Changes in Sleep Quality and Quantity in Concussed Athletes with the Application of 3D-MOT (Neurotracker): A Pilot Study.

by

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We acknowledge and respect the Lək'ʷəŋən (Songhees and Xʷsepsəm/ Esquimalt) Peoples on whose territory the university stands, and the Lək'ʷəŋən and W̱SÁNEĆ Peoples whose historical relationships with the land continue to this day.

Supervisory Committee

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Abstract

Individuals recovering from a concussion often experience sleep complications affecting their sleep quality and quantity, which may prolong their recovery and symptoms experienced following a concussion. This pilot feasibility study aims to examine the effects of 3D-MOT (specifically Neurotracker) on sleep quality and quantity in concussed athletic populations (18-35 years old). The study used a multiple-subject design and collected sleep data from 3 concussed adults (3M). The study collected 3 nights of sleep data before and after 10 Neurotracker sessions over 5 weeks. All participants in this study experienced decreases in REM and deep sleep following 10 Neurotracker sessions. After 10 Neurotracker sessions, performed twice a week for 5 weeks, all participants experienced an increase in perceptual and cognitive performance. Two of the three participants experienced an increase in the number of symptoms and perceived post-concussion symptom severity collected from self-reporting measures using the Post-Concussion Symptom Scale (PCSS). As this is a small-sample study, no definitive conclusions can be drawn. The findings from this study provide observational trends if 3D-MOT, specifically Neurotracker, may affect sleep quality and quantity in concussed adults and increase perceived PCSS. This study recommends future research examining the effects in a larger sample but provides insight into the potential effects of 3D-MOT on sleep quality and quantity.

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Chapter 1 Introduction

1.1 Rationale

Concussions continue to be a widespread health concern, particularly among athletes. Approximately 1.6-3.8 million reported minor traumatic brain injuries (mTBI) are sport-related concussions, and it is estimated that many more cases remain undiagnosed (Lai et al., 2017). A concussion, defined by Wicklund et al. (2020), is a blow or strike to the neck, head, or face that may impair vision, balance, gait, cognitive functions, and sleep-wake cycles, with effects lasting days, months, or even years. Typically, concussion symptoms should significantly decline within 10-14 days, with physical and mental rest recommended for 24 hours post-injury (Hoffman et al., 2020).

Research indicates that up to 25% of individuals who have sustained a concussion may experience sleep disturbances, with shorter sleep durations linked to worsened concussion symptoms, poorer visual memory, and worse gait performance (Howell et al., 2020). Sleep is essential for optimal mental and physical health, influencing several critical biological functions, including hormone regulation, cardiovascular health, immune system maintenance, memory consolidation, and cognitive function (Baranwal et al., 2023). To maintain adequate sleep quality and duration, the National Sleep Foundation and the Canadian Society for Exercise Physiology (CSEP) recommend that adults aim for 7-9 hours of sleep per night (Coats et al., 2023; Doherty et al., 2021). However, epidemiological research indicates that 29%-34% of adults fail to meet these recommendations, leading to adverse health effects such as hypertension, obesity, and cardiovascular diseases (Scott et al., 2024).

Insomnia is reported in 30%-60% of individuals within the first month post-concussion, with some experiencing long-term reductions in sleep quality and quantity that can last up to six years (Bramley et al., 2017). Impaired sleep can have a cascade effect, leading to cognitive impairments, hormonal abnormalities, and mood changes. Furthermore, sleep disturbances interfere with molecular and cellular restoration, immune health, brain growth, and recovery, contributing to long-term health complications (Troynikov et al., 2018).

1.2 Concussions and Sleep Disruptions

Sleep regulation involves complex physiological mechanisms, with melatonin serving a central role. Produced in the pineal gland, melatonin release is controlled by the suprachiasmatic nucleus (SCN), which regulates the body's circadian rhythm (Poza et al., 2022). In concussed populations, damage to the brain's sleep-regulation centres such as the hypothalamus and mid- and basal forebrain can alter neurotransmitter activity, disrupting sleep-wake cycles and melatonin synthesis (Bramley et al., 2017). These disruptions contribute significantly to the sleep disturbances commonly observed in concussion recovery.

Sleep is critical in physical, cognitive, and emotional health, yet up to 70% of concussed athletes experience short-term or chronic sleep disturbances (Hoffman et al., 2020). In addition to the effects of concussion itself, athletes often face additional sleep disruptions due to training, competition schedules, and external pressures from family, coaches, and personal stressors. These factors can exacerbate sleep disturbances, leading to insomnia and impaired daytime functioning, ultimately compromising the quality and quantity of their sleep (Nedelec et al., 2018).

1.3 3D-Multiple Object Tracking and Sleep Quality and Quantity

Within recent years, accessibility to health technologies such as smart watches, inertial measuring units, and even mobile apps has increased, allowing its users to track and evaluate their physical and psychological health during training and rest periods. Emerging technologies such as Neurotracker, a three-dimensional multiple object tracking system (3D-MOT), have been developed to improve perceptual skills and cognitive functions such as memory recall and to help improve brain plasticity within various demographic populations (Corbin-Berrigan et al., 2020). Furthermore, recent research has examined Neurotracker and its beneficial effects in populations with sustained mTBI, suggesting that 3D-MOT programs improve executive functions without exacerbating mTBI symptoms (Corbin-Berrigan et al., 2020). However, despite the high prevalence of concussions, no published studies have examined the effects of 3D-MOT programs like Neurotracker on sleep quality and quantity in both concussed and concussion-naïve athletes. Therefore, this pilot feasibility study aims to investigate the observational trends of how rehabilitation with Neurotracker may impact sleep quality and quantity in concussed athletes (18-35 years old).

1.4 Research Questions

i) Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) affect sleep quality and quantity in concussed participants?

ii) Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) affect perceptual-cognitive performance in concussed participants?

iii) Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) impact perceived symptom severity?

1.5 Limitations

Only concussed adults who agreed to participate and who were eligible were accepted as participants. Due to the small sample size in this study, no statistical analysis or significance testing was performed. Therefore, these findings provide suggestions, and future research is needed to draw conclusions. Furthermore, these pilot findings may not represent all concussed athletes (18-35 years old) within the Greater Victoria region.

1.6 Operational Definitions

Concussion:

Injury to the head results in the brain undergoing rotational acceleration and deceleration. This trauma results in the tearing of axons and a disruption in the brain's metabolic glucose cascade (Patel et al., 2024).

Minor Traumatic Brain Injury (mTBI):

Sometimes used interchangeably with the term concussion. Caused by an outside force, which could be a bump or jolt to the head, resulting in acute or chronic injuries (Greenwald et al., 2012).

Sleep Quality:

An individual's self-satisfaction with all aspects of the sleep experience (Koohsari et al., 2023).

Sleep Quantity: total amount of sleep obtained (Kohyama, 2021).

Sleep disorder: disturbance in the quality or duration of sleep (Koohsari et al., 2023).

Athlete: An individual who is trained in organized sports, aiming to improve performance in individual or group settings (Araújo & Scharhag, 2016).

Chapter 2 Literature Review

2.1 Concussions.

As concussions occur from a rapid deceleration of the brain, either through a strike, blow, or sudden impact to the head, many brain regions may be affected, resulting in somatic, emotional, cognitive, and sleep complications or disturbances (Danielli et al., 2023; Romeu-Mejia et al., 2019). Literature within the past ten years and even more has examined the implications of post-concussion symptoms (PCS) and how individuals with different cognitive abilities may experience symptom severity or recovery time differently, especially comparing concussed adolescent populations to concussed adult populations (Oldenburg et al., 2016). Within concussion literature, research has demonstrated that the degree of symptom severity may be the best predictor of recovery (Hoffman et al., 2020). Several studies have acknowledged the complexity of a physiological injury such as a concussion, as many physiological systems and organs may experience dysfunction post-injury (Dobson et al., 2017). Post injury, symptoms such as light-headedness, dizziness, nausea, headaches, and physical and emotional impairments are common and can lead to cardiovascular autonomic dysfunction (CVAD; Dobson et al., 2017; Patel et al., 2024). Dobson et al. (2017) suggest that many PCS, such as light-headedness and postural disturbances, such as dizziness, are related to vestibular and autonomic dysfunction. Therefore, Dobson et al. sought to examine cardiovascular responses by monitoring BP and HR during standard autonomic tests of orthostatic tolerance and cardiovagal function (2017). Therefore, the purpose of their study was to investigate cardiovascular responses over 2 weeks, examining changes during forced breathing, standing, and the Valsalva maneuver, which involves forceful exhalation (Dobson et al., 2017). They conducted four tests at 48 hours, 24 hours, 1 week, and 2 weeks after the injury, for both the concussed and healthy control groups. To examine the differences in cardiovascular responses, heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) were measured with finger photoplethysmography. The results concluded that 48 hours post-injury, the concussed group had significantly greater resting SBP (P=.002), HR (P=0.03), and DBP (P=0.01) during standing compared to the healthy control group (Dobson et al., 2017). Furthermore, this study provides evidence that traumatic brain injuries (TBI), specifically concussions, may disrupt autonomic control, impacting involuntary regulations throughout the body (Dobson et al., 2017).

2.2 Changes to the Autonomic Nervous System (ANS) Following a Concussion.

The autonomic nervous system (ANS) regulates all internal organ functions, including heart rate, blood pressure, and endocrine secretions, and also innervates cardiac and smooth muscle and regulates metabolism (Pertab et al., 2018; Roche et al., 2024). The ANS system is divided into two subsystems: the parasympathetic nervous system (PNS), known for its "rest and digest" functions, and the sympathetic nervous system (SNS), responsible for "fight or flight" responses (Pertab et al., 2018). Following a mTBI, dysfunction and damage of the ANS can occur, resulting in headaches, dizziness, slurred speech, and exercise intolerance, which are symptoms commonly associated with post-concussion symptoms (Callaway & Kosofsky, 2019). Heart Rate Variability (HRV) reflects ANS control and can help examine ANS dysfunction (Anderson et al., 2020). Previously, research has proposed that resting HRV is negatively altered during the initial stages after a concussion (Harrison et al., 2022). While other publications indicate that during high levels of physiological stress, HRV levels remained altered beyond the initial stages of injury (Harrison et al., 2022; La Fountaine et al., 2009). Therefore, Harrison et al. (2022) examined and assessed HRV during times of physical and mental stress in concussed and non-concussed adolescent athletes. All participants with concussions within the study underwent three series of HRV sessions. The three HRV sessions required participants to rest with no cognitive stimulation, complete a cognitive task while resting, and complete the same cognitive task after a bout of submaximal aerobic exercise. The main findings from the study concluded that concussed athletes at rest did not show any differences in cardio-autonomic functions compared to the healthy control group (Harrison et al., 2022). However, during the cognitive task at rest and after aerobic exercise, athletes with a history of concussions demonstrated higher standard deviation (SD) and normal to normal (NN) intervals than healthy, non-concussed athletes (Harrison et al., 2022). These findings align with current published research, which suggests that stressors may influence and exacerbate functional deficits compared to resting conditions (Harrison et al., 2022). Other research has also reported that concussed athletes exhibit decreased low-frequency (LF) values, increased or decreased high-frequency (HF) values, and increased root mean square of successive differences (RMSSD; Doucet et al., 2023). Therefore, current literature acknowledges that following a concussion, SNS activity increases while PNS activity decreases (Doucet et al., 2023). With trauma and dysfunction to the ANS, alterations to the circadian rhythm may occur, resulting in potential sleep disturbances or sleep deprivation (Purkayastha et al., 2019).

2.3 Sleep Complications and Implications of Lack of Sleep.

Sleep can be defined as a behavioural state which reduces or immobilizes responses to external stimuli (Vyazovskiy, 2015). As sleep is a fundamental need for an individual's mental and physical health, research reports that approximately 70% of concussed athletes report sleep disturbances (Hoffman et al., 2020). Such disruptions can be associated with delayed recovery, worsening PCS, and poorer cognitive function. Within the athletic population, sleep is a crucial component of physical and mental recovery. It has been recommended that athletes aim for approximately 9 to 10 hours of sleep (Watson, 2017). Unfortunately, many athletes report experiencing sleep deprivation due to both high amounts of training, frequent travelling, high stress levels, and lifestyle habits (Doherty et al., 2021). It has been hypothesized that individuals who experience short-term sleep deprivation may experience worsening PCS, delaying recovery. A study conducted by Hoffman et al. examined 151 concussed collegiate athletes, comparing symptom recovery and concussion assessment performance between individuals who either experienced short sleep durations, no sleep change, or prolonged sleep durations (2020). The study concluded that 24 to 48 hours post-injury, individuals who experienced short sleep durations reported higher symptom severity (39.1 ± 20.7) compared with participants who had no change in sleep duration (25.1 ± 18.4, P = 0.007) and those with longer sleep duration (25.7 ± 21.8, P = 0.004).

Furthermore, the study examined participants 2 to 4 days post-injury with similar findings. Individuals with short sleep duration reported higher symptom severity (21.8± 21.8) compared to individuals with no sleep change (10.5 ± 10.8, P= 0.013) and longer sleep (11.9± 14.2, P=0.007; Hoffman et al., 2020). In another study conducted by Hoffman et al. (2019), 149 university students were examined to investigate changes in sleep shortly after and throughout symptom recovery in concussed participants compared to a control group. The primary findings suggested that concussed participants compared to the non-concussed control group experienced greater difficulties falling asleep 2-3 days post injury, significant differences between the Pittsburgh Sleep Quality Index (PSQI) scores as the concussed group reported poorer sleep quality since injury, compared to the control group which reported typical sleep quality, and worse sleep quality during recovery (Hoffman et al., 2019).

To further understand the implications of sleep deprivation within concussed populations, Magliato et al. examined the association of self-reported sleep problems within concussed youth (2023). As poor sleep quality within healthy subjects has been previously associated with anxiety, depression, fatigue, and a decrease in motor function, Magliato et al. wanted to examine the association between post-concussion sleep problems in concussed youth 2023. They aimed to examine postural stability, cognitive functions, symptom severity, and recovery outcomes, while also comparing their findings between patients with and without preexisting sleep problems (Magliato et al., 2023). According to their findings, 207 youth participated in the study, concluding that patients who reported sleep problems after injury exhibited higher symptom severity and poorer postural stability (Magliato et al., 2023). Their findings support prior research and indicate that sleep problems within concussed patients may delay recovery and prolong post-concussion symptoms (Magliato et al., 2023).

2.4 Current Treatments for TBI.

Following a TBI, rest and minimal physical activity were once considered the most effective treatment following injury (Silverberg & Iverson, 2013). Recently, within the past decade, it has been well studied that cognitive and physical rest are only recommended in the first 24-48 hours following injury. For sport-related concussions (SRC), physical rest may be required longer (Leddy et al., 2018). Current research now suggests that complete rest may hinder recovery and contribute to higher risks of depression, anxiety, and deconditioning (Callaway & Kosofsky, 2019). Within the literature, current research has examined youth and sport-related concussions, with limited research examining adult athletes (18+).

2.4.1 Melatonin Supplementation

There are gaps in the literature regarding melatonin prescriptions in adults (18+), as most published research has focused on the benefits for young athletes. Within the literature, two studies have examined melatonin supplementation in adults (18+). In a study conducted by Grima et al. (2018), the researchers acknowledge that untreated sleep disturbances following TBI may lead to lower productivity levels, cognitive dysfunction, and poorer rehabilitation outcomes. The purpose of their study was to evaluate the effectiveness of melatonin supplementation (2mg/day) on sleep quality in participants with mild to severe TBI. The population of interest consisted of thirty-three individuals aged 18–65 who reported sleep complications. Participants were randomly assigned to a 4-week melatonin or placebo treatment. According to their findings, melatonin supplementation was associated with reduced self-reported anxiety and fatigue, improved subjective sleep quality, and enhanced mental functioning (Grima et al., 2018). There were no improvements regarding daytime sleepiness, nor self-reported PCS, such as depression. However, in conclusion, Grima et al. suggest that melatonin supplementation could be a potential treatment option for those who experience sleep disturbances following a TBI (2018). Furthermore, the authors acknowledged that such findings were the first to validate that melatonin prescription following a TBI may be beneficial as a treatment within TBI populations (Grima et al., 2021).

To further expand on their preliminary findings, Grima et al. conducted another study to examine the association between TBI participants and self-reported symptoms, as well as the improvements in sleep quality after 4 weeks of melatonin treatment (2021). The study examined 33 TBI participants, either in a melatonin treatment group (2mg/day) or a placebo group, and asked them to take a capsule 2 hours before bedtime. The main findings of this study suggest that individuals who have sustained a TBI are more likely to benefit from melatonin treatment, regardless of injury timing or individual characteristics such as age or sex (Grima et al., 2021).

2.4.2 Exercise Following TBI

Previously, concussion guidelines recommended cognitive and physical rest post-injury. Still, recent evidence now suggests that complete bed rest and rest until symptom resolution are ineffective approaches towards TBI recovery (Lawrence et al., 2018). As many concussed participants may experience exercise intolerance due to abnormal ANS regulation of cerebral blood flow, Leddy et al. wanted to examine the potential benefits of sub-threshold exercise as a treatment for TBI individuals (2019). Within this study, Leddy et al. examined the effects of aerobic exercise on concussed male youth (13-18 years old) using the Buffalo Concussion Treadmill Test (BCTT; 2019). Participants were divided into two groups: the exercise group and the rest group. To track and observe symptom severity, participants were required to report their symptoms daily in the evening over two weeks. For those in the exercise group, participants were asked to complete 20 minutes of daily exercise on a treadmill or stationary bike at subthreshold aerobic limits. Subthreshold exercise was calculated at 80% of the heart rate achieved at symptom exacerbation. The study concluded that participants in the exercise group had faster recovery times from the initial visit compared to the rest group (8.29±3.85 days versus 23.93± 41.73 days, P=0.048; Leddy et al., 2019). By the end of the study, Leddy et al. reported that the exercise group had significantly fewer symptomatic participants, concluding that early subthreshold aerobic exercise, initiated within one week of a SRC, has the potential to accelerate recovery (2019). As these findings provide preliminary results, several limitations are present in the study. Several limitations were examined only in male adolescent athletes; therefore, the results cannot be generalized to adult or female populations. With acknowledgment of the limited research examining the benefits or risks associated with exercise as a potential treatment post-concussion, Snyder et al. wanted to investigate the effects of implementing aerobic exercise in adults aged 18-32 years old, and its impact on symptom response, mood, sleep, cognition, and postural stability (2021). Concussed participants were either randomized into two groups: 1 week of daily aerobic exercise or 1 week of daily non-aerobic exercise, and non-concussed participants were assigned to the control group (Synder et al., 2021). Following the intervention period, the study concluded that aerobic exercise does not negatively affect recovery. However, for those with greater symptom severity, Snyder et al. (2021) state that exercise tolerance may be lower.

2.4.3 Cognitive Behavioural Therapy (CBT)

Cognitive behavioural therapy (CBT) has been the gold standard for participants diagnosed with insomnia and is now known to benefit individuals who are diagnosed with neurological ailments (Ludwig et al., 2024). Literature now suggests that CBT may be beneficial for participants who have sustained multiple concussions or moderate to severe cases of TBI. Ludwig et al. examined the evaluation of CBT for concussed participants who suffer from insomnia and evaluated changes in sleep outcomes as well as changes in concussion symptoms (2024). There is scarce research regarding CBT as an effective treatment in adult populations for those who have sustained a concussion. Ludwig et al. acknowledge that insomnia is common within concussed populations and that delayed recovery may occur due to poor sleep quality and quantity (2024). Ludwig et al. examined forty individuals who had sustained either a moderate or severe concussion and were randomized into either a group that started CBT immediately following baseline assessment or into a group that started CBT six weeks following baseline assessment (2024). Following intervention in both groups, the results indicate that CBT is an effective treatment for concussed individuals who have insomnia and helps reduce post-concussion symptoms and severity (Ludwig et al., 2024).

2.5 Neurotracker (3D-Multiple Object Tracking Therapy)

Neurotracker is a three-dimensional multiple object tracking (3D-MOT) system that challenges working memory, motion integration, perceptual, and cognitive skills, as well as the ability to process multiple objects in time and space (Acquin et al., 2024). Research now suggests that perceptual-cognitive training may benefit sport-specific tasks and individuals who have suffered either a minor or severe TBI (Corbin-Berrigan et al., 2020). Currently, there is no published research examining 3D-MOT programs, such as Neurotracker, and their effects on sleep in concussed adult athletic populations. Current research has explored programs such as Neurotracker and its significance as a clinical tool for recovery and rehabilitation (Corbin-Berrigan et al., 2020). Corbin-Berrigan et al. (2020) examined symptom resolution, balance and agility testing, along with complete return to cognitive activities in children and adolescents who either recovered from a mild traumatic brain injury (mTBI) or were part of a healthy control group. The study concluded that children and adolescents with mTBI achieved greater training gains than non-injured children in perceptual-cognitive tasks (Corbin-Berrigan et al., 2020).

Furthermore, Corbin-Berrigan et al. found no difference between groups in terms of balance, coordination, fatigue, cognitive function, or quality of life, and suggest that 3D-MOT programs, such as Neurotracker, may contribute to cognitive recovery and reduce the risk of complications following a mild traumatic brain injury (mTBI; 2020). Therefore, the purpose of this multiple-case study is to examine the trends in the application of 10 Neurotracker sessions and the changes in sleep quality and quantity in concussed athletes.

Chapter 3 Method

3.1 Design

A multiple-subject pilot case study design was used to examine changes in sleep quality and quantity following the application of 3D-MOT (Neurotracker) in concussed athletes.

3.2 Research Team

The research team consisted of two professors, one graduate student, and one research assistant. All research members have completed the Canadian Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS-2) course and received ethical approval for data collection (see Appendix A).

3.3 Sampling Frame and Final Sample

Participants were recruited within the Greater Victoria region of BC through email and word of mouth. Emails were sent to the University of Victoria and Camosun College head sport coaches for athletes who had a concussion(s) within the past six years. Eligible participants were: (1) 18-35 years old male and female athletes; (2) who have sustained one or more concussions on or after January 1st, 2020; (3) who have sustained a mild or moderate concussion either self-diagnosed or professionally by a health care provider. Participants were excluded from the study if they: (1) had extreme ADHD or anxiety; (2) had any neurological impairments or diseases; (3) had any sleep impairments such as predisposed insomnia, or currently used any sleeping medications; (4) used any narcotics; or (5) had sustained a severe concussion before January 1, 2020 or during the study duration.

3.4 Measures

Data were collected using a Polar Ignite smartwatch and through participation in a 3D multiple-object tracking (3D-MOT) software program as the intervention. Before and after the intervention, participants assessed their sleep quality over the previous month (Appendix

B) and completed a self-report inventory questionnaire (Appendix C) measuring post-concussion symptoms on a Likert scale. Participants wore the smartwatch for three consecutive nights before the intervention and for three consecutive nights after the five-week intervention period. The study spanned seven weeks and evaluated the impact of 3D-MOT programs, such as Neurotracker, on sleep quality and quantity in concussed participants.

Participants in the study included Camosun Charger athletes and self-identified athletes who engaged in one or more sports within the greater Victoria, BC region. Recruitment occurred from February 2025 to July 2025. Prospective participants contacted the primary researcher via email to request additional information. Eligible individuals completed a screening interview questionnaire (Appendix D), consent form (Appendix E), and intake form (Appendix F) in person with a member of the primary research team at the Pacific Institute of Sport Education (PISE). After all forms were completed and submitted, each participant was assigned a unique, randomly generated identification number and provided with equipment, including a Polar Ignite watch, 3D glasses, a charger, and two questionnaire forms to assess sleep quality, sleep quantity, and post-concussion symptoms. All personal information was stored under assigned identification numbers in a password-protected Excel spreadsheet. Paper copies were shredded after data entry.

3.4.1 Polar Ignite Smartwatch

Polar Ignite smartwatches were used to collect sleep data for three consecutive nights before and after the intervention period. Manufactured by Polar Electro Oy, Finland, these wearable devices provide physiological data, including heart rate, heart rate variability (HRV), sport-related metrics, and information on daily activities such as steps, walking, or hiking and when worn overnight on the non-dominant hand, provides sleep and breathing data (Budig et al., 2021). For sleep and movement tracking, the smartwatches utilize an accelerometer to record movement and estimate wakefulness and inactivity as proxies for sleep (Parent et al., 2024). The devices generate measures such as total sleep time, total time scored as sleep, sleep onset latency (the interval from going to bed to the first epoch of sleep), wake after sleep onset, and sleep period time (Parent et al., 2024). Recent literature has evaluated the validity of Polar smartwatches, with findings indicating that Polar Electro Oy, Finland, provides sleep stage recognition accuracy comparable to or exceeding that of other smartwatch devices when assessed against polysomnography (PSG; Parent et al., 2024). All data collected from the Polar Ignite smartwatch was synced to the Polar Flow application (version 6.33.0, Polar Electro Oy, Kempele, Finland) by the primary researcher. The sleep data was then stored on a password-protected Excel spreadsheet.

3.4.2 Neurotracker

Neurotracker is a 3D multiple-object tracking (MOT) computerized program that challenges and trains visual abilities such as depth perception and peripheral vision, as well as visual-motor and perceptual-cognitive skills for sport-specific tasks, along with non-sport vision and attention skills (Vater et al., 2021). Neurotracker, developed in Montreal, Canada, and promoted and sold by the Faubert Applied Research Centre, requires participants to sit in a dark room, wear 3D glasses, and fixate on a green dot in the center of the screen while tracking the movement of 8 spheres (Vater et al., 2021). Each participant received a pair of 3D glasses and was asked to complete 2 sessions per week, each session typically lasting six minutes, for 5 weeks, for a total of 10 sessions. In terms of test-retest reliability, Deschamps et al. (2022) examined and compared the test-retest reliability of the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) and NeuroTracker across two consecutive seasons in athletic populations at high risk for mTBI. ImPACT is a computerized tool used to assess memory, attention span, reaction time, and processing speed (Mayers & Redick, 2012). Within the results section of Deschamps et al., (2022) they concluded that Neurotracker demonstrates acceptable test-retest reliability compared to ImPACT after 1 year. In addition, Neurotracker demonstrated equal or better reliability than ImPACT in composite score comparisons.

3.4.3 Sleep and Symptom Severity Checklist

The Pittsburgh Sleep Quality Index (PSQI) is a 19-item self-reported questionnaire designed to assess subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction over a one-month interval. The PSQI is a valid and reliable tool used in multiple studies examining sleep disturbances, primarily insomnia. The PSQI can be completed in five minutes or less and examines subjective and objective dimensions of sleep. Regarding scoring, there are seven subsections, each scored 0-3, yielding a global score of 0-2; any score greater than 5 indicates poorer sleep quality (Farrahi Moghaddam et al., 2012). In a preliminary study, Hoffman et al. (2020) examined the relationship between days to symptom recovery and all aspects of sleep, as measured by the PSQI, in a cohort of concussed athletes. The results of the study highlight the importance of the PSQI in identifying sleep disturbances but also note the limitations of self-reporting inventory questionnaires, which may be inaccurate because participants may only report or recall negative experiences (Hoffman et al. 2020). In another study examining the reliability and validity of the PSQI among healthcare workers during the COVID-19 pandemic, Wang et al. (2022) found that the PSQI is a strong indicator of sleep disturbances, particularly among participants with insomnia. As healthcare workers experience poor sleep quality and quantity, Wang et al. acknowledge that the PSQI demonstrates good reliability and validity but has limitations in its daytime dysfunction subsection (2022).

The Post-Concussion Symptom Scale (PCSS) is a self-reporting measure used to evaluate the post-concussion symptoms for concussed athletes to determine symptom severity. The questionnaire comprises 22 items, each evaluated on a 7-point scale ranging from 0 (no symptoms) to 6 (severe). The PCSS is used to assess mTBI symptoms and is highly responsive and reliable within concussed populations. Langevin et al. examined the internal and external responsiveness of the PCSS among patients with long-term post-concussion symptoms, as well as the longitudinal validity of the PCSS relative to other questionnaires with similar goals (2022). The study examined participants with ongoing symptoms and concluded that the PCSS is highly responsive to changes in these patients (Langevin et al., 2022). The PCSS scale has some limitations, as it has been reported that participants, more often in athletic populations who have sustained a concussion, are more likely to under-report symptoms due to the belief and fear of being removed or held back from their sport (Merritt et al., 2018).

3.5 Procedure

Participant data was collected through the utilization of the Polar Ignite watch to obtain REM, deep sleep, actual sleep, sleep time, sleep continuity, and sleep cycles, sleep data such when uploaded to the Polar Flow application while all Neurotracker data was collected through NeurotrackerX (the next generation of this platform), to obtain percentage of targets correct, percentage of consistency score, score, total time, and average response time. All participants had their own Polar and Neurotracker accounts created, and data extraction and syncing were conducted upon completion of the study. Participants were instructed to wear the Polar watch for three consecutive nights before and after the five weeks of Neurotracker. Each participant received verbal instructions and a folder containing written instructions for logging in to their own Neurotracker account, two copies of the PSQI questionnaire, one copy of the PCSS questionnaire (post-test PCSS was emailed to the participant once they completed the study), and an in-depth PowerPoint on navigating Neurotracker (See Appendix F). The research assistant sent daily text and email reminders to each participant to wear their watches, to ensure they completed two Neurotracker sessions per week for five weeks, and to check their current study completion status. Participant information was also collected through an intake form, which recorded their identification number, age, sex, gender, weight, number and year concussions occurred, if consciousness was lost and for how long, mechanism of injury, if the concussion was self or professionally diagnosed, and the time duration it took to return to sport. Once all participants had completed the study and returned all equipment to the primary researcher, each participant was emailed the PCSS to complete.

Chapter 4 Results

4.1 Sample Population Characteristics

The recruitment goal of this study was approximately 15 participants. The initial number of participants in the study was N=7 (2 females), but due to high participant dropout, only three male participants completed this feasibility study (N=3; participants A, B, and C). Due to several complications, such as participant drop out due to either moving away or moving away for work, limited equipment due to participants taking longer than the anticipated seven weeks of completion, recurrence of severe concussion(s), difficulties with residual concussion symptoms, and frustration or difficulty adhering to the study's protocol, resulted in only 5 participants completing the study. After completion, participants D and E's data could not be used due to incomplete or compromised data, leaving three participants. All female participants in the study dropped out. Participant F quotes dropping out of the study because "*…my mental health and concussion pain have been really struggling this season of my life. With all the hiccups it was to get started made it a challenge. And then when I finally tried Neurotracker, it made me feel incredibly insecure and made my mental health plummet even more."* Furthermore, participant G dropped out due to sustaining a concussion and reported, *"not feeling well enough to continue the study*". The remaining two female participants did not start the study as one obtained a job in a remote location with no internet connection, and the other participant had to move out of the province.

Participant D's data was incomplete, and due to the use of narcotics that may have confounded results, was not included. Participant E's data set is incomplete due to complications with memory recall, regardless of multiple reminders. Only three participants successfully completed the study and had complete data sets. When comparing trends among participants in the study (A, B, and C) vs. participants who dropped out (D, E, F, and G), the total number of concussions each participant sustained may have influenced the dropout rate. Participants who dropped out recorded sustaining 3 or more concussions, compared to the participants who completed the study, who only sustained one or two concussions. Therefore, the participant dropout rate may have been attributed to these observational trends.

Because of the low number of subjects, each was treated as a multiple-subject design for trend analysis purposes and to answer the research questions. Participant A, B, and C characteristics are presented in Table 4.1.

Table 1

Demographic Characteristics of Concussed Athletes (N=3) Participating in the Study within the Greater Victoria Region

ID	Age	Sex	Weight (Kg)	Level of Education	Total # of Concussion	Date of Concussion(s)	Lose Con	Mech of Injury	Concussion Diagnosis
A	23 years	Male	86.18kg	High school	2	2018, 2022	Yes-2018	Baseball Basketball	Athletic Therapist
B	24 years	Male	84.37kg	Bachelor's degree	1	2021	No	Playing sports	Athletic Therapist
C	33 years	Male	84.82kg	Bachelor's degree	2	2023	No	Volleyball	Self-Reported

Note. Lose Con = loss of consciousness; Mech of Injury = mechanism of injury. Number and dates of concussion(s) are based on participant self-report or medical diagnosis

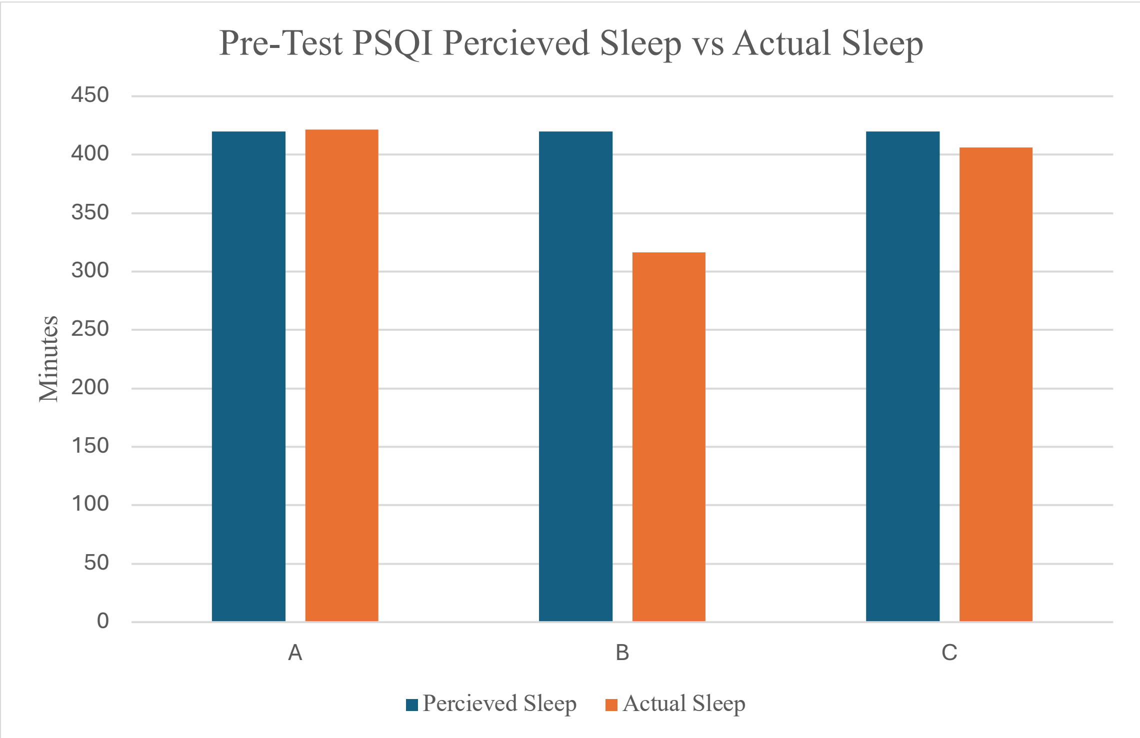
4.2.1 Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) affect sleep quality and quantity in concussed participants?

4.2.2 Pittsburgh Sleep Quality Index (PSQI): Perceived sleep vs. Actual sleep

Figure 1 displays the average pre-test perceived vs. actual sleep time for each participant, using data from the Pittsburgh Sleep Quality Index (PSQI) and the Polar Ignite watch, while Table 4.3 displays the average perceived vs. actual sleep time for each participant, using post-test PSQI scores and Polar Ignite data. In the pre-test scores, all participants reported a perceived sleep duration of 420 minutes, but the individualized actual sleep data indicate varying discrepancies. Participant averages are: 422 minutes of actual sleep for participant A, 317 minutes of actual sleep for participant B, and 406 minutes of actual sleep for participant C. In the post-test scores, the same trend of overestimating sleep occurred for participant A, who reported 425 minutes of perceived sleep but only had 328 minutes of actual sleep and participant C, who reported 435 minutes of perceived sleep but had 425 minutes of actual sleep. In the post-test, Participant B slightly underestimated their sleep, reporting 390 minutes of actual sleep compared to 397 minutes.

Figure 1

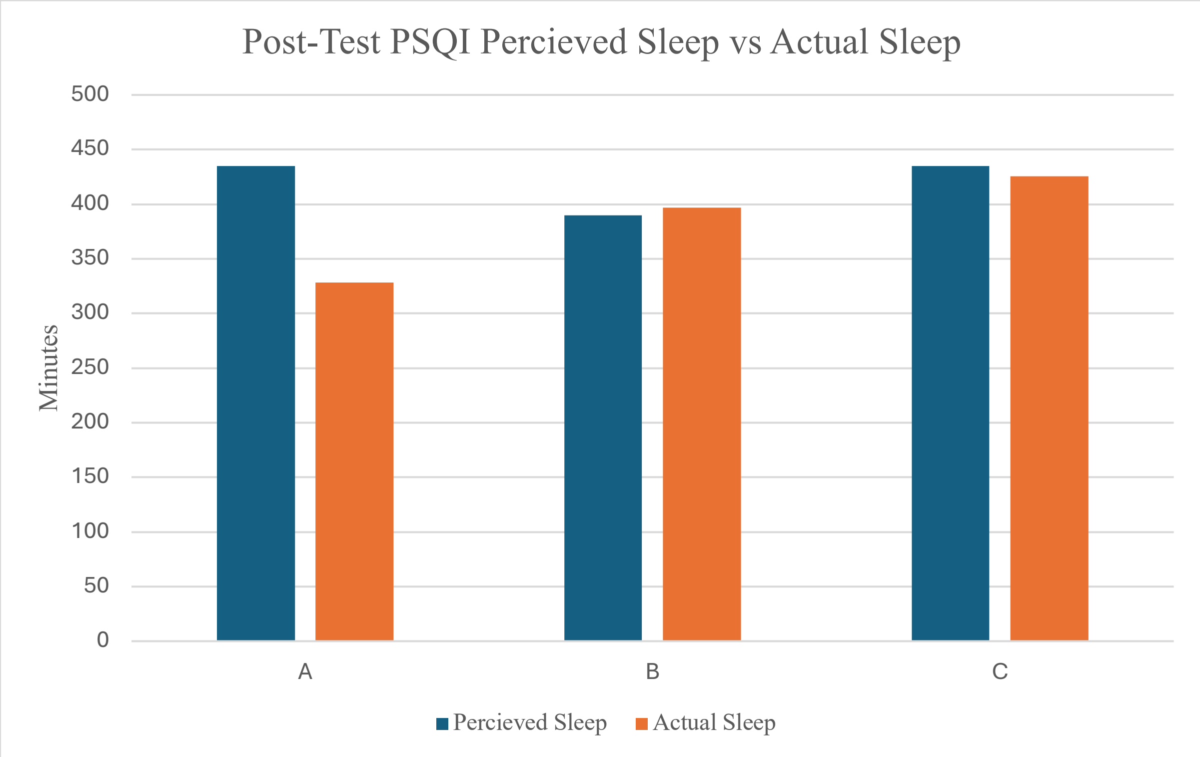
Pre-Test PSQI Perceived Sleep vs. Actual Sleep Duration



Note. Sleep duration is expressed in minutes.

Figure 2

Post-Test PSQI Perceived Sleep vs. Actual Sleep Durations



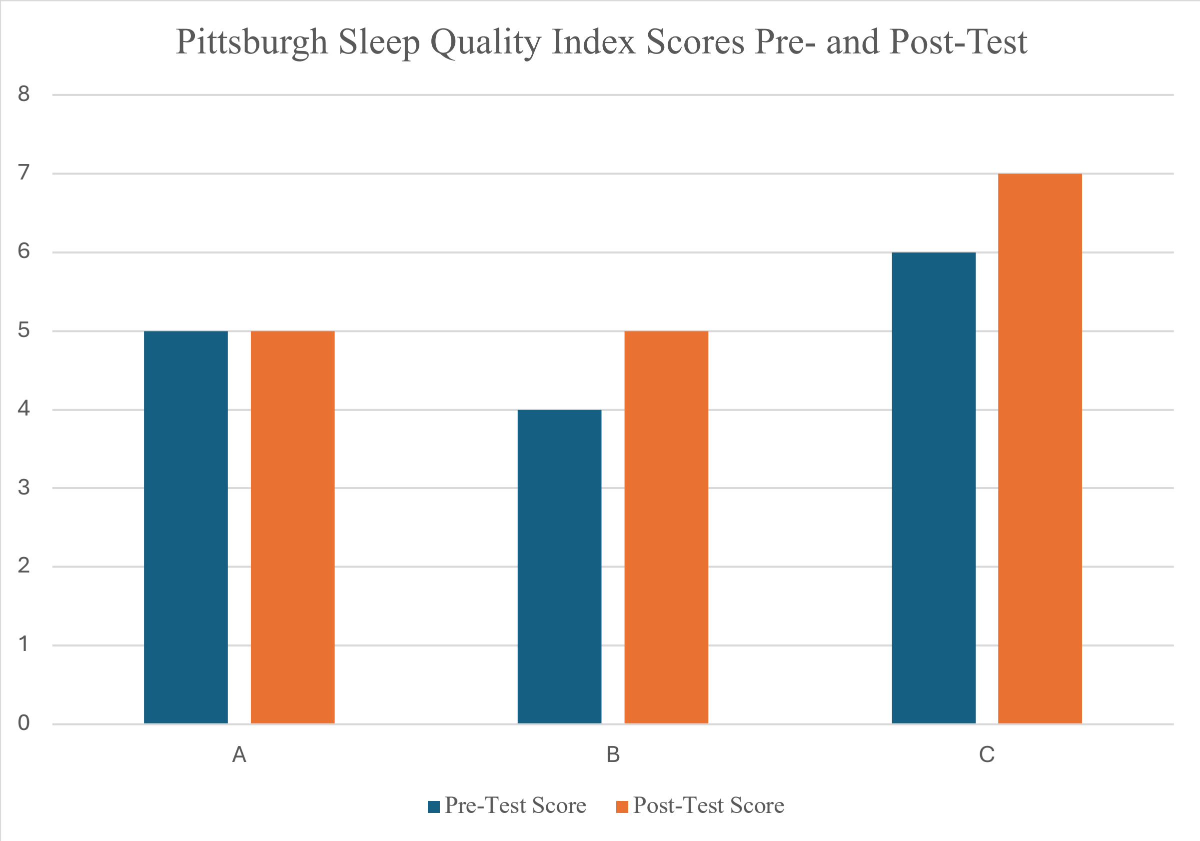
Note. Sleep duration is expressed in minutes

4.2.3 Pittsburgh Sleep Quality Index (PSQI) Scores

Figure 3 displays the pre- and post-test PSQI scores for each participant. Participants showed that PSQI remained the same pre- to post-test or trended upward slightly. Individually, participant A scored a 5 on both the pre- and post-test, while participant B scored a 4 on the pre-test but a 5 on the post-test. Participant C scored a 6 on the pre-test compared to a 7 on the post-test.

Figure 3

Pittsburgh Sleep Quality Index (PSQI) Scores Pre- and Post-Test Scores



Note. Any score 5> poor sleep quality or sleep disorder (Carpi, 2025).

4.2.4 Polar Ignite Sleep Data

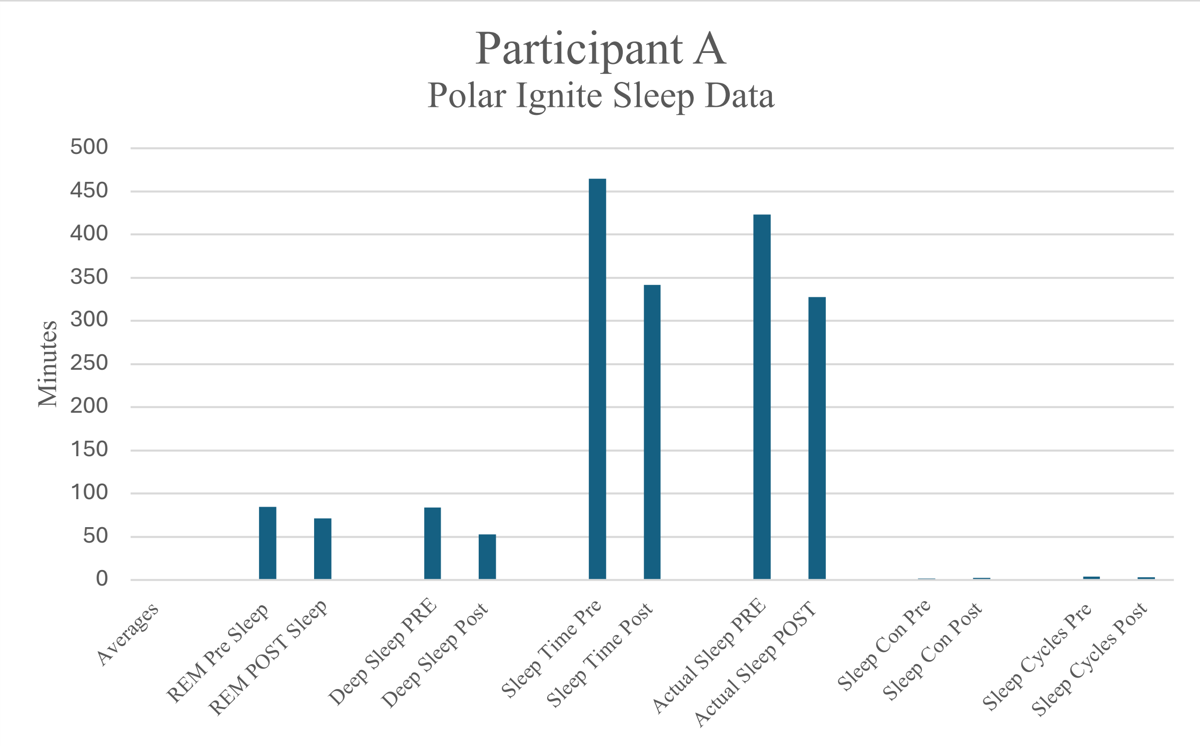
Figure 4 represents participant A's sleep data as REM sleep decreases from 85 minutes to 71 minutes, and deep sleep decreases from 84 minutes to 53 minutes. Sleep time also decreased from 465 to 342 minutes, and actual sleep time decreased from 423 to 328 minutes. Sleep continuity increased from 2/5 to 2.4/5, while sleep cycle averages decreased from 4 to 3.5

Figure 5 presents the average sleep data for participant B. As with the previous participant, REM sleep decreased from 58 to 53 minutes, and deep sleep decreased from 67 to 57 minutes. Sleep time increased from 339 to 428 minutes, as well as an increase in actual sleep time from 317 to 397 minutes. Sleep continuity decreased from 3.3/5 to 2.5/5, while sleep cycles increased from 4.3 to 4.7.

Participant C's data is presented in Figure 6. Their REM sleep data shows a decrease from 117 minutes to 104 minutes, and their deep sleep averages also decrease from 59 minutes to 56 minutes. Their sleep time increased from 444 to 461 minutes, and their actual sleep time increased from 406 to 425 minutes. Regarding their sleep continuity scores, participant C increased from 2.5/5 to 3.4/5, while their average sleep cycles decreased from 6 to 5. Across all three participants, a trend emerges: all three experience a decrease in REM and deep sleep from pre- to post-test.

Figure 4

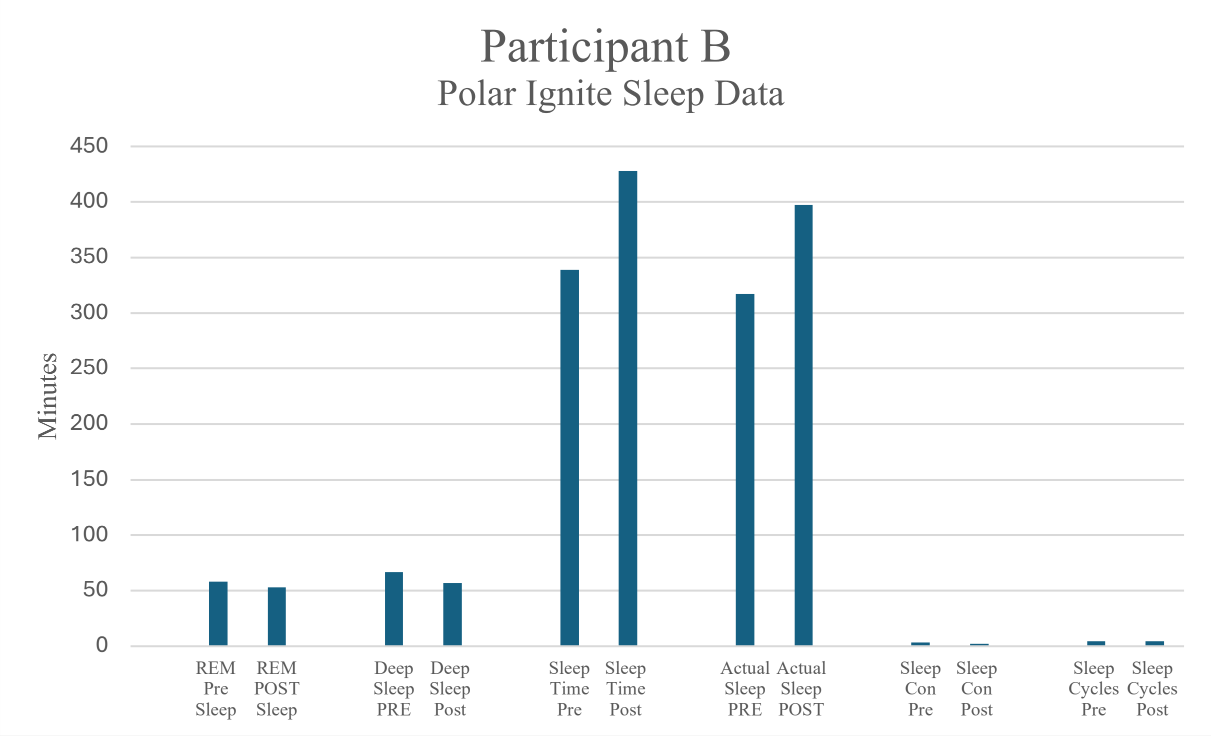
Participant A Polar Ignite Sleep Data.



Note. Pre and post-test sleep data were averaged, and sleep duration is expressed in minutes.

Figure 5

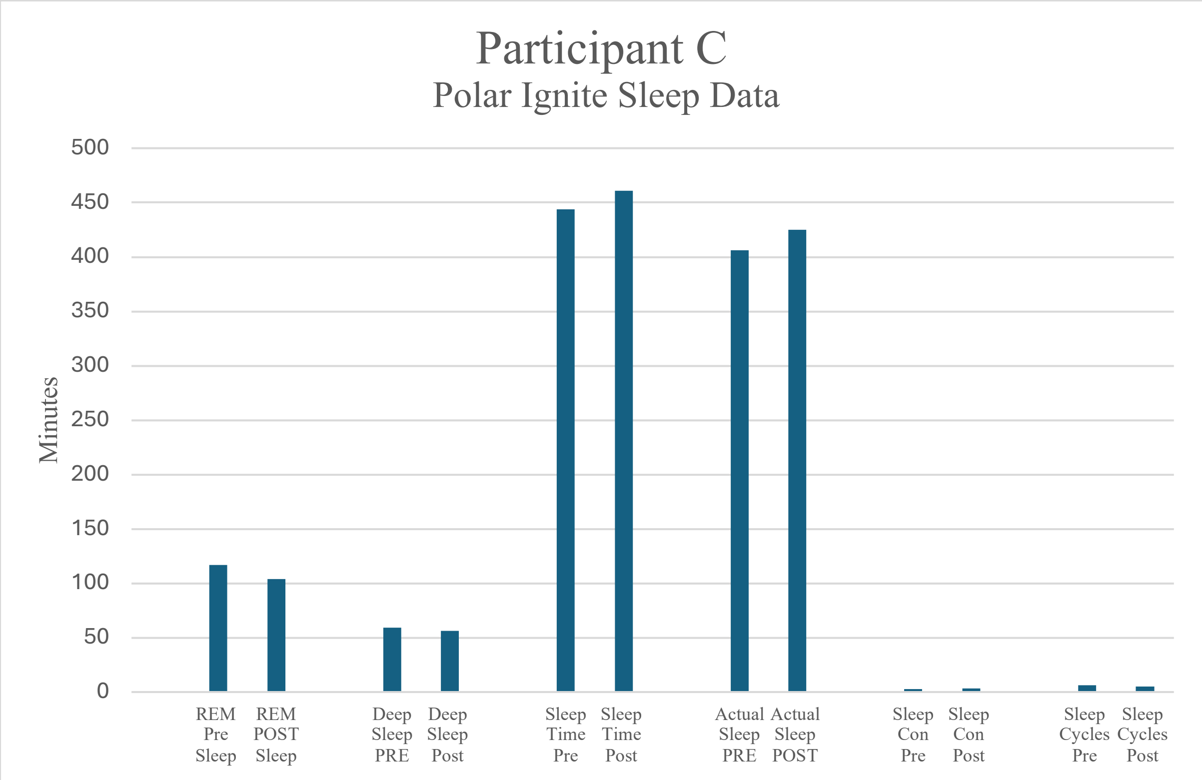
Participant B Polar Ignite Sleep Data.



Note. Pre and post-test sleep data were averaged, and sleep duration is expressed in minutes.

Figure 6

Participant C Polar Ignite Sleep Data.



Note. Pre and post-test sleep data were averaged, and sleep duration is expressed in minutes.

4.3 Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) affect perceptual-cognitive performance in concussed participants?

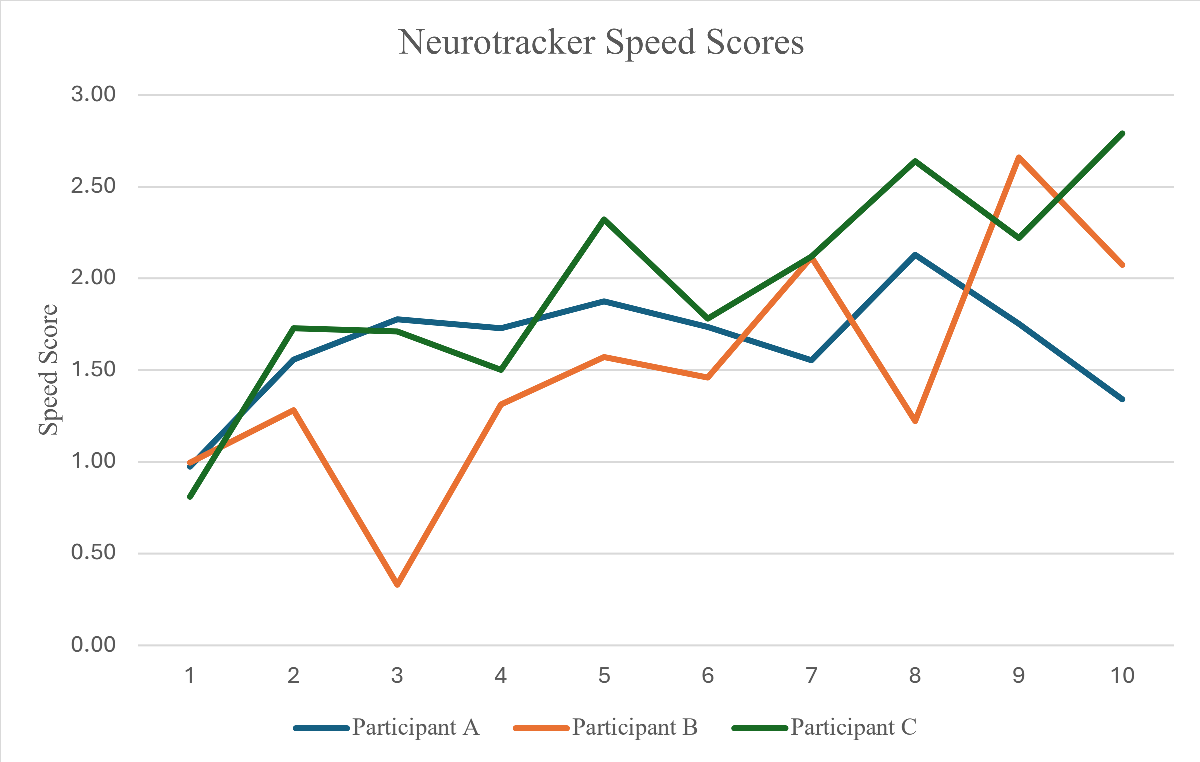
4.3.1 Neurotracker Speed Scores

Figure 7 presents Neurotracker scores for all participants across 10 sessions.

Participant A (range: 0.97–2.13), Participant B (range: 0.99–2.66), and Participant C (range: 0.81–2.79). While examining scores, participant C improved the most over the 10-session duration. Their lowest score was in their first session (0.81) and their highest in their last session (2.79). Participants B and C completed 30 sessions, so their data were averaged, resulting in a greater learning bias than the others.

Figure 7

Neurotracker Speed Scores from all 10 Sessions.



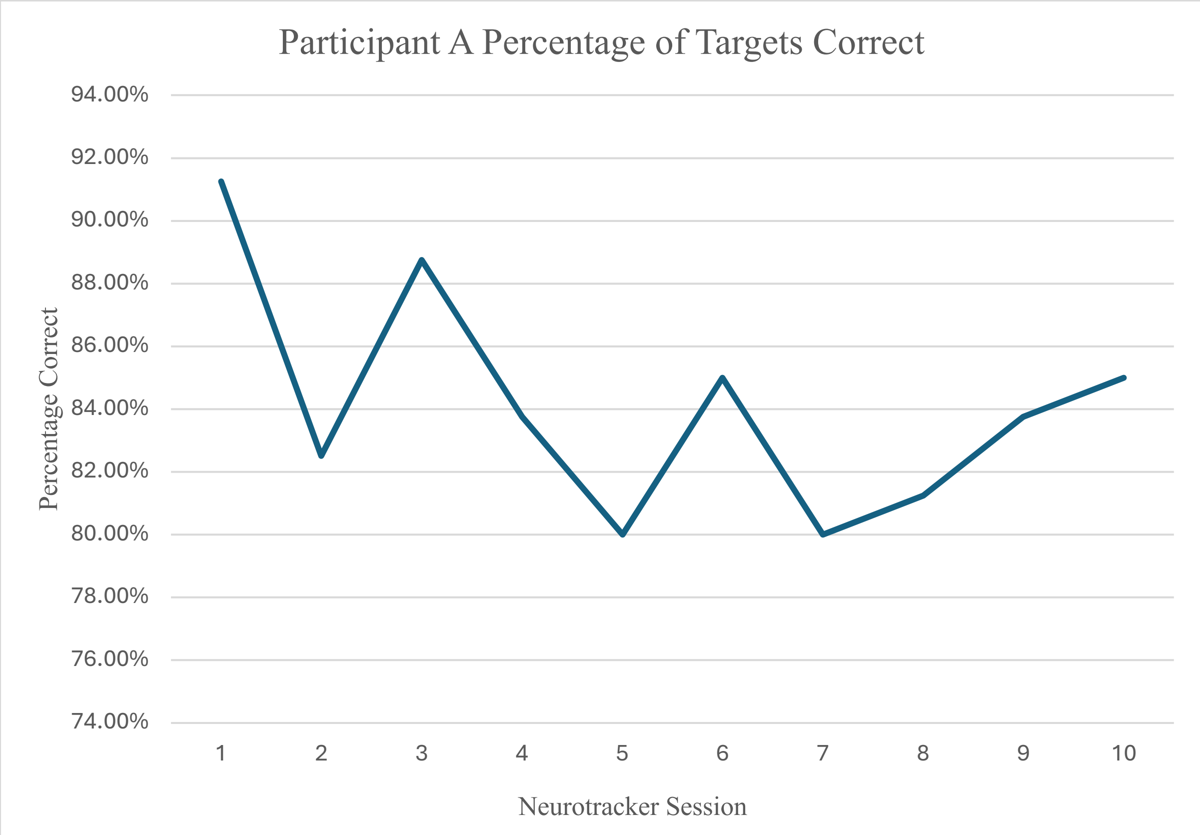
Note. Speed scores reflect the Neurotracker speed threshold, defined as the maximum speed at which participants maintained accurate identification of target spheres.

4.3.2 Percentage of Target Correct

Participants' percentages of targets correct are displayed in Figure 8 for participant A, Figure 9 for participant B, and Figure 10 for participant C. Participant B had the least variability in their percentages correct across the 10 Neurotracker sessions, with percentages ranging from 75% to 91.25%. Both participants A and C experienced a decrease in their percentage correct over the course of the sessions, but the main difference is that participant A's percentage increased from sessions 7 to 10, whereas participant C's percentage decreased from sessions 8 to 10. Participant A’s percentage correct ranged from 80%-91.25%, and participant C’s percentage correct ranged from 76.25% to 87.5%.

Figure 8

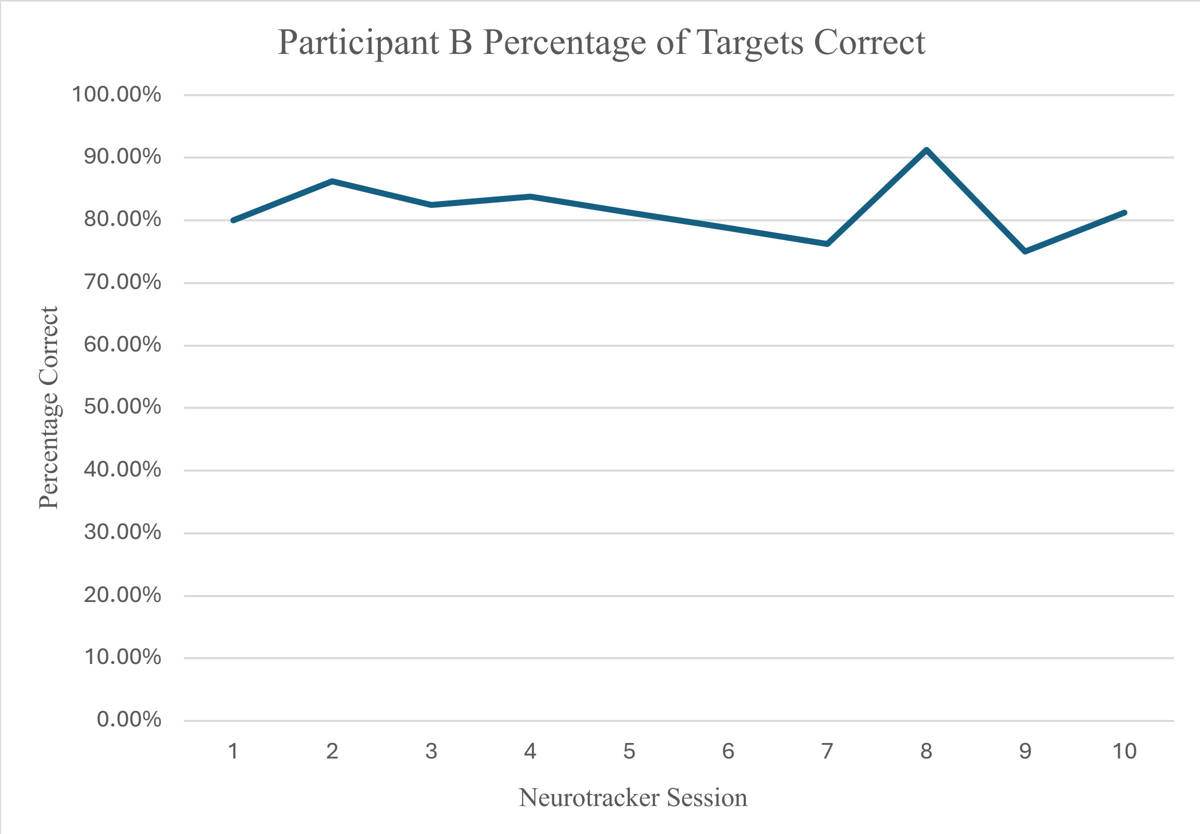
Participant A Percentage of Targets Correct Following Each Neurotracker Session



Note. Accuracy represents the proportion of correctly identified spheres in each Neurotracker session.

Figure 9

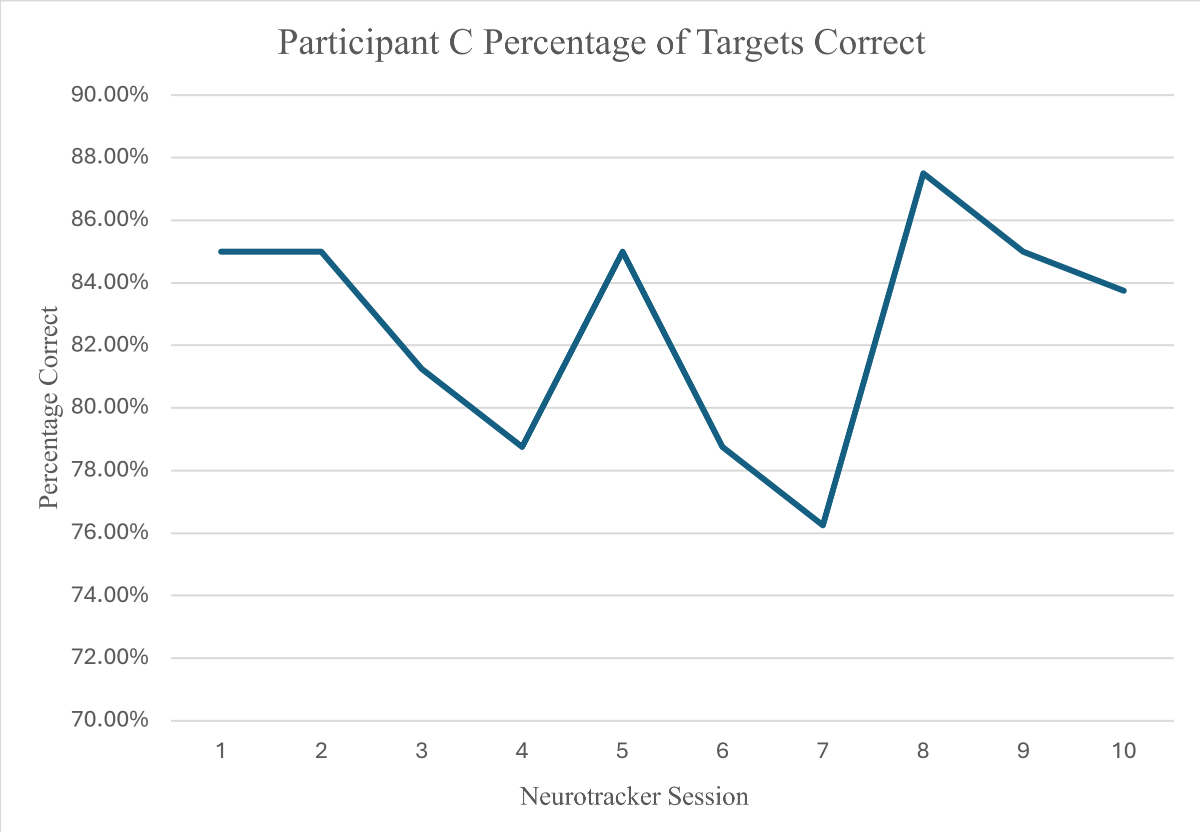
Participant B Percentage of Targets Correct Following Each Neurotracker Session



Note. Accuracy represents the proportion of correctly identified spheres in each Neurotracker session.

Figure 10

Participant C Percentage of Targets Correct Following Each Neurotracker Session



Note. Accuracy represents the proportion of correctly identified spheres in each Neurotracker session.

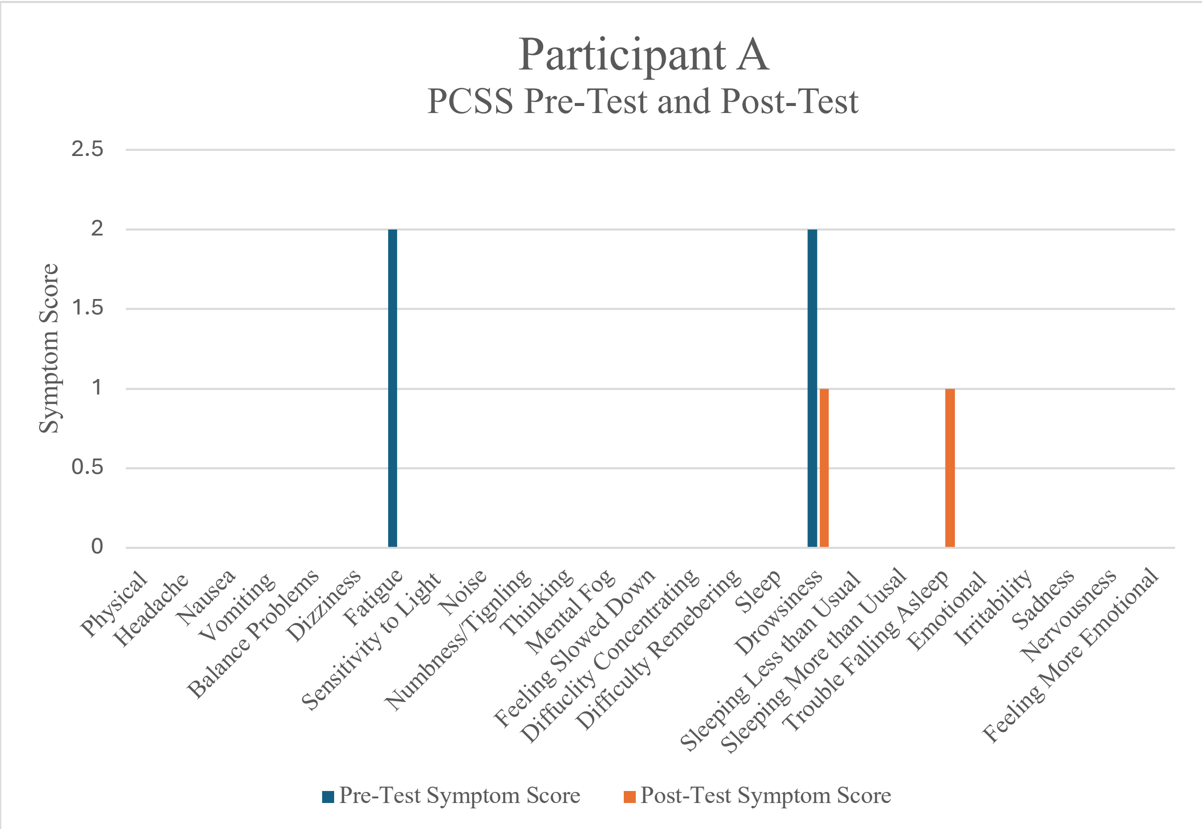
4.4 Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) impact perceived symptom severity?

Figures 11, 12 and 13 display each participant's pre-test and post-test scores on the Post-Concussion Symptom Scale (PCSS). The most frequently reported pre-test symptom was fatigue or reduced sleep, while the most common post-test symptoms were drowsiness, mental fog, dizziness, and sadness. In the pre-test data, participant A reported a decrease in symptom severity from 4 to 2. The number of reported symptoms remained consistent across both pre-and post-test; however, the specific symptoms reported differed between the two.

Participant B experienced an increase in both symptom severity score and in the PCSS. They reported experiencing 5 symptoms in the pre-test and 11 in the post-test, and their PCSS increased from 6 to 12. Lastly, participant C also experienced an increase in both symptom severity score and in the PCSS. Participant C reported 1 symptom in their pre-test data, compared with 7 in their post-test. Participant C also experienced an increase in their PCSS from 1 in the pre-test to 10 in the post-test. Figure 14 displays the total symptom severity score for all three participants.

Figure 11

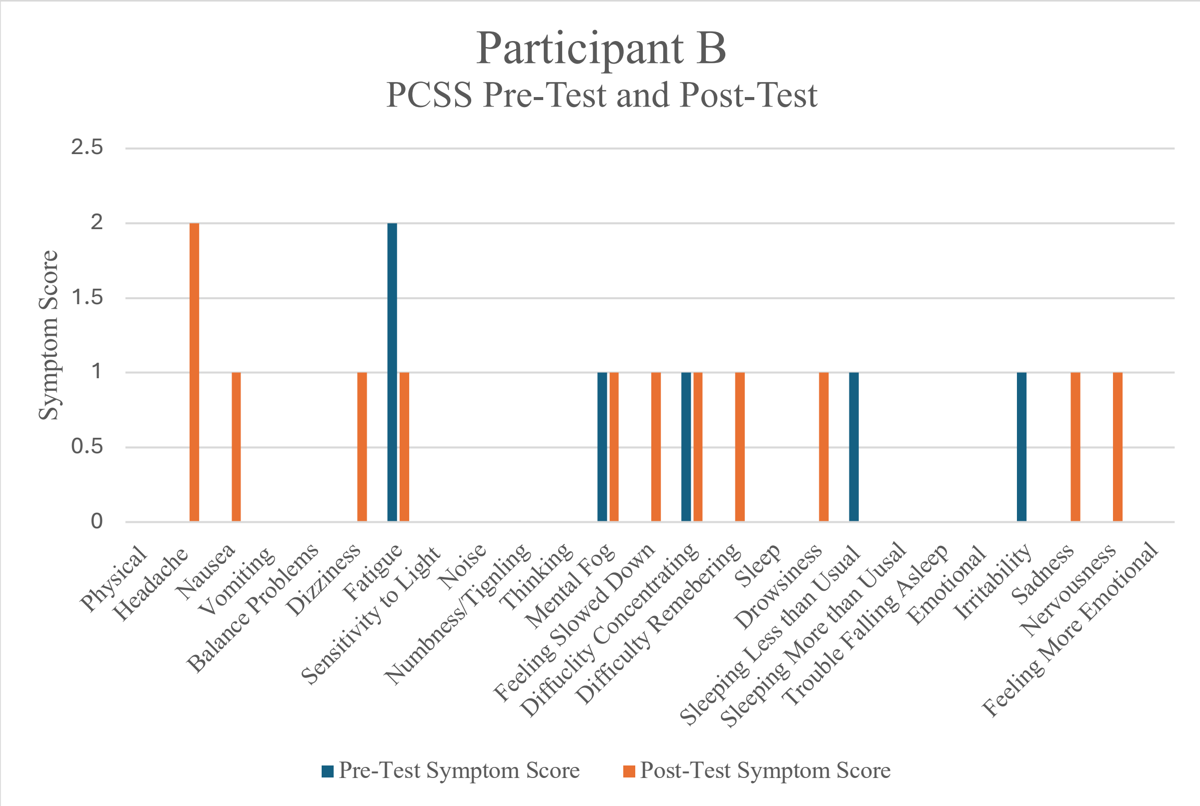
Participant A Post-Concussion Symptom Score Pre-and Post-Test



Note. Symptom scores represent self-reported symptom severity collected at pre- and post-intervention timepoints, with higher scores indicating greater symptom severity.

Figure 12

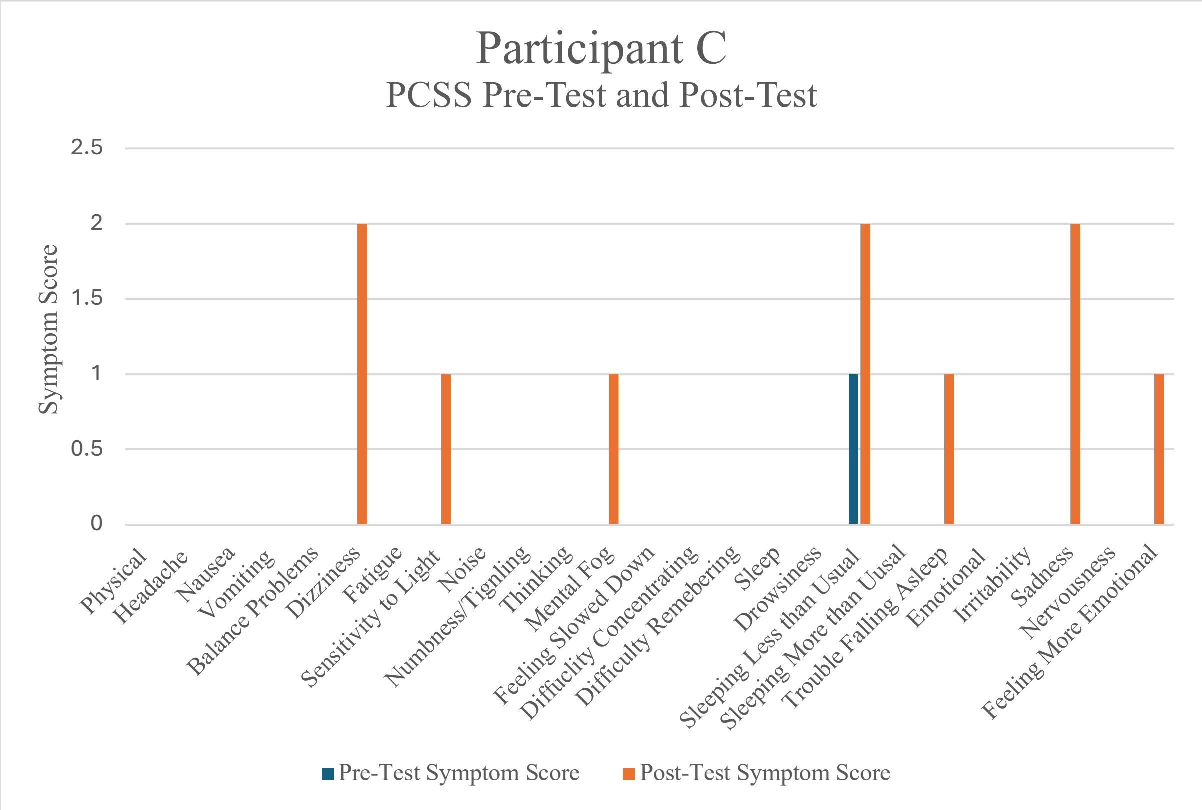
Participant B Post-Concussion Symptom Score Pre-and Post-Test



Note. Symptom scores represent self-reported symptom severity collected at pre- and post-intervention timepoints, with higher scores indicating greater symptom severity.

Figure 13

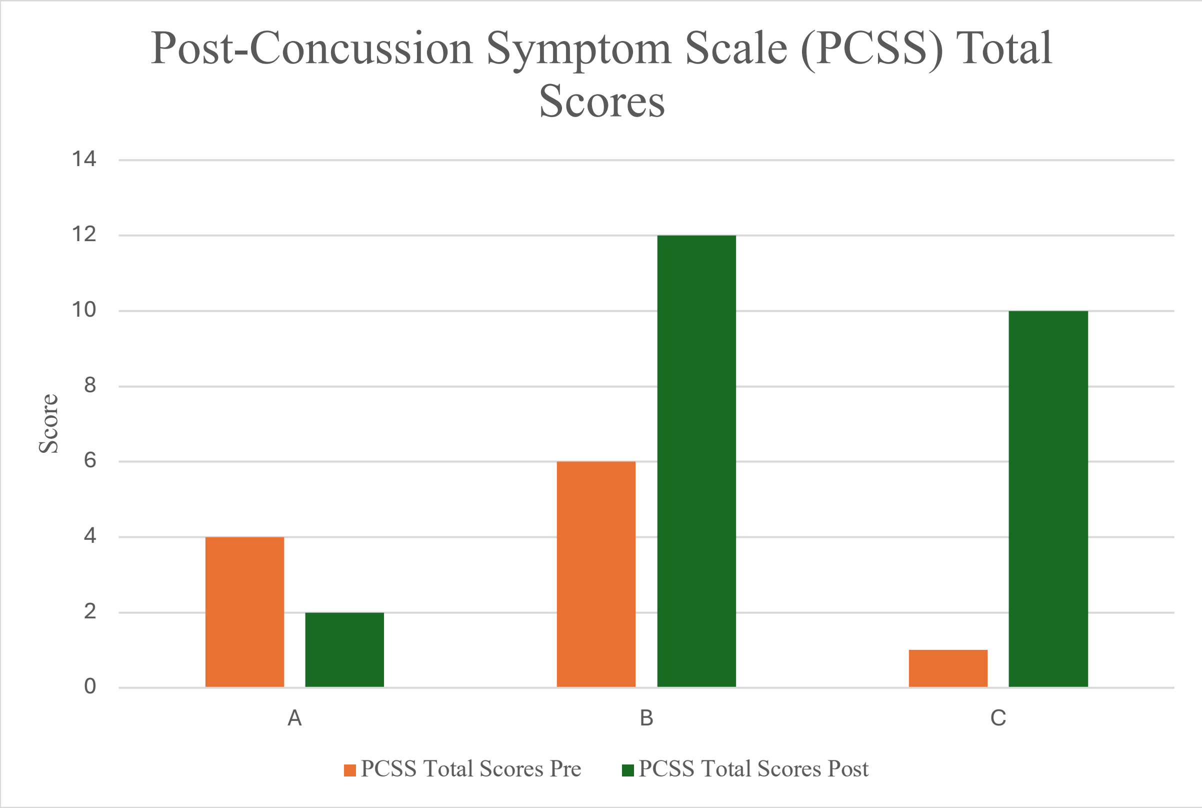
Participant C Post-Concussion Symptom Score Pre-and Post-Test



Note. Symptom scores represent self-reported symptom severity collected at pre- and post-intervention timepoints, with higher scores indicating greater symptom severity.

Figure 14

Post-Concussion Symptom Scale Score Pre- and Post-Test for all Participants



Note. Total symptom scores represent the sum of self-reported post-concussion symptom severity across all participants at pre- and post-intervention, with higher scores indicating greater symptom burden.

Chapter 5 Discussion

Neurotracker is a 3D multiple-object tracking (3D-MOT) training tool designed to improve perceptual-cognitive functions, such as attentional control, processing speed, and working memory, which are commonly impaired following concussion. As a result, it has been increasingly used as a rehabilitation modality in athletic populations, with previous research demonstrating improvements in cognitive performance in concussed individuals (Acquin et al., 2024; Corbin-Berrigan et al., 2020; Moen et al., 2018; Vater et al., 2021). In addition to cognitive deficits, individuals recovering from a concussion frequently report disruptions in sleep, which are known to negatively impact cognitive and perceptual functioning. Despite the established relationship between sleep and cognition, no studies have examined whether Neurotracker training influences sleep quality and quantity in concussed populations. Therefore, this pilot feasibility study aims to explore observational trends to determine whether Neurotracker may influence sleep quality and quantity, perceptual-cognitive performance, or perceived symptom severity in concussed athletes.

5.1) Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) affect sleep quality and quantity in concussed participants?

While all participants in the study reported an average of 420 minutes (7 hours) of perceived sleep, the actual sleep data indicate they received fewer than 420 minutes. Research indicates that regularly sleeping less than 420 minutes per night may negatively impact cardiovascular, physical, and mental health (Watson et al., 2015). Regarding pre-test scores obtained through the PSQI questionnaire and post-test scores obtained through the Polar Ignite watch, participant A was the only participant who reported their sleep accurately, while the remaining three participants overestimated the amount of sleep they were obtaining (perceived vs. actual sleep). These results are similar to those of Carter et al. (2020), who found that, on average, athletes tend to overestimate the amount of sleep they obtain. Based on the PSQI scores, both the pre-test and post-test data indicate that all three participants experience sleep disturbances and complications. The PSQI questionnaire is frequently used in clinical research to assess sleep disorders, and any score of 5 or higher indicates poor sleep quality (Carpi, 2025). All participants scored 5 or higher on both the pre-test and the post-test; participants B and C reported higher PSQI scores than their pre-test scores. Therefore, these observational trends suggest each participant in this study experienced an increase in poor sleep quality with the application of Neurotracker over the five weeks.

Regarding the sleep data from the Polar Ignite watches, a trend emerges: participants' sleep time and actual sleep time increase for two participants when comparing pre- and post-test data, whereas the opposite occurs for participant A. For all three participants, comparing pre- and post-test data, both REM sleep and deep sleep declined. This data suggests that, regardless of whether sleep quantity increased or decreased, sleep quality decreased and was affected by completing 10 Neurotracker sessions. This could also be reflected in changes in sleep cycles, especially for participants A and C, who showed a decrease in the number of sleep cycles in their post-test sleep data. These pilot results suggest that, with 10 Neurotracker sessions, an inverse relationship exists within this project: as sleep duration increases, sleep quality decreases. This may be similar to a training response experienced during physical training. A training response occurs when a new stimulus is introduced, leading to acute and chronic adaptations when the stimulus is repeated over time (Hawley, 2002). During the initial training stimulus, performance decreases and fatigue increases; depending on frequency, duration, progressive overload, specificity, and recovery, cellular and metabolic adaptations occur, and over time with prolonged exposure to the stimulus, performance increases and fatigue decreases (Hawley, 2002). Future research could investigate longitudinal changes in cognitive adaptations by increasing the number of

Neurotracker sessions per week and extending the study duration to further examine the effects of Neurotracker and the changes in sleep quality and quantity in concussed athletes.

5.2 Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) affect perceptual-cognitive performance in concussed participants?

Research examining 3D-MOT (Neurotracker) technology suggests that it improves attention and working memory and enhances perceptual-cognitive performance in populations who have suffered an mTBI (Lysenko-Martin et al., 2020). Furthermore, previous research has concluded that 3D-MOT performance may be linked to the severity of concussion symptoms (Lysenko-Martin et al., 2020). Following a Neurotracker session, each participant received a score representing their attention capacity during the session. The score represents the fastest speed at which the participant can correctly track the targets about 50% of the time during the task. When interpreting the speed scores obtained at the end of one session, the speed score adapts to provide the optimal level of challenge. In 3D-MOT programs such as Neurotracker, there may be a speed-accuracy trade-off. As one value increases, such as speed, accuracy tends to decrease as Neurotracker progressively overloads after each trial.

Participant A demonstrated the highest percentage of targets correct in the first session (91.25%) and maintained high accuracy (about 80–90%) throughout the 10 sessions. Over the same period, speed scores increased from 0.97 to 2.13, suggesting improved perceptual-cognitive processing. Participant B showed an overall increase in speed across sessions (0.99 - 2.66), indicating improved perceptual-cognitive capacity. The percentage of targets correctly identified remained high (75–91%) even at higher speeds. Participant C showed increased speed across sessions (0.81-2.79), suggesting improved perceptual-cognitive processing capacity, while the percentage of targets correct remained high (76–

87%) throughout training. All three participants improved during the 10 Neurotracker sessions, but two participants (B and C) completed three times the requested number of sessions. These observational trends suggest that 10 sessions of Neurotracker may improve perceptual-cognitive performance, while reductions in sleep quantity and quality were observed during the study period.

5.3 Does the application of a 10-period intervention of three-dimensional multiple object tracking (3D-MOT) impact perceived symptom severity?

As the PCSS scale is used to report the number and intensity of symptoms following a concussion, each participant's pre- and post-test scores were totalled. The higher the participant's score, the greater the severity of PCS. In both the pre-test and post-test data, all participants scored within the mild range (1-2) for experiencing a symptom, and no participant reported a level 3 or higher, which is considered moderate.

Previously, research suggested that post-concussion symptoms (PCS) typically resolve within 7 days post-injury, but current research indicates that PCS, such as headaches, fatigue, and dizziness, may persist for longer than previously expected (Eisenberg et al., 2014; Majerske et al., 2008). Participant A reported a decrease in the severity of perceived symptoms (pre-test score 4 and post-test score 2) but still reported experiencing 2 PCS symptoms in both the pre- and post-test data. Both participants B and C experienced an increase in the number of reported PCS and in their PCSS score. Participant B reported 5 symptoms pre-test and 11 post-tests, and their perceived symptom score increased from 6 in the pre-test to 12 in the post-test. Participant C reported 1 symptom pre-test and 7 symptoms post-test, and an increase in their PCSS score from a 1 in the pre-test to a 10 in the post-test.

As 3D-MOT programs such as Neurotracker require cognitive focus and activity, rest and recovery are essential for regulation in productivity, memory, alertness, and attentional focus. When sleep quality and quantity decrease, executive functions are impaired, cognitive control and attention decline, and sensory processing is compromised (Hyndych et al., 2025). Therefore, in concussed populations, individuals who experience sleep complications post-concussion experience more severe symptoms than those who do not (Magliato et al., 2022). Therefore, these observational trends suggest that 3D-MOT may affect perceived symptom severity and the number of PCS, but further research is needed.

5.4 Limitations

As this is a pilot feasibility study with only three subjects successfully completing all of the intervention and data collection, several limitations apply. First, the sample size is small; in future research, a larger sample would allow for statistical analysis and enable the detection of statistical significance. Second, even though the research assistant sent daily reminders to participants to complete their 3D-MOT sessions to help ensure adherence and keep them on track throughout the project's 7 weeks, many participants forgot and took longer than 5 weeks to complete all 10 sessions or completed three times the amount of Neurotracker sessions, which could have resulted in a learning bias. In future research, having participants travel to and commute to a facility to complete the sessions may improve adherence rates and ensure that participants complete the required number of sessions. This would also ensure that participants completed the sessions at a scheduled time, as they did not consistently do so at the same time of day or on the same day each week. Despite the small number of participants, this study provides insight into individual responses to Neurotracker and its effects on sleep quality and quantity, as well as PCS, which may help inform future research and directions.

5.5 Conclusions

The current study's goal was to determine if 3D-MOT technology impacted sleep quality and quantity in concussed adults. The data obtained in this feasibility study provide observational trend data that 3D-MOT technology improves perceptual-cognitive performance but affects sleep quality and perceived symptoms commonly experienced post-concussion. To date, this feasibility study is the first to examine 3D-MOT and its potential effects on sleep quality and quantity. As this study cannot draw conclusions due to its small sample size, it can only report observational trends suggesting that 3D-MOT therapy may negatively impact sleep quality and PCS symptoms in some individuals. Future research should examine the effects of longer-duration 3D-MOT therapies on sleep quality and quantity, as well as on PCS symptoms, in larger samples of concussed individuals.

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Appendix A

University of Victoria

Office of Research Services | Human Research Ethics Board
Michael Williams Building Rm B202 PO Box 1700 STN CSC Victoria BC V8W 2Y2 Canada
T 250-472-4545 | F 250-721-8960 | uvic.ca/research | ethics@uvic.ca

Certificate of Approval

PRINCIPAL INVESTIGATOR:	**Lynneth Stuart-Hill** (Supervisor)	**ETHICS PROTOCOL NUMBER:** Board member review - delegated	**24-0301**
PRINCIPAL APPLICANT:	**Angie Schaaf** **Master's student**	ORIGINAL APPROVAL DATE:	28-Feb-2025
		APPROVED ON:	28-Feb-2025
UVIC DEPARTMENT:	**Exercise Science, Physical and Health Education EPHE**	APPROVAL EXPIRY DATE:	27-Feb-2026

PROJECT TITLE: **Effect of concussion of sleep quality and quantity**

RESEARCH TEAM MEMBERS: **None**

DECLARED PROJECT FUNDING: **None**

DOCUMENTS INCLUDED IN THIS APPROVAL:
tcps2_core_certificate-1.pdf - 21-Jul-2024
PSQI.pdf - 21-Jul-2024
Polar Manual-1.pdf - 21-Jul-2024
oral-swab-saliva-collection-device-instructions-1-1.pdf - 21-Jul-2024
Neurotracker X 1(1).docx - 21-Jul-2024
Biosafety Cert Angie.pdf - 22-Jul-2024
Biosafety Emergency Cert.pdf - 22-Jul-2024
Written Instructions for using NeuroTrackerX the first time(2).docx - 22-Jul-2024
Post-Concussion Symptom Scale (PCSS).pdf - 09-Jan-2025
Mobile Application.docx - 10-Jan-2025
POLAR ELECTRO END.docx - 10-Jan-2025
Passive.jpg - 10-Jan-2025
NEURO Glasses.jpeg - 10-Jan-2025
Samsung Tablet.jpg - 10-Jan-2025
Screening Questions.docx - 10-Jan-2025
Email Draft to Coaches 2025.docx - 12-Jan-2025
Email Draft_Athletes. 2025 non eligible.docx - 12-Jan-2025
Email Draft_Athletes. 2025. copy.docx - 12-Jan-2025
Informed Consent 2025.doc - 12-Jan-2025
Email Draft for Eligible Participants.docx - 12-Jan-2025
Biosafety Registration 2025.pdf - 24-Feb-2025

Conditions of approval

This Certificate of Approval is valid for the above term provided there is no change in the protocol.

Amendments
To make changes to the approved research procedure in your study, please submit "Amendments" or "Annual renewal with amendments" form. You must receive research ethics approval before proceeding with your amended protocol.

Renewals
Your ethics approval must be current for the period during which you are recruiting participants or collecting data. To renew your protocol, please submit a “Request for Renewal” form before the expiry date on your certificate. You will be sent an emailed reminder prompting you to renew your protocol about six weeks before your expiry date.

Project Closures
When you have completed all data collection activities and will have no further contact with participants, please notify the Human Research Ethics Board by submitting a “Notice of Project Completion” form.

Certification
This certifies that the UVic Human Research Ethics Board has examined this research protocol and concluded that, in all respects, the proposed research meets the appropriate standards of ethics as outlined by the University of Victoria's policies for research involving human participants. Dr. Sandra Gibbons, Chair, Human Research Ethics Board Dr. Cindy Holder, Vice-chair, Human Research Ethics Board

Certificate Issued On: 28-Feb-2025

Appendix B

PITTSBURGH SLEEP QUALITY INDEX (PSQI)

INSTRUCTIONS: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

1. During the past month, when have you usually gone to bed at night?

   USUAL BED TIME ____________________

2. During the past month, how long (in minutes) has it usually take you to fall asleep each night?

   NUMBER OF MINUTES ____________________

3. During the past month, when have you usually gotten up in the morning?

   USUAL GETTING UP TIME ____________________

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed.)

   HOURS OF SLEEP PER NIGHT ____________________

INSTRUCTIONS: For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you...

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(a) ...cannot get to sleep within 30 minutes	☐	☐	☐	☐
(b) ...wake up in the middle of the night or early morning	☐	☐	☐	☐
(c) ...have to get up to use the bathroom	☐	☐	☐	☐
(d ...cannot breathe comfortably	☐	☐	☐	☐
(e) ...cough or snore loudly	☐	☐	☐	☐
(f) ...feel too cold	☐	☐	☐	☐
(g) ...feel too hot	☐	☐	☐	☐
(h) ...had bad dreams	☐	☐	☐	☐
(i) ...have pain	☐	☐	☐	☐

(j) Other reason(s), please describe

____

____

How often during the past month have you had trouble sleeping because of this?	☐	☐	☐	☐

	Very good	Fairly good	Fairly bad	very bad
6. During the past month, how would you rate your sleep quality overall?	☐	☐	☐	☐

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
7. During the past month, how often have you taken medicine (prescribed or "over the counter") to help you sleep?	☐	☐	☐	☐
8. During the past month, how often have you had trouble staying awake while driving, eating meals, or engaging in social activity?	☐	☐	☐	☐

	No problem at all	Only a very slight problem	Somewhat of a problem	A very big problem
9. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	☐	☐	☐	☐

	No bed partner or roommate	Partner/ roommate in other room	Partner in same room, but not same bed	Partner in same bed
10. During the past month, how much of a problem has it been for you to keep up enough enthusiasm to get things done?	☐	☐	☐	☐

If you have a roommate or bed partner, ask him/her how often in the past month you have had...

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(a) ...loud snoring	☐	☐	☐	☐
(b) ...long pauses between breaths while asleep	☐	☐	☐	☐
(c) ...legs twitching or jerking while you sleep	☐	☐	☐	☐
(d) ...episodes of disorientation or confusion during sleep	☐	☐	☐	☐
(e) Other restlessness while you sleep; please describe	☐	☐	☐	☐

SCORING INSTRUCTIONS FOR THE PITTSBURGH SLEEP QUALITY INDEX:

The Pittsburgh Sleep Quality Index (PSQI) contains 19 self-rated questions and 5 questions rated by the bed partner or roommate (if one is available). Only self-rated questions are included in the scoring. The 19 self-rated items are combined to form seven "component" scores, each of which has a range of 0-3 points. In all cases, a score of "0" indicates no difficulty, while a score of "3" indicates severe difficulty. The seven component scores are then added to yield one "global" score, with a range of 0-21 points, "0" indicating no difficulty and "21 " indicating severe difficulties in all areas.

Scoring proceeds as follows:

Component 1: Subjective sleep quality

Examine question #6, and assign scores as follows:

Response	Component 1 score
"Very good"	0
"Fairly good"	1
"Fairly bad"	2
"Very bad"	3

Component 1 score:________

Component 2: Sleep latency

1. Examine question #2, and assign scores as follows:

Respo\nse	Score
≤15 minutes	0
16-30 minutes	1
31-60 minutes	2
> 60 minutes	3

Question #2 score: ________

2. Examine question #5a, and assign scores as follows:

Response	Score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Question #5a score: ________

3. Add #2 score and #5a score

Sum of #2 and #5a: ________

4. Assign component 2 score as follows:

Sum of #2 and #5a	Component 2 score
0	0
1-2	1
3-4	2
5-6	3

Component 2 score:________

Component 3: Sleep duration

Examine question #4, and assign scores as follows:

Response	Component 3 score
> 7 hours	0
6-7 hours	1
5-6 hours	2
< 5 hours	3

Component 3 score:________

Component 4: Habitual sleep efficiency

1. Write the number of hours slept (question #4) here:________
2. Calculate the number of hours spent in bed:

    Getting up time (question #3):________

    Bedtime (question #1):________

    ____

    Number of hours spent in bed:________

3. Calculate habitual sleep efficiency as follows:

    (Number of hours slept/Number of hours spent in bed) X 100 = Habitual sleep efficiency (%)

    (________/________) X 100 = %

4. Assign component 4 score as follows:

Habitual sleep efficiency %	Component 4 score
> 85%	0
75-84%	1
65-74%	2
< 65%	3

Component 4 score:________

Component 5: Step disturbances

1. Examine questions #5b-5j, and assign scores for each question as follows:

Response	Score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

5b score: ________

5c score: ________

5d score: ________

5e score: ________

5f score: ________

5g score: ________

5h score: ________

5i score: ________

5j score: ________

2. Add the scores for questions #5b-5j:

Sum of #5b-5j: ________

3. Assign component 5 score as follows:

Sum of #5b-5j	Component 5 score
0	0
1-9	1
10-18-4	2
19-27	3

Component 5 score: ________

Component 6: Use of sleeping medication

Examine question #7 and assign scores as follows:

Response	Component 6 score
Not during the past month	0
Less than once a week	1
Once or twice a week	2
Three or more times a week	3

Component 6 score: ________

Component 7: Daytime dysfunction

1. Examine question #8, and assign scores as follows:

Response	**Score**
Never	0
Once or twice	1
Once or twice each week	2
Three or more times each week	3

Question#8 score: ________

2. Examine question #9, and assign scores as follows:

Response	**Score**
No problem at all	0
Only a very slight problem	1
Somewhat of a problem	2
A very big problem	3

Question #9 score: ________

3. Add the scores for question #8 and #9:

Sum of #8 and #9: ________

4. Assign component 7 score as follows:

Sum of #8 and #9	**Component 7 score**
0	0
1-2	1
3-4	2
5-6	3

Component 7 score: ________

Global PSQI Score

Add the seven component scores together:

Global PSQI Score: ________

Appendix C

Post-Concussion Symptom Scale (PCSS)

Intermountain Health

Name: ______________________ DOB: ______________ Date: ______________

Instructions: For each item, indicate how much the symptom has bothered you over the past 2 days.

	Symptoms	None	Mild		Moderate		Severe	
Physical	1 Headache	0	1	2	3	4	5	6
	2 Nausea	0	1	2	3	4	5	6
	3 Vomiting	0	1	2	3	4	5	6
	4 Balance problems	0	1	2	3	4	5	6
	5 Dizziness	0	1	2	3	4	5	6
	6 Fatigue	0	1	2	3	4	5	6
	7 Sensitivity to light	0	1	2	3	4	5	6
	8 Sensitivity to noise	0	1	2	3	4	5	6
	9 Numbness/Tingling	0	1	2	3	4	5	6
Thinking	10 Feeling mentally foggy	0	1	2	3	4	5	6
	11 Feeling slowed down	0	1	2	3	4	5	6
	12 Difficulty concentrating	0	1	2	3	4	5	6
	13 Difficulty remembering	0	1	2	3	4	5	6
Sleep	14 Drowsiness	0	1	2	3	4	5	6
	15 Sleeping less than usual	0	1	2	3	4	5	6
	16 Sleeping more than usual	0	1	2	3	4	5	6
	17 Trouble falling asleep	0	1	2	3	4	5	6
Emotional	18 Irritability	0	1	2	3	4	5	6
	19 Sadness	0	1	2	3	4	5	6
	20 Nervousness	0	1	2	3	4	5	6
	21 Feeling more emotional	0	1	2	3	4	5	6
	TOTAL_____/126							

Do you have any visual problems? ☐ Yes ☐ No

Do these symptoms worsen with:

- Physical Activity ☐ Yes ☐ No ☐ Not applicable
- Thinking/Cognitive Activity ☐ Yes ☐ No ☐ Not applicable

Over the past 2 days, my daily activity level has been _____% of normal.

If "YES" to any visual problems, further qualify with the Convergence Insufficiency Symptom Survey.

Permission from Wolters Kluwer; Lovell and Collins, *Journal of Head Trauma and Rehabilitation* 1998;13:9-26. Baseline levels should be taken and compared.

Appendix D

Date:

Name:

Age:

Sex:

1. Have you received a concussion between January 1, 2020, and the current date?

2. Was the concussion self-diagnosed, or was it diagnosed by a healthcare practitioner?

3. Please answer the following questions with a YES or NO.

Do you have severe ADHD?

Do you have severe anxiety?

Do you have any neurological diseases?

Do you have (currently) any sleep impairments and/or complications?

Do you use narcotics?

Have you sustained one or more severe traumatic brain injuries?

Appendix E

University of Victoria

Participant Consent Form

Changes in Sleep Quality and Quantity in Concussed Athletes with the Application of 3D- Multiple Object Tracking (3D-MOT)
You are invited to participate in a study entitled Sleep Quality and Quantity, which is being conducted by Angelina Schaaf. Your participation is voluntary, and you are not obligated to participate in this study.

Angelina is a Graduate student in the Department of Exercise Science, Physical & Health Education at the University of Victoria. If you have further questions, you may contact her at ascha674@gmail.com.
As a Graduate student, I am required to conduct research as part of my degree requirements in Kinesiology. I am conducting it under the supervision of Lynneth Stuart Hill and co-supervisor Brian Christie. You may contact Dr. Lynneth Stuart Hill at 250-721-7884 and/or Dr. Brian Christie at 250-472-4244.

Purpose and Objectives
Neurotracker is a noninvasive 3D visual exercise program that uses multiple object tracking (MOT) to improve cognitive abilities such as attention, executive function, and awareness. In Neurotracker, you visually track targets in a 3D environment. The exercise adjusts speed and difficulty based on your level.

The purpose of this research project is to examine whether 3D-MOT technology, such as Neurotracker, helps with sleep quantity and quality in concussed participants.

Importance of this Research
Research of this type is important because currently, limited research has examined if technology such as 3D-MOT, helps improve sleep quality and quantity in concussed participants. Research to date has examined how 3D-MOT had been beneficial in concussed pediatric populations as well as a potential future clinical marker for recovery. Therefore, this research serves importance for future research.

Participants Selection
You are being asked to participate in this study if you are an active adult (18-35 years old) who participates in sport and has sustained a concussion **on or after January 1st, 2020**. Individuals who are both symptomatic and asymptomatic for concussions are eligible to participate. Diagnosis of concussion by an athletic trainer or other health professional (MD, Physiotherapist, Nurse practitioner, etc.) is preferred but not necessary. A screening interview will take place to determine eligibility. The exclusion criteria are the following: severe ADHD, severe anxiety, neurological diseases, sleep impairments/ complications, use of narcotics, and severe traumatic brain injury.

What is involved
Suppose you consent to participate in this research voluntarily. Your participation will include approximately 30 minutes to an hour a week for 5 weeks, two sessions of Neurotracker per week, and a weekly questionnaire assessing sleep quality.

Before and after the intervention, sleep pre-test and post-test data will be collected for three days; the total study time is 7 weeks. The intervention is conducted at the participant's private residence. Participants will also complete a sleep and symptom questionnaire pre- and post-test. If eligible, all equipment (Polar Ignite watches, Samsung tablet, 3D glasses, and charging cables) will be provided.

Participants may be asked if they consent to having their photograph taken and used for presentations and/or thesis figures related to this work. You will be asked to sign a consent form for video/photograph if you agree. Participants in any photographs will not be identified by name, or research group assignment, to help maintain patient confidentiality.

Inconvenience
Participation in this study may cause some inconvenience to you, including travelling to the University of Victoria for equipment pickup and drop off, wearing a watch during sleep, and finding time to complete the sleep questionnaire. There are two sessions per week, approximately 20 minutes per week for Neurotracker. However, as this study is conducted in your private residence, inconveniences are reduced.

If you need assistance with the equipment, such as troubleshooting, please contact the lead researcher.

Risks
There are some potential risks to you by participating in this research as it includes travelling to and from the University of Victoria.

Benefits
The potential benefits of your participation in this research include the state of society, the state of new knowledge, and the participants. As previously stated, limited research has studied the effects of 3D-MOT technology and how it may impact sleep quality and quantity. Current research has examined how 3D-MOT is an effective clinical marker of recovery, and it is well-known that sleep is imperative for physical and cognitive recovery. Participation in this research may provide new or alternative treatment plans for concussed participants who report poor sleep quality and quantity. Participation in this research might help improve cognitive-perceptual skills for participants and the athletic population.

Voluntary Participation
Your participation in this research is entirely voluntary. If you decide to participate, you may withdraw at any time without any consequences or explanation. Collected data will not be used if a participant withdraws from the study.

If you sustain another concussion during the study, please contact the lead researcher immediately. If the concussion is not severe, please continue participating in the study.

If you have sustained a severe concussion, please get in touch with the lead researcher, as you will have to withdraw from the study.

Anonymity
Due to the nature of this study, there are limits to protecting participants' anonymity. The researcher will be interviewing participants and obtaining personalized identifying information for data collection, so participant anonymity may be limited. To protect all self-identifying information, each participant will receive a code. All attempts will be made to ensure personalized data remains anonymous.

Confidentiality
Your confidentiality and the confidentiality of the data will be protected by storing all data in a password protected computer program and on encrypted data sticks. All hardcopy paper files will be stored in a locked cabinet in which only authorized personals have access to. All hardcopy information will have no participant identifying information as participates will receive a randomly generated number. Anonymized data will also be shared with Cognisens, the maker of Neurotracker. The researcher is licensed to use Neurotracker for research.

Dissemination of Results
It is anticipated that the results of this study will be shared with others in the following ways:
1. Directly to the participants via PowerPoint at the end of study if requested.
2. Thesis defense
3. Presentation at scholarly meetings.
4. Published article

Disposal of Data
Data from this study will be stored in locked filing cabinets and password-protected computer files for 10 years after which, all hard copies of the data collected relating to the study will be shredded. Data stored on encrypted data sticks will be erased and deleted.

Use of Laboratory Materials Statement

I, ______________________________ (participant name) agree to care for the borrowed laboratory equipment (Samsung tablet, Polar Ignite Watches, 3D glasses, and charging cables), and return all the equipment back to the laboratory after the cessation of the current research study.

Contacts
Individuals that may be contacted regarding this study include:

Angelina Schaaf	Email: Ascha674@gmail.com Aschaaf@uvic.ca
Dr. Lynneth Sturat Hill	Phone: (250)-721-7884 Email: lstuhill@uvic.ca
Dr Brian Christie	Phone: (250)-472-4244 Email: brain64@uvic.ca

In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Human Research Ethics Office at the University of Victoria (250-472-4545 or ethics@uvic.ca).

I understand that the data gathered for this study is for research purposes only and not for the diagnosis of health conditions. _____________(Participant initials)

I understand that my individual research data from this study will not be released to me. _________ (Participant initials)

Your signature below indicates that you understand the above conditions of participation in this study, that you have had the opportunity to have your questions answered by the researchers, and that you consent to participate in this research project.

Name of Participant	_Signature_	_Date_

Visually Recorded Images/Data Participant or parent/guardian to provide initials, *only if you consent*:

- Photos may be taken of me for: Analysis _______ Dissemination* ________
- Videos may be taken of me for: Analysis _______ Dissemination* _________

Future Use of Data

I consent to the use of my data in future research: _______________(Participant to provide initials)

I **do not** consent to the use of my data in future research: _______________(Participant to provide initials)

I consent to be contacted in the event my data is requested for future research: _______________(Participant to provide initials)

A copy of this consent will be left with you, and a copy will be taken by the researcher.

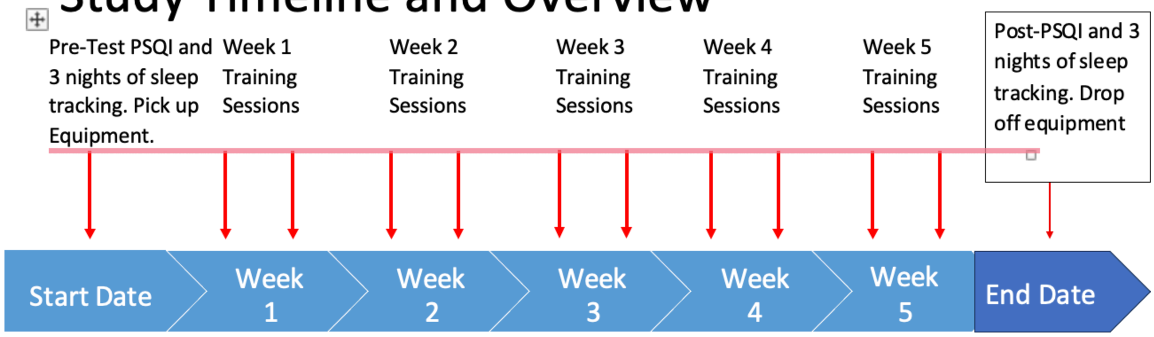
Appendix F

Using the NeuroTrackerX Program at home for participation in a research study.

Visual and Written Instructions

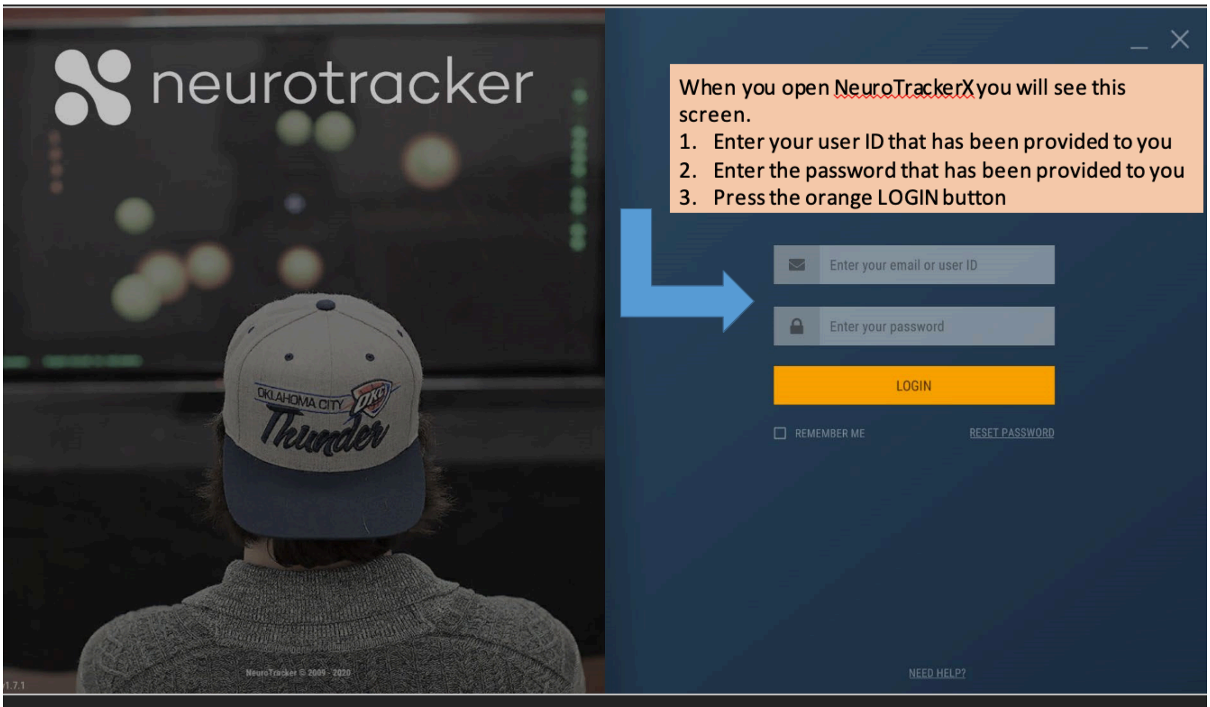
Angelina Schaaf. Email: Angelinas@uvic.ca. Phone: (403)999-3950

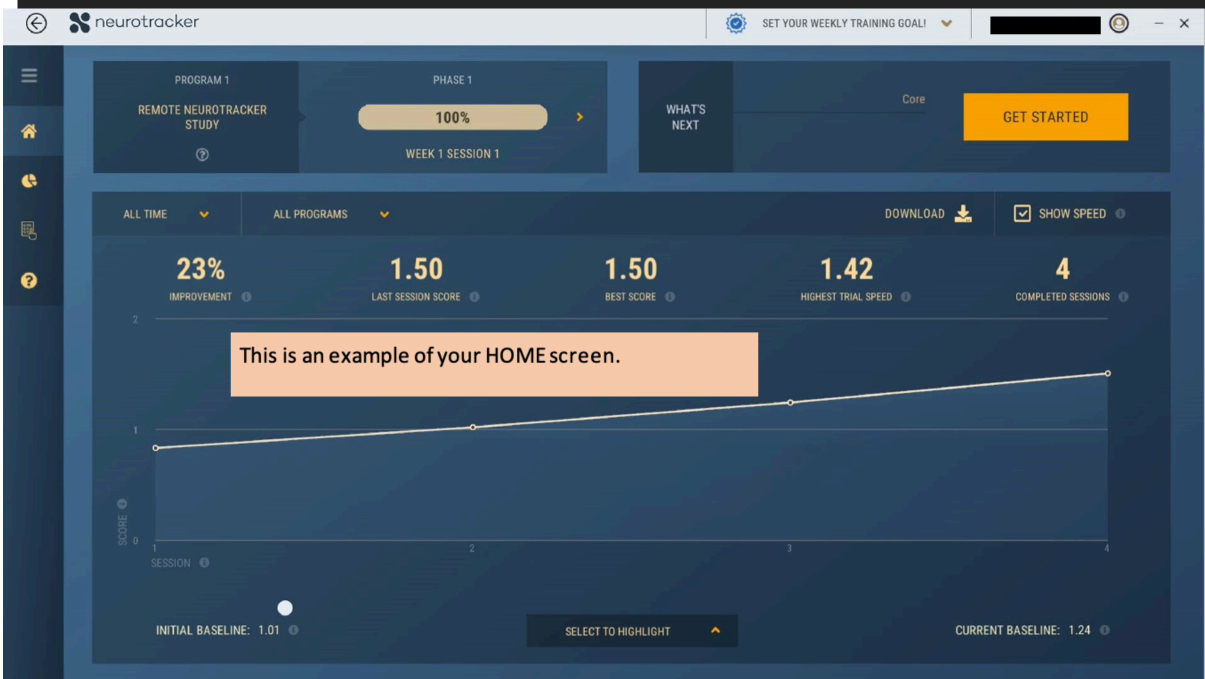
Study Timeline and Overview

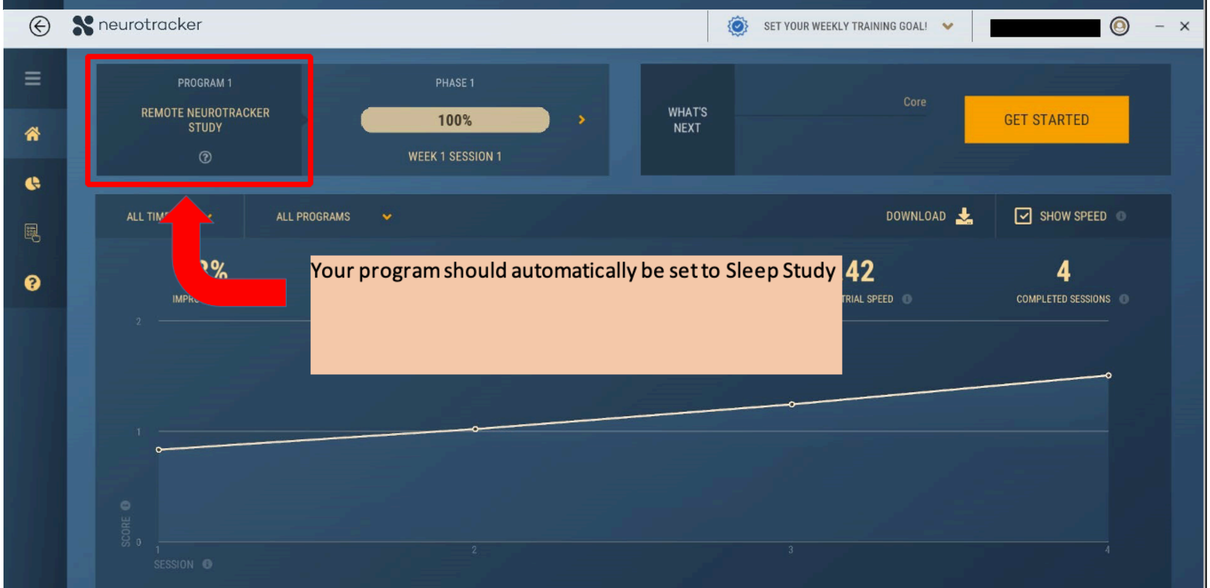


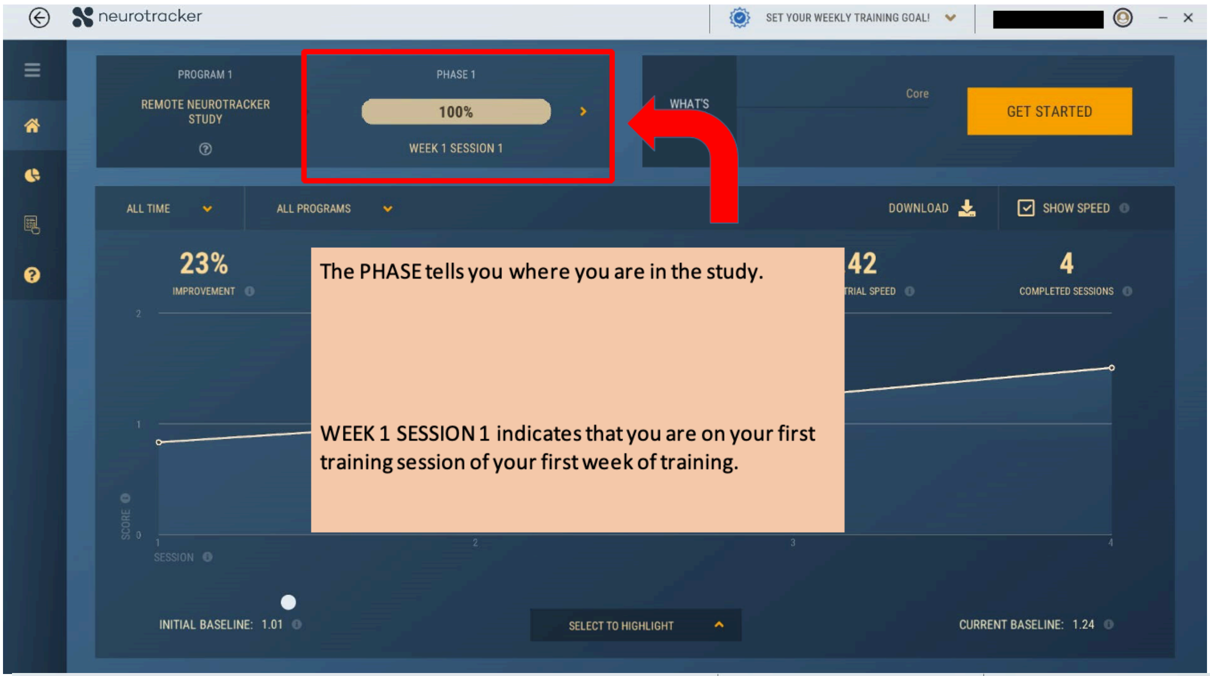
- This study involves 10 sessions over 5 weeks (2 training days per week)

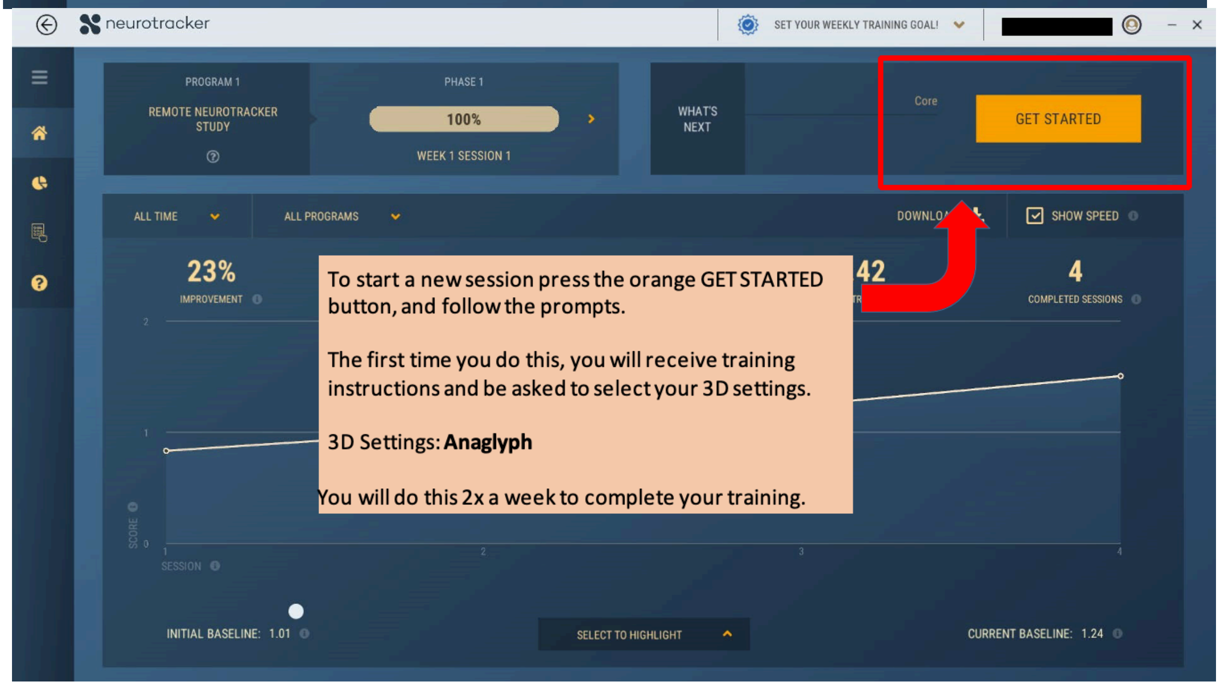
Navigating NeuroTrackerX

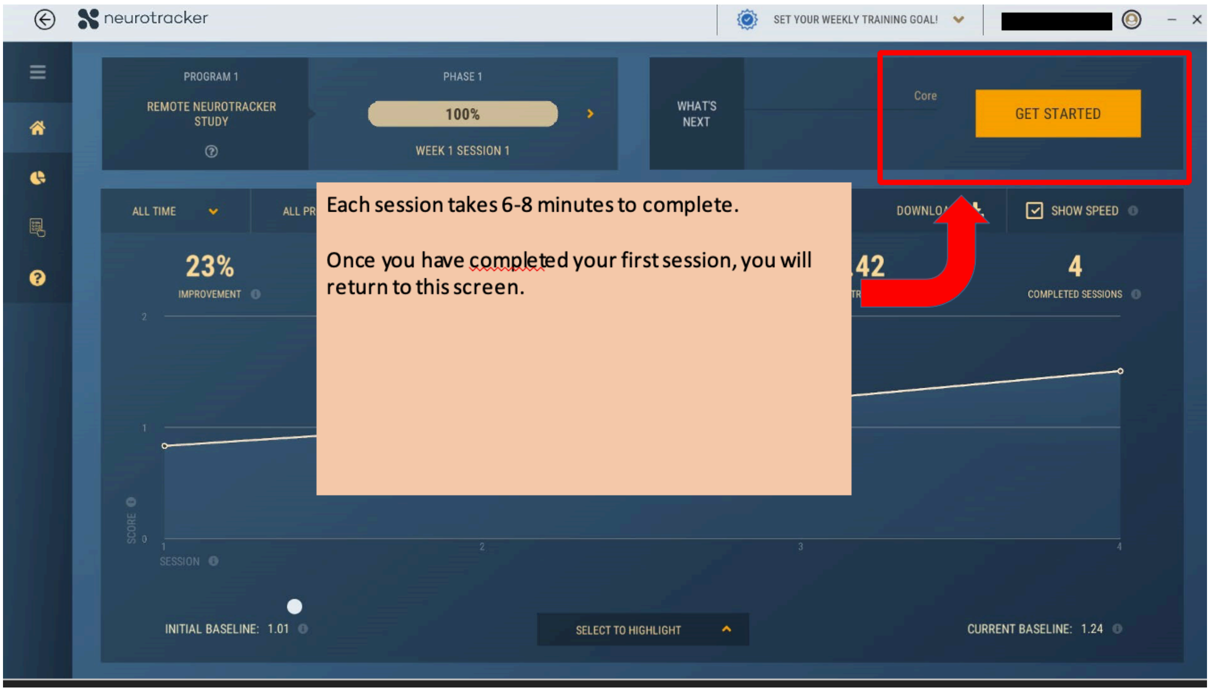

neurotracker
When you open NeuroTrackerX you will see this screen.
1. Enter your user ID that has been provided to you
2. Enter the password that has been provided to you
3. Press the orange LOGIN button
Enter your email or user ID
Enter your password
LOGIN
REMEMBER ME
RESET PASSWORD
NEED HELP?

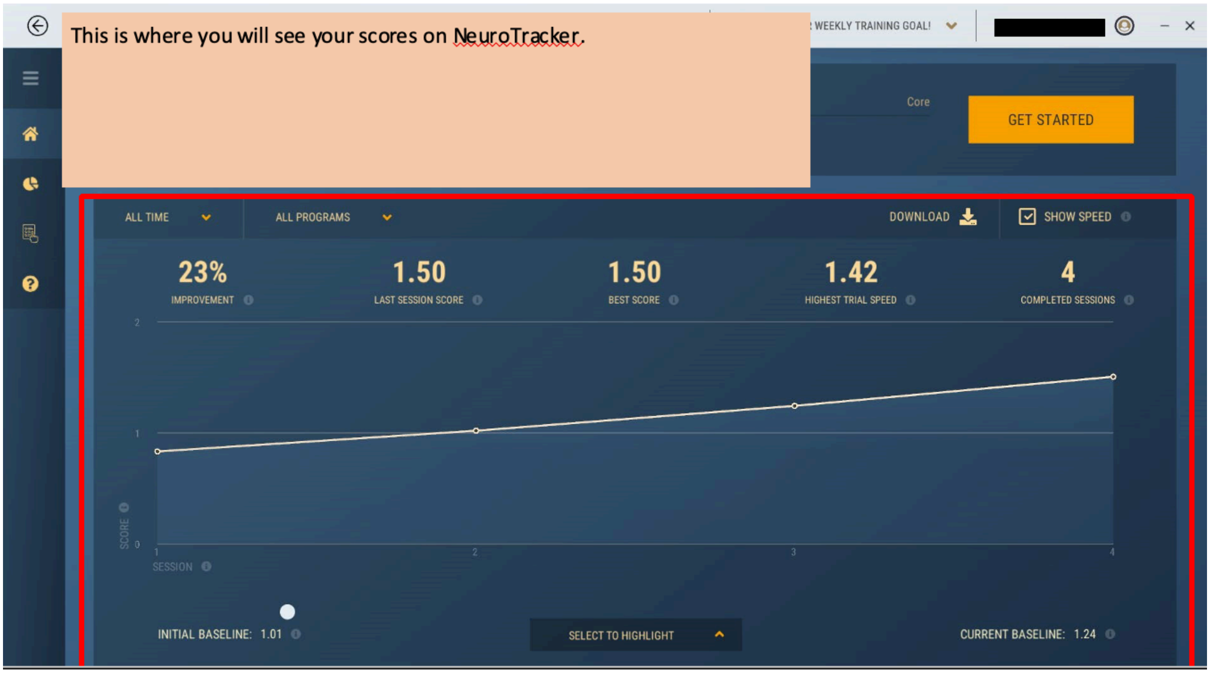

neurotracker
SET YOUR WEEKLY TRAINING GOAL!
[redacted]
PROGRAM 1
REMOTE NEUROTRACKER STUDY
PHASE 1
100%
WEEK 1 SESSION 1
WHAT'S NEXT
Core
GET STARTED
ALL TIME
ALL PROGRAMS
DOWNLOAD
SHOW SPEED
23%
IMPROVEMENT
1.50
LAST SESSION SCORE
1.50
BEST SCORE
1.42
HIGHEST TRIAL SPEED
4
COMPLETED SESSIONS
This is an example of your HOME screen.
SCORE
SESSION
INITIAL BASELINE: 1.01
SELECT TO HIGHLIGHT
CURRENT BASELINE: 1.24

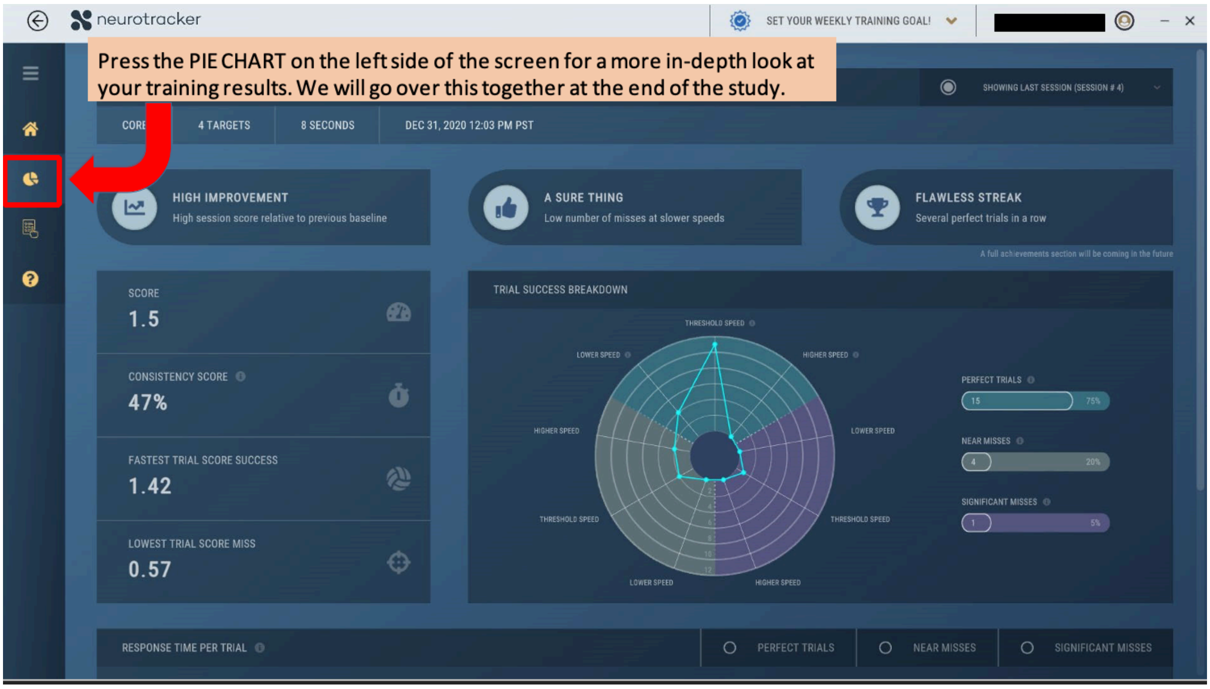

neurotracker
SET YOUR WEEKLY TRAINING GOAL!
[redacted]
PROGRAM 1
REMOTE NEUROTRACKER STUDY
PHASE 1
100%
WEEK 1 SESSION 1
WHAT'S NEXT
Core
GET STARTED
DOWNLOAD
SHOW SPEED
Your program should automatically be set to Sleep Study
4
COMPLETED SESSIONS
SCORE
SESSION


neurotracker
SET YOUR WEEKLY TRAINING GOAL!
[redacted]
PROGRAM 1
REMOTE NEUROTRACKER STUDY
PHASE 1
100%
WEEK 1 SESSION 1
WHAT'S
Core
GET STARTED
ALL TIME
ALL PROGRAMS
DOWNLOAD
SHOW SPEED
23%
IMPROVEMENT
The PHASE tells you where you are in the study.
WEEK 1 SESSION 1 indicates that you are on your first training session of your first week of training.
42
TRIAL SPEED
4
COMPLETED SESSIONS
SCORE
SESSION
INITIAL BASELINE: 1.01
SELECT TO HIGHLIGHT
CURRENT BASELINE: 1.24


neurotracker
SET YOUR WEEKLY TRAINING GOAL!
[redacted]
PROGRAM 1
REMOTE NEUROTRACKER STUDY
PHASE 1
100%
WEEK 1 SESSION 1
WHAT'S NEXT
Core
GET STARTED
ALL TIME
ALL PROGRAMS
SHOW SPEED
23%
IMPROVEMENT
To start a new session press the orange GET STARTED button, and follow the prompts.
The first time you do this, you will receive training instructions and be asked to select your 3D settings.
3D Settings: Anaglyph
You will do this 2x a week to complete your training.
42
4
COMPLETED SESSIONS
SCORE
SESSION
INITIAL BASELINE: 1.01
SELECT TO HIGHLIGHT
CURRENT BASELINE: 1.24


neurotracker
SET YOUR WEEKLY TRAINING GOAL!
[redacted]
PROGRAM 1
REMOTE NEUROTRACKER STUDY
PHASE 1
100%
WEEK 1 SESSION 1
WHAT'S NEXT
Core
GET STARTED
ALL TIME
SHOW SPEED
Each session takes 6-8 minutes to complete.
Once you have completed your first session, you will return to this screen.
23%
IMPROVEMENT
4
COMPLETED SESSIONS
SCORE
SESSION
INITIAL BASELINE: 1.01
SELECT TO HIGHLIGHT
CURRENT BASELINE: 1.24


This is where you will see your scores on NeuroTracker.
WEEKLY TRAINING GOAL!
[redacted]
Core
GET STARTED
ALL TIME
ALL PROGRAMS
DOWNLOAD
SHOW SPEED
23%
IMPROVEMENT
1.50
LAST SESSION SCORE
1.50
BEST SCORE
1.42
HIGHEST TRIAL SPEED
4
COMPLETED SESSIONS
SCORE
SESSION
INITIAL BASELINE: 1.01
SELECT TO HIGHLIGHT
CURRENT BASELINE: 1.24



Written Instructions for using NeuroTrackerX the first time.

1. Open NeuroTrackerX and enter your UserID and Password. Both of these will have been emailed to you.
2. A pop-up window will appear with the Terms and Conditions of Use. You must agree to these terms to continue using the program.
3. A pop-up window will appear to explain the training dashboard, program progression and changing profile settings. Click 'NEXT' to move through the explanations.
4. Select 'GET STARTED' in the upper right corner of the screen to begin your first session!
5. Enter your 3D settings (ANAGLYPH)
6. Follow the instructions in the 'HOW TO TRAIN' pop-up, and follow the prompts to begin your session
7. After each session, you will see your score and be able to enter any comments. Feel free to include anything you noticed during your session (I was tired, distracted by my pet, there was construction outside etc.)
8. Congratulations on completing your first session!
9. Once you have finished your session, you are done for the day! Be sure to do this 2 times per week (for a total of 10 sessions over the 5 weeks). If you have questions about this, please contact the researcher.

TIPS for Using NeuroTrackerX

SETTING-UP

- Your computer monitor should be at a height such that your eyes are level with the middle of the screen. If you are sitting to high or too low, the 3D may be distorted.

- You should sit at a distance equal to the diagonal of your screen size.
- The 3D may be distorted if you sit too close or too far.
- Example: If you are using a 24" monitor, sit aprox. 24" away

- You should sit in a quiet area, free from distractions while engaging in NeuroTracker training
- Turn off music, silence your phone, turn off the TV
- It is OK to have coffee/tea and snacks with you during the sessions

- We do NOT recommend putting the 3D glasses on prior to your screen being in 3D. This can cause dizziness and headaches. You are welcome to wear the 3D glasses overtop of your regular glasses.

During the Sessions:

TIPS for Using NeuroTrackerX

- To select targets, you can use the number pad on your keyboard, or you can use your mouse to select the targets
- To deselect a target, either type its assigned number again, or click on the target again
- Once you have selected 4 targets, you will not be able to change your answer
- To PAUSE: press the ESC key. Note: the session will only pause once the balls are no longer moving
- To QUIT: press the ESC key and press quit. If you did not finish your session, do not save it. You will have to redo this session.
- Stare at the centre dot in the middle of the screen, and do your best to use your peripheral vision to follow the targets. This will likely be very challenging at first!
- If it starts out too fast, just do your best and do not fret. Soon the program will learn the perfect speed for you!
- Have fun! You are not expected to get everything right. The system works to challenge you, so you should expect to have a range of successes and failures.

Analyzing your results:

TIPS for Using NeuroTrackerX

- Following completion of all your training sessions, together we will go over your progress throughout the sessions
- On your dashboard (main screen), you will begin to see your scores as you complete sessions
- Your SCORE from each session gives you an idea of your "Speed Threshold". A Speed Threshold is the speed at which you can successfully track the targets about 50% of the time. A higher score means that you can track the targets at a faster rate. The goal of this program is to see how high you can get your score.
- **Initial Baseline**: This is the average score of your first three sessions
- **Current Baseline**: This is the average score of your most recent three sessions (This will only appear once you have done at least 4 sessions)
- **% Improvement**: This compares your current baseline to your initial baseline. Sometimes it will be positive (you scored higher), and sometimes it will be negative (you scored lower).
- **Best Score**: This is your highest session score
- **Highest Trial Speed**: This is your highest trial speed that you have successfully tracked the targets

Creating a Training Schedule: