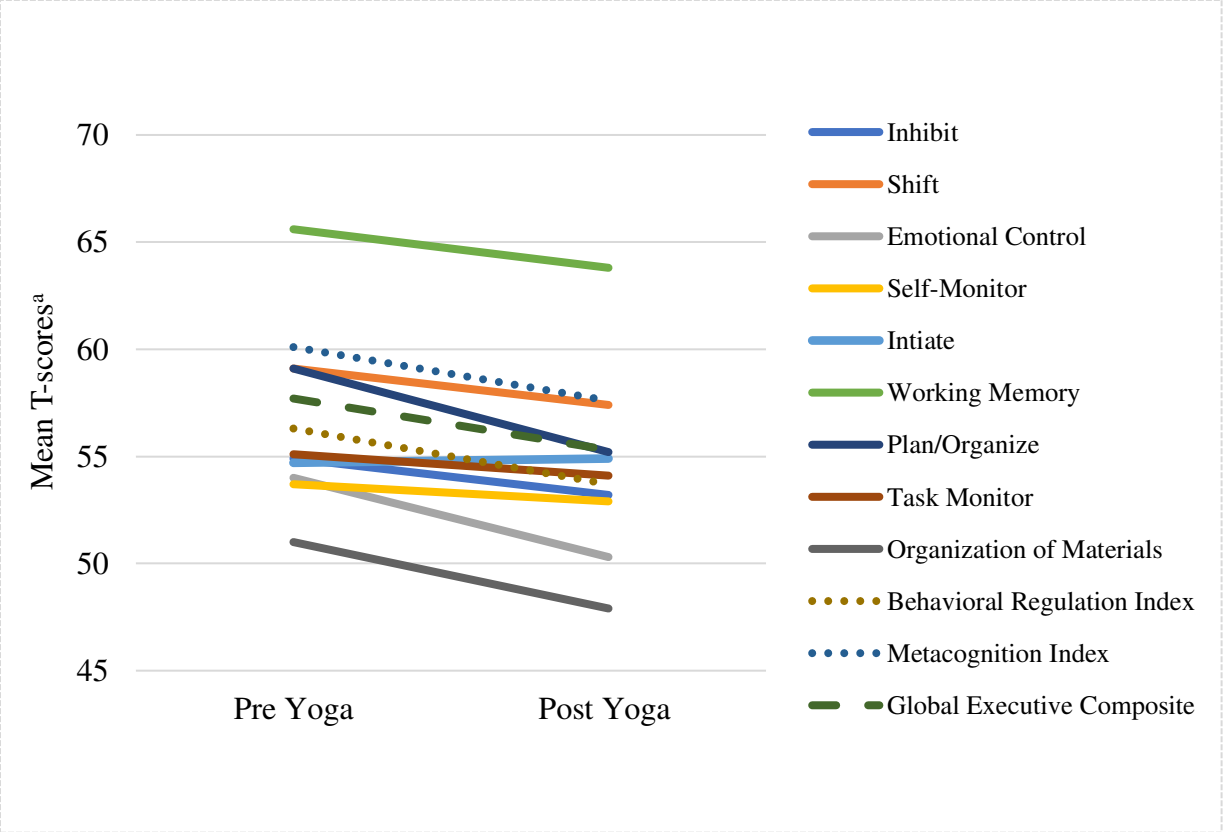

Figure 1

Changes in Executive Function on BRIEF-A Pre to Post Yoga

BRIEF-A = Behavior Rating Inventory of Executive Function for Adults

Note: Solid lines represent scales of EF, dotted lines represent two broad indices, and the dashed line represents the overall summary score. A decrease in T-score indicates improvement in executive function

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LIST OF ABBREVIATIONS

ABI	Acquired Brain Injury
BRIEF-A	Behavioral Regulation Index of Executive Function- Adult Version
BRI	Behavioral Regulation Index
CHAIH	Complementary Health Approach and Integrative Health
COVID-19	Coronavirus Disease 2019
EF(s)	Executive Function(s)
GEC	Global Executive Composite
HPA	Hypothalamus-pituitary-adrenal
MI	Metacognition Index
OT	Occupational Therapy
OTs	Occupational Therapists
TBI	Traumatic Brain Injury
SNS	Sympathetic Nervous System