SENSORY DYSREGULATION IN POST TRAUMATIC STRESS DISORDER

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SENSORY DYSREGULATION

IN

INDIVIDUALS WITH POST TRAUMATIC STRESS DISORDER

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## Lay Abstract

Sensory processing is defined as how an individual apprehends sensory details from the outside world and from feelings within their body and organizes them to make sense of the environment around them. Understanding sensory processing is crucial given its impact on how individuals interact with the environment and manage stress. This thesis examines how sensory processing is altered among individuals with posttraumatic stress disorder (PTSD). Our findings suggest that individuals who have been exposed to a traumatic event and/ or have diagnosed with PTSD experience a heightened sensitivity to their external environment and weak sensitivity to their internal body sensations, leading, for example, to “out-of-body” sensations and to difficulty completing tasks in their daily lives. In addition, these results indicate that performance on a test of mental abilities investigating seeing and understanding space influences the relations between out-of-body experiences and difficulty with everyday functioning. On balance, these findings point towards the urgent need for urgent research surrounding sensory processing issues experienced by individuals who are trauma exposed/diagnosed with PTSD.

**Abstract**

Sensory processing is an umbrella term used to describe the process by which an individual organizes sensory information from both their external and internal world to interact effectively within their physical, emotional and social environments (Costa-López et al., 2021). Well-established research in autism spectrum disorder (ASD) has found significant impairments in the quality of life of individuals who experience sensory processing dysfunction (Costa-López et al., 2021; DuBois et al., 2017). Notably, nascent research suggests that sensory processing dysfunction may also underlie, in part, the cognitive, emotional and overall daily impairment experienced by those with neuropsychiatric conditions, including posttraumatic stress disorder (PTSD) (Boogert er al., 2022). Here, basic principles of cognition and of emotional regulation suggest that integration of information from our senses, known as multisensory integration, to form an understanding of our environment is crucial for appropriate behavioural response to stressors. In the present thesis, we investigated the effects of sensory processing dysfunction on daily functioning in psychological-trauma-exposed samples in relation to the domains of dissociation and cognition. This thesis contributes key findings to the PTSD literature by first providing an overview of the current neural and behavioural understanding of sensory processing in PTSD, as well as providing a summation of current somatic therapeutic interventions. Secondly, empirical evidence was found that individuals who are trauma exposed/ diagnosed with PTSD self-report higher sensory sensitivity in raw and in affective sensory processing. Finally, sensory processing and its relation to cognitive functioning among trauma-exposed individuals was investigated. The results of this study suggest that measures of visuospatial processing and of spatial working memory may moderate, in part, of the relation between dissociation and functional impairment. On balance, these findings suggest that that alterations in sensory processing alterations among trauma-exposed populations warrant further investigation to address the relative paucity of

research that currently exists within this critical area of functioning necessary to navigate the social world.

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I would like to dedicate this work to my parents Maria and Santino Parise and my brother Victor Parise as well. Without your support I would not be the woman and researcher I am today. I owe much of my success to having such a strong foundation under me. You are all the light leading me down the path that we call life. You are all an inspiration to me.

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## List of Abbreviations

| | |
|---|---|
| **ACC** | Anterior Cingulate Cortex |
| **ASD** | Autism Spectrum Disorder |
| **BootLLCI** | Bootstrapped Lower-Level Confidence Interval |
| **Boot ULCI** | Bootstrapped Upper-Level Confidence Interval |
| **CAPS-5** | Clinician Administered PTSD Scale for DSM-5 |
| **DERS** | Difficulties in Emotion Regulation Scale |
| **DLPFC** | Dorsolateral Prefrontal Cortex |
| **DMN** | Default Mode Network |
| **DSM-5** | Diagnostic and Statistical Manual of Mental Disorders |
| **EEG** | Electroencephalogram |
| **EMDR** | Eye Movement Desensitization and Reprocessing |
| **fMRI** | Functional Magnetic Resonance Imaging |
| **GAD** | Generalized Anxiety Disorder |
| **HSPS** | Highly Sensitive Persons Scale |
| **HC** | Healthy Controls |
| **IPV** | Intimate Partner Violence |
| **MBCT** | Mindfulness-based Cognitive Therapy |
| **MBSR** | Mindfulness-based Stress Reduction |
| **MDI** | Multiscale Dissociation Inventory |
| **MTURK** | Amazon Mechanical Turk (Crowdsourcing platform) |
| **M-RS** | Modified Resting State |
| **PCL-5** | PTSD Checklist for DSM-5 |
| **PCC** | Posterior Cingulate Cortex |
| **PFC** | Prefrontal Cortex |
| **PPI** | Pre Pulse Inhibition |
| **PSP** | Public Safety Personnel |
| **PTSD** | Post Traumatic Stress Disorder |
| **RHI** | Rubber Hand Illusion |
| **RCT** | Randomized Control Trial |

| | |
|---|---|
| **SD** | Standard Deviation |
| **SPQ** | Sensory Perception Quotient |
| **S-RS** | Standard Resting State |
| **USA** | United States of America |
| **WHODAS** | World Health Organization Disability Assessment Scale |
| **VOI** | Variables of Interest |

## Declaration of Academic Achievement

All data was collected through experimental studies from the Trauma and Research Recovery Unit (TRRU) run by Dr. Margaret McKinnon. Research and analyses design were a collaboration between Vanessa Parise and Dr. Margaret McKinnon. All analyses, figures, and manuscripts were conducted / created by Vanessa Parise

# CHAPTER 1:
# GENERAL INTRODUCTION

## General Introduction

Posttraumatic stress disorder (PTSD) is a chronic psychological condition that may develop following the experience or witnessing of one or more traumatic events (Lancaster et al., 2016) (American Psychiatric Association, 2013). In Canada alone, it is estimated that, currently, about 8% of the adult population meet criteria for moderate to severe symptoms of PTSD (Statistics Canada, 2024). Strikingly, it was not until 1980 that PTSD was recognized as a mental health disorder by the American Psychiatric Association (APA) (Committee on the Assessment of Ongoing Effects in the Treatment of Posttraumatic Stress Disorder & Institute of Medicine, 2012). Overall, there is an urgent need to investigate and better understand the neural and behavioural underpinnings of this condition to not only to better treat those who are suffering in the aftermath of a traumatic experience, but to also ward against the development of PTSD in the face of personnel, political, and natural events, such as climate disasters, occurring at an increasingly rapid pace within a climate of increased global insecurity.

Individuals with PTSD experience a host of symptoms that include re-experiencing of the traumatic event, hyperarousal, negative alterations in cognition, avoidance of traumatic reminders and in some cases, dissociative tendencies (APA, 2013). Often, these symptoms occur when the individual is placed in an environment where traumatic reminders may be present. Given that it is nearly impossible for one to avoid possible somatic triggers of a traumatic event during experiences of everyday life, it is crucial that somatic underpinnings of PTSD symptomology be well understood. Although this line of research is gaining traction, there remains a paucity of research on how somatic experience and alterations in sensory processing impact associated PTSD symptomology and in turn, overall functional ability in daily life

### 1.1 Sensory Processing

To better understand the somatic experience of individuals with PTSD, an appreciation of sensory processing and its possible alterations following trauma exposure is necessary. Sensory processing is described as the ability to register, organize and modulate incoming sensory information from one's external environment and internal sensations to meet environmental demands (Costa-López et al., 2021). Under standard conditions, through the process of multisensory integration, incoming stimuli is processed though brainstem structures including the Superior Colliculus/Periaqueductal gray (SC/PAG), Vestibular Nuclei (VN) and the Locus Coeruleus (LC) (Harricharan et al., 2021). Sensory information is then transferred to the insula where interceptive inference and awareness of sensory experience occurs. In its final stages of integration, this information is transferred to the prefrontal cortex, where higher-order processes including executive functioning and emotion regulation occur in relation to this incoming information (Harricharan et al., 2021). This process provides a healthy individual with the means to function effectively within their everyday life.

### 1.2 Sensory Processing in the Aftermath of Trauma: Dissociation and Cognition

In the aftermath of trauma, emerging evidence suggests that the standard process of multisensory integration is disrupted (Harricharan et al., 2021) (Frewen & Lanius, 2006). For example, individuals who have been trauma exposed/diagnosed with PTSD report altered hypervigilance to their external and internal sensations that may be associated with feelings of panic. Here, neuroimaging research points to a possible underlying mechanism of this effect, where individuals with PTSD show increased connectivity between the insula and limbic structures, such as the amygdala, thus leading to an increased feeling of threat (Bruce et al., 2013). In some cases, trauma-exposed individuals also report dissociative experiences of

depersonalization and derealization when met with overwhelming sensory stimuli. It is postulated that this effect stems from increased activity from the insula to areas involved in the visual system (occipital cortex) and self-referential processing (e.g., PCC and precuneus) (Harricharan et al., 2021) (Spiegel et al., 2011).

Although sensory processing is involved in a variety of bottom-up processes within the brain, effective usage of sensory information and its influence on downstream functional activities rely heavily upon the integration of sensory information with reciprocally operating cognitive and affective processing that contribute to literacy, self-reflection, logical reasoning, critical thinking and executive functioning (Harvey et al., 2019). Despite this reliance, in the aftermath of trauma, crucial sensory stimuli may not be integrated effectively with higher-order cognitive and affective processes mediated by the frontal cortex leading to potentially disordered cognitive functioning, decreased emotion regulation and associated alterations in functional ability within the everyday world. Additionally, individuals that report higher levels of dissociation show decrements in visuospatial processing and working memory that have been associated with functional impairment (Rivera-Vélez et al., 2014) (Bruce et al., 2013). Taken together, literature points to an urgent need to investigate the effects of sensory processing alterations on classic symptomology and the ability to function effectively in the social world.

### 1.3 Overall Goals

To address the relative paucity of information surrounding sensory processing in the face of trauma exposure, we first sought to determine whether individuals who have been exposed to psychological trauma show changes in sensory processing. Here, we investigated sensory sensitivity through the lens of alterations in daily functioning and dissociation. In addition, we examined whether lower scores on sensory-based cognitive assessments were associated with

higher levels of functional impairment and of dissociation scores were correlated to, Firstly, we conducted a scoping review of the extant literature to frame our current understanding of the neural, behavioural and therapeutic correlates of sensory processing in trauma-exposed populations. We next performed an experimental study (Chapter 3), where trauma-exposed participants completed a battery of questionnaires aimed at capturing the subjective experiences of sensory sensitivity in relation to dissociation and functional impairment. In a second experimental study (Chapter 4), trauma-exposed participants completed a similar battery of subjective sensory questionnaires alongside sensory-based cognitive assessments. In both cases, we hypothesized that trauma-exposed individuals, the majority of whom met diagnostic criteria for a probable diagnosis of PTSD would experience alterations in sensory processing that would be captured in their subjective and objective test performance and that would correlate positively with elevated levels of dissociation and overall disrupted functioning in daily life.

### 1.4 Thesis Outline

The subsequent chapters of this thesis explore the possibility of alterations in sensory processing among trauma-exposed individuals with PTSD. Specifically, in chapter 2, the scope of the current literature was reviewed via the PRISMA scoping review guidelines (Tricco et al., 2018) to investigate the neural, behavioural, and therapeutic correlates of sensory processing in trauma exposed/PTSD populations. Each domain was s initially explored separately to pinpoint themes and then integrated to provide a cohesive scope of the empirical evidence of sensory processing alterations in trauma exposed/PTSD populations. Chapters 3 and 4 are experimental investigations investigating sensory processing among trauma-exposed individuals, the majority of whom met diagnostic criteria for a probable diagnosis of PTSD. Specifically, Chapter 3 investigates the relation between sensory sensitivity measures, dissociation, and functional

impairment using well-validated self-report questionnaires. In Chapter 4, related constructs are investigated through exploration of relation between performance on online sensory-based cognitive assessments and self-report measures of functional impairment and dissociation in a population of public safety personnel. Both experimental studies did not have a control group but instead investigated correlations between continuous measures to identify relationships and possible mediators of performance. Finally, chapter 5 is a general discussion on the primary findings of this thesis, as well as its limitation and possible future directions.

# CHAPTER 2: SENSORY PROCESSING DEFICITS IN PTSD POPULATIONS: A SCOPING REVIEW INVESTIGATING NEURAL, BEAHVIOURAL AND THERAPEUTIC CORRELATES

**Abstract**

**Objective:** Emerging research points towards the presence of alterations in sensory processing among trauma-exposed populations, including individuals with a formal diagnosis of post-traumatic stress disorder (PTSD). The aim of the present scoping review was to identify and then integrate the extant literature concerning the neural, behavioural and therapeutic correlates of sensory processing in trauma-exposed populations, including those with PTSD, with the overall objective of enhancing our comprehension of putative alterations in sensory processing among this population.

**Method:** A search of the literature pertaining to sensory processing alterations in trauma-exposed/ PTSD clinical populations was conducted.

**Results:** Fifty-seven articles were selected for review. Of these 57 articles, 11 articles explored neural correlates, 21 articles explored behavioural correlates, and 25 articles explored therapeutic correlates. Together, the extant evidence suggests that individuals who are trauma-exposed, including those with a diagnosis with PTSD, experience altered levels of interoceptive and exteroceptive processing. Critically, brain regions found to be implicated in altered sensory processing among these groups were predominately associated with visual processing/detection and spatial and body awareness, which have been implicated in processes such as self-reference and hypervigilance. Finally, sensorimotor psychotherapy and other modified versions of mindfulness-based interventions appear at the forefront of "gold-standard" somatic interventions for trauma-exposed/PTSD populations.

**Conclusion:** These findings contribute to an emerging understanding of alterations in sensory processing among trauma-exposed, including PTSD, clinical populations. Here, sensory processing plays a critical role in the ability to perform daily tasks, raising the potential that alterations in sensory processing may underlie, in part, difficulties with functional abilities observed frequently among individuals exposed to trauma. Notably, this knowledge may be leveraged to further refine the current corpus of somatic-based therapies for PTSD.

**Key words:** Sensory processing; posttraumatic stress disorder; scoping review

**Significant Outcomes**

- Trauma-exposure, including among individuals with PTSD, is associated with a weaker sense of interoceptive sensation and hyperactive experience of exteroceptive sensation.
- Sensorimotor psychotherapy and modified versions of mindfulness-based interventions are at the forefront of somatic therapeutic interventions for PTSD.

**Limitations**

- Due to constraints in time, a secondary screening of referenced articles from articles included in this review was not completed.
- Majority of the studies included in the review did not include the dissociative subtype of PTSD (PTSD-DS) as a sample group

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## Introduction

As reported by Statistics Canada, over 5 million Canadians (18%) aged 15 years or older met diagnostic criteria for a mood, anxiety or substance use disorder within the last 12 months (Statistics Canada, 2023). With an increase in Canadians seeking mental health services, the Government of Canada has taken action to increase accessibility to Canadians who are suffering. This is evident through the introduction of the Mental Health Promotion Innovation Fund (MHP-IF) where over 12 million dollars has been allocated to mental health services and promotion across Canada (Public Health Agency of Canada, 2022). Despite these efforts, following the experience of a traumatic event, about 8% of individuals will subsequently report symptomology congruent with a probable diagnosis of posttraumatic stress disorder (PTSD) with the prevalence being higher amongst public safety personnel and Canadian Armed Forces (CAF) members (StatCan, 2024) (Carleton et al., 2018).

PTSD, as defined in the Diagnostic and Statistical Manual for Mental Disorders (DSM-5), is a trauma -and stress-related disorder that may occur following exposure to one or more traumatic events (APA, 2013). Here, classically described symptoms of PTSD include feelings of being on-edge (hyperarousal), avoidance of traumatic reminders, negative alterations in mood and re-experiencing of the traumatic event though nightmares or flashbacks (APA, 2013). it is thought that this classic symptomology may arise, in part, through alterations in bottom-up processes reliant upon basic perception of sensory information (Grabbe & Miller-Karas., 2018).

Here, incoming sensory information from the internal body and from the external environment is processed in brainstem structures implicated in sensory response and then further processed by higher-order brain regions that subscribe meaning to one's sensory experience (Passarello et al., 2022). More recently, it has been hypothesized that alterations in sensory processing among trauma-exposed individuals may contribute to a more classic hyperarousal state or, conversely, to a dissociative phenotype when responding to sensory stimuli (Fleming et al., 2024)

Convergent research has begun to further identify the potential neural pathways contributing to altered somatosensory processing among individuals with a diagnosis of PTSD. f Notably, these studies point towards alterations in neural pathways associated with cognitive processes that mediate sensory processing and integration. For example, in one study, individuals with PTSD showed decreased functional connectivity from the dorsolateral prefrontal cortex (DLPFC) to the precuneus (Olsen et al., 2018). This finding is in keeping with previous suggestions that hyperactivity in posterior sensory/perceptual systems may lead to decreased goal-oriented connectivity to the Prefrontal Cortex (PFC) (Patel et al., 2012). Behaviourally, an early study by Roca & Freeman. (2002), found that in a sample of combat veterans with PTSD, the presence of psychosensory symptoms, defined as a sensory experience that lacks an external stimulus but is perceived as real to the individual, correlated positively with overall symptom severity, and with measures of dissociation, aggression, and hostility. Here, it appears probable that alterations in experience of sensory processing among individuals with PTSD make impact everyday functioning, an area that remains unexplored.

Given recent growth in this field of study, we sought to identify and to integrate the current literature surrounding the neural and behavioural correlates of alterations in sensory processing among trauma-exposed populations, including PTSD, and to review current

somatosensory therapies for PTSD. In this review, I broadly explore the literature to uncover the current understanding of the neural, behavioural and therapeutic targets of sensory processing/dysregulation in those who have experienced trauma and/or have a diagnosis of PTSD.

**Materials and methods**

To obtain literature, the following databases (Embase, Global Health, Ovid Healthstar, Ovid Medline Epub Ahead of Print, Ovid MEDLINE, APA PsychInfo, EMB Reviews, Ovid Emcare, and Scopus) where used to search for articles/book reviews/chapters published between January 1900 and April 2023. Key words used included "posttraumatic stress disorder", "trauma", "sensation disorders, "sense" and "dysregulate". A full list of search terms can be found in Table 1. To be included in the review, references had to explore sensorimotor processing deficits in PTSD populations in one or more of the following research areas: i) neural; ii) behavioural and iii) therapeutic correlates (see Table 1 for associated research terms). To ensure that the search conducted was exhaustive of the extant literature on this topic, references were excluded only if they did not explicitly investigate a modality of sensorimotor processing within a trauma-exposed population. Articles that were not excluded during the abstract screening process were screened by one rater (VP) and classified by the research area they focused on (Neural (n= 11), behavioural (n= 21), Therapeutic (n=25). The search terms and strategy were approved by a health science librarian at McMaster University. See Table 2 for inclusion and exclusion criteria for abstract and full-text screening.

**Results**

This section presents the findings from the current review focused on the neural, behavioural and therapeutic correlates of sensory processing dysfunction in trauma-exposed

populations, including PTSD. This review aimed to map out the existing literature, identify key findings, and suggest future directions to advance the literature.

A total of 4080 references were identified through the initial search. After the removal of duplicates and completion of abstract screening, a total of 125 full-text articles were assessed for eligibility. Finally, 57 articles/reviews were selected to be included in the for review (see Fig. 1 for the scoping review screening process). Studies were included if they evaluated an aspect of sensory/body processing and regulation, involved adolescent/adult participants with a primary diagnosis of PTSD or who were trauma exposed, and were tested in human populations (see Table 2 for more information). Measures of interrater reliability (IR) were not available for title and abstract screen as only one reviewer was used. IR was high (0.796) as assessed by Cohen's Kappa indicating a substantial agreement between both raters during full-text review.

A total of 11 studies were found to specifically examine the neural underpinnings of sensory processing dysregulation in PTSD and trauma. Most of these studies compared a PTSD group to aged-matched controls in a cross-sectional design (n=8), followed by systematic reviews (n=2) and by a randomized control trial (RCT) (n=1). Most of these studies did not specify type of trauma exposure (e.g., childhood abuse or neglect; single accident), with two studies specifically examining combat trauma exposure. The most common sensory modality studied was the visual system and its associated functions (n=5), followed by broad sensation through all modalities (n=2), and by auditory (n=1), tactile (n=1) and proprioception (n=1). One study did not investigate a specific modality but instead focused on connectivity between the cerebellum and brain regions associated with sensory processing.

A total of 21 studies were found to meet eligibility for inclusion in review of behavioural correlates. These studies included comparator groups of individuals diagnosed with PTSD,

PTSD-DS, trauma controls, and healthy age-sex matched controls. The majority of these studies were experimental in nature and aimed to uncover sensory dysregulation through retroactive self-reports or validated experimental paradigms (n= 17), RCT's (n=3) and a single psychometric validation paper (n=1). Behaviour specific studies provided a much more rounded understanding of alterations in sensory processing among trauma-exposed individuals through investigation of a broad range of sensory modalities: visual (n=2), tactile (n=1), proprioception (n=5), olfactory (n=1), auditory (n= 4) and broadly investigation of sensory processing (n=8).

The findings of identified studies investigating neural and behavioural correlates of sensory processing overlapped significantly and could be organized into two themes: (1) heightened hypervigilance and increased visual scanning and (2) weakened interoception. In line with the presence of increased hypervigilance among trauma-exposed individuals, one study investigated alpha connectivity between the occipital parietal lobe and frontal regions of the brain, reporting supressed posterior alpha activity and a diminished influence of lower-level sensory regions on higher-level cognitive regions (bottom-up granger causality) (Clancy et al., 2017). Alpha activity/alpha oscillations (8-12Hz) are a brainwave frequency that corresponds with a state of resting wakefulness among healthy individuals. When these oscillations are supressed between brain regions, it can lead to impaired cognitive functioning, a decrease in communications among brain regions and most notably, increased sensory processing (Clancy et al., 2017; Nicholson et al., 2020). Accordingly, these findings point towards limited inhibition of sensory cortical activity from the visual cortex to higher-order cognitive networks located in the PFC, leading to hyperactivity of incoming visual input. (Clancy et al., 2017).

With respect to weakened interoception, an illustrative study by Terpou et al. (2018) investigated pulvinar connectivity (a brain region associated with processing of visual

information), with brain regions associated with interoception and sympathetic activation among individuals with a classic presentation of PTSD, individuals with the dissociative subtype of PTSD (PTSD-DS), and healthy controls via resting state fMRI. Here, individuals in the PTSD and the PTSD-DS group showed decreased activity between the pulvinar nuclei and parietal regions underlying multimodal sensory processing, suggesting decrease in spatial awareness of one's body. These findings were echoed in a related study conducted by Reinhardt et al. (2020) that investigated the interoceptive abilities of sexual trauma survivors. In this study, Participants who reported higher levels of PTSD symptoms showed lower levels of interoceptive accuracy of their heart rate thus providing further evidence of weakened interoceptive awareness among individuals with PTSD.

To identify therapeutic correlates of sensory processing alterations in PTSD, we chose literature that either (1) had a primary focus of alleviating somatic trauma symptoms through the use of sensorimotor techniques, (2) Used a sensory modality as a primary facilitator of therapeutic connection (i.e. visual processing in Eye Movement Desensitization and Reprocessing (EMDR) or (3) was aimed at bringing awareness back to bodily sensations and somatic experience as a primary therapeutic technique. Therefore, we examined the current literature surrounding therapeutic interventions that rely, at least in part, upon sensory processes thought to be altered in a trauma-exposed populations. A total of 25 studies were found to have met eligibility criteria for inclusion in this review. These included conceptual articles (n=10), book reviews (n=3), case studies (n=4), textbook/chapter (n=2), RCT (n= 4), and dissertation (n=1). Thematic analysis revealed that these outputs focused primarily on (1) sensorimotor therapies and (2) mindfulness-based activities. Specific topics explored included sensorimotor psychotherapy/modified protocol of sensorimotor psychotherapy (n=18), mindfulness-based

interventions (ex. Mindfulness-based Stress Reduction (MBSR) and Mindfulness-Based Cognitive Therapy (MBCT)) (n=2), EMD) /modified EMDR protocol (n=3) and yoga interventions (n=2). On average, therapies studied amongst trauma exposed/PTSD populations were described as having effectiveness in addressing common symptoms of PTSD; empirical evidence for these conclusions was, at present, lacking, with an overreliance on case reports and theoretical postulation surrounding presumed effectiveness Notably, a study by King et al. (2016) examined the effects of mindfulness training on a group of 181 OEF/OIF veterans with a diagnosis of PTSD. Following completion of these sessions, post-pre contrasts revealed increased connectivity between the Default Mode Network (DMN), DLPFC and the anterior cingulate cortex (ACC), which were in turn correlated to improvement in avoidant and hyperarousal symptoms.

Examining the therapeutic literature further, results from the RCTs included in the current review provided novel insight into the efficacy of sensory based therapies. In a study examining the difference between Bikram yoga (BY) (a modified version of mindfulness hot yoga) and High Intensity Interval Training (HIIT) in a group of women with persistent pain and a history of trauma, results found that those who were in the BY group achieved significant improvement in self-report measures of physical and mental functioning (Flehr et al., 2019). Additionally, in another study examining the efficacy of a modified sensorimotor psychotherapy in women with a history of childhood trauma, results also found that individual in the intervention group, as compared to waitlist controls, reported increased somatic awareness of their body and soothing receptivity to the therapeutic protocol (Classen et al., 2021)

A more detailed description and synthesis of studies included in this review can be found in Table 3 (A-C), Table 4 (A-B) and Table 5.

**Discussion**

The primary aim of this scoping review was to identify and synthesize the current literature concerning the neural, behavioural, and therapeutic correlates of sensory processing among samples of trauma-exposed individuals and/or individuals with a primary diagnosis of PTSD. More specifically, the review aimed to identify common themes and trends amongst each correlate to inform future research within the field. Here, the extant literature, summarized in Table 3, suggests strongly the presence of alterations in sensory processing among trauma-exposed individuals that are expressed at the neural and behavioural level. Here, a small number of body-based therapeutic interventions have emerged that aim, in part, to address unresolved somatic symptoms of trauma that may have downstream consequences for more classically described symptoms of PTSD and for resolution of dissociative symptoms. To our knowledge, despite an emerging corpus of quantitative studies examining trauma-related alterations in sensory processing to date, no qualitative or mixed-methods studies have been conducted to examine the phenomenological experience of these alterations among individuals with PTSD; such studies also have the potential to reveal an associated lack of insight concerning these alterations.

Three recurring themes were identified throughout the literature included in the review. The first concerned the emergence of increased hypervigilance to the external world in the aftermath of trauma exposure, a finding illustrated in the neural and behavioural correlates of alterations in sensory processing Many of the neuroimaging studies reviewed investigated whether functional connectivity between brain regions implicated in classic symptomology of PTSD and regions implicated in integration of exteroceptive stimuli were altered following trauma exposure. Here, alterations in connectivity were observed between areas involved in self-

regulation (frontal cortices and DMN), areas implicated in the sensory experience of stimuli (occipital cortices, insula) and the re-experiencing of memories (hippocampus) were found (Clancy et al., 2017; 2020) (Rabellino et al., 2018) (Lee et al., 2018) (Choi et al., 2022). Together, these findings suggest exposure to trauma may result in decreased inhibition of incoming sensory stimuli and increased multimodal attention to trauma reminders.

These results appear consistent with literature surrounding behavioural changes associated with sensory processing dysfunction in PTSD. Here, numerous studies reported decreased sensory gating during Pre-Pulse-Inhibition tasks (PPI) and an increased focus on psychosensory sensations experienced during or after a traumatic event (Acheson et al., 2022; Pineles et al., 2016; Meteran et al., 2018). Taken together, these finding suggest the presence of a theoretically postulated, sensory based "traumatic filter" operational during the uptake of sensory stimuli from the environment.

Interestingly, contradictory findings emerged where in two studies individuals with PTSD displayed decreased attention and increased avoidance to potentially traumatic stimuli (Herzog, DePierro & D'Andrea, 2018; Punkski-Hoogervorst, Engel-Yeger & Avital, 2023). These findings point towards a more complex relationship between alterations in sensory processing, vigilance, and PTSD where individual differences (e.g., presence of dissociative symptoms) may alter disease expression. Future research concerning the developmental time in which trauma was experienced and disease subtyping is highly warranted.

The second theme that emerged from the literature concerned reports of weakened interoception among individuals who have been trauma-exposed, including those diagnosed with PTSD. As with the previous theme, these findings emerged across studies of the neural and behavioural correlates of alterations in sensory processing. Among the behavioural studies

identified, the majority focused on interoception, pointing towards a decreased ability among trauma-exposed populations to accurately perceive and describe sensations surrounding their own body. More specifically, elevated levels of alexithymia and deficits in interoceptive accuracy were reported. These findings are consistent with substantial alterations in functional connectivity found between key brain regions associated with the experience of emotion regulation (pre-frontal cortices), visceral information from the body (anterior insula) and proprioceptive awareness (vestibular nuclei) observed in the literature surrounding neural correlates. Interestingly, in the studies that explored the dissociative subtype of PTSD (PTSD-DS) in comparison to a classic presentation of PTSD and to healthy controls found weakened interoception to be more pronounced on a neural and behavioural level, providing impetus to increased study of susceptibility factors associated with the emergence of PTSD-DS in the aftermath of trauma.

The final theme that emerged is the overwhelming use of sensorimotor psychotherapy and mindfulness-based therapies as therapeutic interventions to treat somatic symptoms emerging from trauma exposure, including diagnosis of PTSD. Sensorimotor psychotherapy has been described as a holistic approach to healing trauma and attachment issues by integrating the body and movement into traditional talk therapies (Ogden & Minton, 2000; Ogden, Minton & Clare, 2006). Techniques in sensorimotor processing included mindful tracking of bodily sensations while recollecting details from the patient's traumatic event. Using this technique appeared to allow patients to ground themselves back within their own bodies where many reported feelings out of touch with themselves in the aftermath of their trauma (Ogden & Minton, 2000; Lee, 2007; Leavitt, 2006). Other studies that did not explicitly study sensorimotor

psychotherapy did report the use of other mindfulness-based techniques such as trauma-informed yoga or sensorimotor art therapy.

One noteworthy finding surrounding the use of therapeutic interventions to treat somatic symptoms of PTSD concerned the use of gamified virtual reality to integrate a body-based intervention and prolonged exposure therapy. Here, patients were immersed in a scene that mimicked the environment in which their trauma exposure occurred while being asked to track their physical sensations as the scene progressed. This integrative approach suggests a s a potential area for further exploration of novel tools that may be utilized in sensorimotor psychotherapy, recognizing that prolonged exposure therapy may be contraindicated among survivors of trauma (e.g., prolonged childhood abuse; sexual assault).

The literature included in this review had many strengths including the use of well-validated empirical designs in the neuroimaging and behavioural literature. In addition, therapeutic examinations often provided a detailed background and description of the approaches examined.

One of the major limitations of the findings included in this review concerned the paucity of research concerning the dissociative subtype of PTSD, of the 57 reports included in this review, only five studies included PTSD-DS as a study group. Given known differences in the neural circuitry and behavioural patterns of those with PTSD as compared to those with its dissociative subtype (Harricharian et al., 2021), it is critical that such differences be explored in relation to alterations in sensory processing among trauma-exposed populations. In addition, many of the studies included among the therapeutic correlates were comprised of case studies or were conceptual in nature. Although critical to the understanding of current therapies available that integrate sensory processing in PTSD, a lack of experimental studies hinders understanding

of the effectiveness of the therapies described. Finally, in addition to the absence of a second reviewer, time and resource concerns precluded a secondary search of grey literature and further examination of relevant references from articles included in this review. Such work will occur in the months ahead. This review provides robust evidence of alterations in sensory processing among trauma-exposed individuals, including those with PTSD. Future studies should focus on furthering the investigation of neural correlates of sensory processing deficits because, as it currently stands, only 19% of the current review investigated neural correlates directly indicating a paucity in the current research. Additionally, it important that individuals who meet criteria for the dissociative subtype of PTSD are included as a sample group in future research to ensure that the neural and behavioural correlates of sensory processing deficits within PTSD-DS are accurately described and utilized to inform future therapeutic interventions.

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**Declaration of Interest**

None.

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**Tables and Figures**

Table 1. Associated search terms investigated in the scoping review

| Search Terms✞ | |
|---|---|
| **PTSD related terms** | **Sensory processing related terms** |
| Post traumatic stress disorder* | Sensation disorders |
| Stress disorders | Sense* |
| Traumatic | Sensory or somatic |
| PTSD | Dysregulate* |
| Post traumatic stress injur* | Imbalance* |
| Trauma | Hyperactive* |
| | Inhibit* |
| | Disinhibit* |
| | Hypoactive* |
| | Overload* |

✞where appropriate, search terms were mapped to keyword heading and had its term exploded

*Search was conducted on several combinations of character proceeding the keyword

Table 2: Exclusion and Inclusion Criteria used for abstract and full-text review

| Inclusion Criteria | Exclusion Criteria |
|---|---|
| • English/ English translated articles<br>• Chapters/ Peer reviewed Studies / reviews<br>• Available electronically through McMaster Libraries<br>• Studied in adolescent (10-18) and/or adult populations.<br>• Tested in human populations.<br>• Clinically diagnosed or clinically measured probability of trauma exposure/PTSD | • Does not explicitly investigate sensory processing and/or one or more sensory modalities.<br>• Not available in online format to be reviewed. |

Table 3 (A-B): Study characteristics of studies included in the review (A) Neural correlates, (B) Behavioural correlates

**A.**

| Author (year), Country | Type of Study | Sample Groups | Type of Trauma | Type of Task | Sensory Modality | Brain Region/MNI Space |
|---|---|---|---|---|---|---|
| Badura-Brack et al (2015), USA/Canada | Cross-sectional | Veterans with PTSD (N=16)<br>Mean Age =33.7yrs<br>Combat exposed Controls (N | Combat | Unilateral tactile stimulation of the pad of the fifth digit of the right hand using a small airbladder (puff of air) | Tactile | Left postcentral gyrus (–40, –31, 52)<br>Right prefrontal cortices (23, 44, 37)<br>Left superior parietal area (: –24, –73, 43) |
| Choi et el (2022), USA/Europe | Cross-sectional | Trauma (N=10)<br>Control (N=18) | Mixed | fMRI with stress provocation | Visual System (Stress Response) | Trauma > Ctrl<br>Left hippocampus<br>Right insula<br>Occipital cortex<br>Parietal lobe<br>Fusiform gyrus<br>Primary motor cortex<br>Midcingulate cortex<br>Ctrl > Trauma<br>Ventromedial prefrontal cortex<br>Lateral prefrontal cortex<br>Ventromedial prefrontal cortex<br>Temporal lobe<br>Dorsal Striatum |
| Clancy et al (2017), USA | Cross-sectional | PTSD (N=28)<br>GAD (N=24)<br>HC (N=23) | Mixed | Standard Resting State (SR-R) and Modified Resting State (M-RS) EEG | Visual cortical activity | Occipitoparietal lobe (right, middle and left)<br>Frontal sites of the right and left hemispheres |
| Clancy et al (2020), USA | RCT | PTSD (N=25)<br>GAD +HC (N=44) | Mixed | f Standard Resting State (SR-R) and Modified Resting State (M-RS) | Visual system (Visual Cortex) | PCC (15, -45, 40/-5, -50, 35; Visual Cortex: bilateral cuneus (peaks: 5, -70, 30/-5, -70, 30, bilateral precuneus (peaks: 5, -60, 35/-5, -65, 25, right superior occipital gyrus (peak: 40, -80, 25;<br>mPFC (15, 60, -10/-15, 65, -15 |
| Harricharan, McKinnon & Lanius (2021), Canada | Review | N/A | Mixed | N/A | All Modalities (Broad sensory processing) | PTSD<br>Limbic and brainstem structures (i.e. Amygdala)<br>PTSD-DS<br>Occipital cortex |

Table 3A Continued

| Author (year), Country | Type of Study | Sample Groups | Type of Trauma | Type of Task | Sensory Modality | Brain Region/MNI Space |
|---|---|---|---|---|---|---|
| Lee et al (2018), USA | Cross-sectional | Activity duty military (N-18) | Combat | Allostatic neurotechnology (HIRREM) for auto calibrations of neural oscillations. | Auditory | Anterior portion of DMN (Medial prefrontal Cortex)Sensorimotor Network |
| Marlatte et al (2022), Canada/ Israel | Cross-sectional | PTSD (N=23) Mean 32 Trauma Exposed Controls(N= 23) | Mixed | Verbal description of an imaginary scene And a virtual navigation task | Visuospatial processing | White matter tracts connecting the hippocampus, thalamus and cortical sensory regions |
| Rabellino et al (2018), Canada | Cross-sectional | PTSD (N=65) PTSD-DS (N=37) HC (N=47) | Mixed | Resting state fMRI | N/A | Left Lobule<br>PTSD > HC<br>Fusiform gyrus (28, -40,-14)<br>Hippocampus (38, -28, -6)<br>HC >PTSD-DS<br>Middle temporal gyrus(66, -40, -6)<br>Supraparietal lobule/supramarginal and angular gyrus (36, -38, 50)<br>Right Lobule<br>PTSD>HC<br>Posterior insula (38, -12, 12)<br>Planum polare (48, -6, -2)<br>HC >PTSD-DS<br>Middle temporal gyrus (68. -40, -4)<br>Supramarginal and angular gyri/TPJ/parietal operculum/ postcentral gyrus (60, -56, 26) |
| Rabellino et al (2020), Canada | Review | N/A | Mixed | N/A | All Modalities (Broad sensation and perception) | Premotor cortex<br>Intraparietal sulcus<br>Putamen<br>Supramarginal gyrus<br>post-central gyrus<br>Cerebellum<br>Insula<br>Vestibular system |

Table 3A Continued

**B.**

| Author (year), Country | Type of Study | Sample Groups | Type of Trauma | Type of Task | Sensory Modality | Brain Region/MNI Space |
|---|---|---|---|---|---|---|
| Harricharran et al (2017), Canada | Cross-sectional | PTSD (N=60)<br>PTSD-DS (N=41)<br>HC (N=40) | Mixed | To obtain resting state functional connectivity data, participants were asked to close their eyes and let their mind wander without focusing on anything. The fMRI sessions lasted for 6 minutes | Proprioception | PTSD > Ctrl LVN - Angular Gyrus (56, -62, 28)<br>PTSD > Ctrl RVN- Supramarginal Gyrus (66, -28, 30)<br>Ctrl LVN > PTSD-DS - Supramarginal gyrus (-52. -26, 42), Precentral gyrus (-26, -20, 74), Middle frontal gyrus (-34, 8, 62), Middle temporal gyrus (-68, -34, -8), Precuneus (-2, -36, 56)<br>Ctrl RVN > PTSD-DS -Precuneus (-4, -36, -56) |
| Terpou et al (2018), Canada | Cross-sectional | PTSD (N=81)<br>PTSD-DS (N=49)<br>HC (N=51( | Mixed | Resting-state fMRI | Visual Detection/ Spatial awareness | Ctrl > PTSD-DS (Left pulvinar seed)<br>Middle temporal gyrus (L)(-62, -56, -4)<br>Superior parietal lobe (L) (-22, -58, 60)<br>Postcentral gyrus(R) (32, -36, 52)<br>Ctrl > PTSD-DS (Right pulvinar seed)<br>Superior frontal gyrus (L)(-24, 0, 72)<br>Superior parietal lobule (L)(-22, -58, 60)<br>Precuneus (Left/right)(-26, -52, 48 and 6, -54, 48)<br>Inferior parietal lobe (R)(38, -42, 54)<br>Post central gyrus medial segment(R) (12, -26, 54)<br>Ctrl > PTSD ( Left pulvinar seed)<br>Fusiform gyrus (L) (-46,-52,-16)<br>Superior parietal lobule (L)(-32,-66,54)<br>Ctrl > PTSD (Right pulvinar seed)<br>Superior parietal lobule (L)(-20, -62,54)<br>Precuneus (L) (-22, -82, 40) |

| Author (Year), Country) | Type of Study | Sample Characteristics | Type of Trauma | Type of Task | Sensory Domain |
|---|---|---|---|---|---|
| Acheson et al (2022), USA | Experimental | No PTSD (N=1182)<br>PTSD (N=46) | Military/combat | Acoustic prepulse inhibition | Auditory |
| Acheson et al (2022), USA | Experimental | Undergraduates with trauma exposure (N=200) | Sexual | Heartbeat Counting Task (Measure of interoceptive awareness) | Proprioception |
| Belrose et al (2020), Europe/Australia | Experimental | Patients with PTSD (N=22)<br>Healthy Controls (N=15) | Mixed | NSS were evaluated using the Psychomotor Assessment of the sweet signs (PASS)(Marionneau et al, 2018). Thiis consisted of 27 tasks aimed at evaluating 9 categories of NSS: (1) walking, (2) static and dynamic equilibrium tasks, (3) perseverance in task , (4) tonus, (5)Motor integration, (6)sensory integration, (7)dysrhythmias, (8)synkinesis, (9)somatognosis and spatial self-perception. The higher the score, the more errors made on each task | All Modalities (Broad sensation and perception) |
| Clancy et al (2020), USA | RCT | Combat trauma exposed Veterans (N=86) | Combat | Resting state EEG -Alpha Oscillations<br>A subsample which a subsample of veterans were asked to smell 6 combat related (i.e. Gunpowder) and six non-combat related scents (i.e.. Cleaning products) and asked to rate how often these scents were experienced during combat and how strongly they were associated with their deployment | Olfactory |
| Joon & Bae (2022), Republic of Korea | Experimental | Students form general school (public high school,) (N=140)<br>Students from alternative school (N=140) | Childhood trauma | N/A | All Modalities (Broad sensation and perception) |

Table 3B Continued

| Author (Year), Country) | Type of Study | Sample Characteristics | Type of Trauma | Type of Task | Sensory Domain |
|---|---|---|---|---|---|
| Kraus et al (2008), Europe | Experimental | Combat Veterans with PTSD (N=10)<br>Combat controls (N=10)<br>Healthy controls (N=10) | Combat | Non-painful warm and cold stimuli were applied to the dorsum of the hands using a Peltier-based 3cm x 3. cm contact thermode. Participants were asked to indicate the detection of a warm or cold stimuli and the point in which it became painful using a mouse click | Tactile |
| Llyod et al (2019), Canada | Validation | Individuals who reported post-traumatic tonic immobility responses within the past month (N=462) | Mixed | N/A | All Modalities (Tonic Immobility) |
| Llyod et al (2021), Canada/Germany | Experimental | Absent alexithymia: (N=51)<br>Probable Alexithymia :(N= 46) | Childhood Maltreatment/Neglect | Verbal task. Participants were asked to describe their somatic experience of 14 emotion words and 1 neutral word. For each word, participants were also asked to colour in bodily regions on a silhouette where the bodily sensation increased/activated when they were presented with the emotion word | Proprioception |
| Machorrinho et al (2022), Portugal | Experimental | PTSD from IPV<br>N =38 | Intimate Partner Violence | Heartbeat Counting Task (Measure of interoceptive awareness)<br>Rubber Hand Illusion (Measure of body ownership) | Proprioception |
| Meteran et al (2018), Europe | Experimental | Refugees with PTSD (N=25)<br>Refugees without PTSD (N=20) d | Lived in country of war/subject to torture | PPI, P50 suppression, mismatch negative it and selective attention paradigms, always administered in that order. While this was occurring EEG and EMG recordings of the activity in the right medial orbicularis oculi to measure startle response. | Auditory |
| Pineles et al (2016), USA | RCT | Women with PTSD (N=22)<br>Women without PTSD (N=25) | Mixed | Auditory Pre-Pulse Inhibition (PPI) task administered during the early follicular phase (eFP) and midluteal phase (mLP) of the menstrual cycle. Participants were fitted with 4-mm Ag/Ag-Cl surface electrodes placed below the eye over the left orbicularis oculi muscle. Startle stimuli were 100dB noise pulses with a 50-ms duration and the pre-pulse were 70dB noises of 20ms. Participants were exposed to 2 types of trials: startle stimulus presented alone, or startle stimulus preceded by pre-pulse with 120ms between the onset of the startle stimulus. | Auditory |

Table 3B continued.

| Author (Year), Country) | Type of Study | Sample Characteristics | Type of Trauma | Type of Task | Sensory Domain |
|---|---|---|---|---|---|
| Rabellino et al (2018), Canada | Experimental | PTSD: (N=4)<br>PTSD-DS: (N=6)<br>HC: (N=7) | Mixed | Rubber Hand Illusion (Measure of body ownership) | Proprioception |
| Raingruber and Kent (2003), USA | Experimental | Nursing Students (N=18)<br>Social-work Students (N=14)<br>Nursing Instructors (N=5)<br>Social Work faculty (N=4)<br>Psychiatrist (N=6) | Work-place related secondary trauma | N/A | All Modalities (Broad sensation and perception) |
| Roca & Freeman (2002), USA | Experimental | Combat PTSD Veterans (N=60)<br>Substance abusing Veterans (N=18) | Combat | N/A | All sensory modalities (Illusions) |
| Skinner et al (1999), USA | Experimental | Controls (Alcohol use or combat exposed) (N=15)<br>Female rape victims (N=9)<br>Healthy controls (N=9) | Rape or Combat | P1 potential was recorded at the vertex (Cz) referenced to a frontal electrode (Fz). Eye movements were detected using diagonally placed canthal electrodes and jae movements were detected using a lead over the mentalis muscle. | Auditory |
| Stewart & White (2008), USA | Experimental | Total = 336<br>PTSD (N=32)<br>Trauma but no PTSD (N=144)<br>Low trauma group (N=153) | Mixed | N/A | All Modalities (Broad sensation and perception) |

Table 3B Continued.

| Author (Year), Country) | Type of Study | Sample Characteristics | Type of Trauma | Type of Task | Sensory Domain |
|---|---|---|---|---|---|
| Thomas et al (2022), USA | Experimental | Patients admitted to hospital for either physical assault or motor vehicle accidents (N=29) | Physical assault or motor vehicle accident | Threat-related attentional bias was measured using a computer administered dot-prove task (DPT). Participants were asked to stare the computer screen while either 60 trauma-relevant/neural image pairs or 30 neutral/neutral image pairs were presented. | Visual |
| Tsur (2020), Israel | Experimental | Mother and daughter dyads with a history of childhood maltreatment (N-194) | Childhood trauma | N/A | All Modalities (Broad sensation and perception) |
| Van't Wout-Franka et al (2019), USA | RCT | Veterans with warzone-related PTSD (N=12) | Combat | All participants completed six VR sessions over two weeks. Each VR session included three 8-min driving scenarios with standardized presentation of 12 warzone events (i.e. IED, ambushes). Participants were randomized to either receive 25min of 2mA active or sham tDCS with anode over AF3 and cathode over PO8 | All modalities (psychophysiological arousal) |
| Zdankiewicz, Odachowska and Tworek (2018), Europe | Experimental | *All groups have childhood trauma exposure<br>Recently started training in the gym (N= 20)<br>Attended yoga beginner groups (N= 20)<br>Undertaking no physical activity (N= 16) | Childhood trauma | N/A | Proprioception |

**C.**

| Author (Year), Country | Type of Study | Objective | Intervention Used |
|---|---|---|---|
| Angelini (2006), Europe | Conceptual Article | Provide an conceptual understanding of how the use of sensorimotor skills and techniques can be beneficial for automimic regulation in the body in the aftermath of trauma | Sensorimotor Psychotherapy |
| Champagne (2009), USA | Case Study | Describe a case study that highlights the interrelated nature of mental health symptoms, occupational engagement and occupational stress and how it impacts perceptions of well-being and quality of life | Sensory modulation program (SMP) in conjunction with approaches from cognitive behavioural therapy (CBT) |
| Classen et al (2021), Canada | RCT | To examine the efficacy of a body-oriented group therapy designed to address chronic fear states in individuals with complex trauma. The group intervention aimed to increased somatic awareness to build relational awareness to the environment | Trauma and the Body Group (20 session group therapy) |
| Coetzee & Regal (2005), Europe | Conceptual Article | Provide a review on the process of EDMR and evaluate the biological mechanism that may underly the therapeutic effect | Standard EDMR processing Protocol |
| Fisher (2011), USA | Conceptual Article | Provide a conceptual understanding of how increasing self-regulation is crucial to the effectiveness of treatment for problems caused by childhood neglect, trauma and attachment failure | Sensorimotor Psychotherapy |
| Fisher (2018), USA | Conceptual Article | Provide a detailed background and description of somatically oriented talk therapy in the treatment of traumatic stress | Sensorimotor Psychotherapy |
| Flehr et al (2019), Australia | RCT | Provide preliminary evidence of the efficacy and feasibility of two types of vigorous exercise (Bikram Yoga (BY) and High Intensity Interval Training (HIIT)as bottom-up sensorimotor therapies to improve persistent pain severity in a group of women with persistent pain and a history of trauma | Vigorous Exercise: Bikram Yoga (BY) or High Intensity Interval Training (HIIT) |
| Hetherington & Gentile (2022), Italy | Case Study | Investigate the effects of Sensorimotor art therapy on stress management of a 13-year old boy, with trauma exposure, 15-months after living with his adoptive parents | Sensorimotor Art Therapy |

Table 3C Continued

| Author (Year), Country | Type of Study | Objective | Intervention Used |
|---|---|---|---|
| Joesphs (2017), USA | Book Review | Provide a comprehensive review of the book titled "Sensorimotor Psychotherapy: Interventions for Trauma and Attachment, by Pat Ogden and Janina Fisher (2015)) | Sensorimotor Psychotherapy |
| Jones et al (202), Canada | RCT | Investigate the impact of 3MDR on PTSD symptoms among military members and veterans with treatment resistant PTSD | Multi-modular Motion-assisted Memory Desensitization and Reconsolidation (3MDR) |
| King et al (2016), USA | RCT | Examine the effect of mindfulness training on DMN function in PTSD by comparing Mindfulness-based Exposure Therapy (MBET) to a non-mindful active control therapy, Present-centered group therapy (PCGT) | Mindfulness-based Exposure Therapy (MBET) |
| Lanius (NA), Canada | Conceptual Article | Provide insight on a bottom-up processing protocol (sensory processing) to be used during EDMR therapy | Modified EMDR Processing Protocol |
| Leavitt (2006), USA | Book Review | Provide a comprehensive review of the book titled " Pat Ogden, Kekuni Minton and Clare Pain, Trauma and the Body: A Sensorimotor Approach to Psychotherapy" | Sensorimotor Psychotherapy |
| Lee (2007), USA | Book Review | Provide a comprehensive review of the book "Trauma and the Body: A sensorimotor approach to Psychotherapy" written by Pat Ogden, Kekuni Minton and Clare Pain | Sensorimotor Psychotherapy |
| Lohrasbe & Ogden (2017), Canada/USA | Conceptual Article | To provide a comprehensive framework of sensorimotor psychotherapy to help identified priorities for therapeutic stabilization for children and family members with abuse and neglect histories of trauma. | Sensorimotor Psychotherapy |
| Murphy (2016), USA | Dissertation | Example the relationship of individuals who have been exposed to trauma with overall symptom severity, mindfulness, social connectedness and levels of post-traumatic growth | Modified Sensorimotor Psychotherapy |
| Ogden (Unknown), USA | Textbook | To provide a comprehensive understanding of "Acts of Triumph" in the aftermath of trauma through somatic experiences through sensorimotor psychotherapy | Sensorimotor Psychotherapy - |
| Ogden and Minton (2000), USA | Conceptual Article | Propose how sensorimotor processing interventions can help to regulate emotional and cognitive processing by confronting somatic issues directly in trauma expose clients. | Sensorimotor Psychotherapy |

Table 3C Continued

| Author (Year), Country | Type of Study | Objective | Intervention Used |
|---|---|---|---|
| Ogden and Minton (2002), USA | Chapter | Propose how sensorimotor processing interventions can help to regulate emotional and cognitive processing in the aftermath of trauma | Sensorimotor Psychotherapy |
| Ogden, Minton & Clare (2006), USA | Conceptual Article | Conceptualize how sensorimotor therapy is used towards helping with pain and trauma through the use of the body and body signals | Sensorimotor Psychotherapy |
| Reuille-Dupont (2021), USA | Case Study | Discuss the foundations of somatic psychology and movement psycho-regulation as well as provide 5 case examples of movement intervention in outpatient treatment | Somatic psychology and movement psychotherapy |
| Scagnetto, Benedetti &Notari (2021), Europe | RCT | Investigate changes in emotional dysregulation and alexithymia in a population with PTSD when a dog is added to the sensorimotor psychoeducational protocol. | Modified Sensorimotor Psychotherapy (Addition of dog) |
| Spinazzola et al (2011), USA | Quasi-experimental/ Case Study | Explore the use of yoga in traumatized youth that are enrolled in residential treatment | Trauma sensitive yoga Intervention |
| Warner et al (2004), USA | Conceptual Article | Investigate intervention approaches that utilize somatic forms of regulation for use with traumatized adolescents for who somatic, affect and behavioural dysregulation are disruptive and where language based approaches are difficult to implement | Somatic based interventions |
| Warner et al (2013), USA | Conceptual Article | Provide insight on the application of sensory motor approaches to treatment for behavioural dysregulation in adolescents with complex trauma in residential treatment centres | Sensory Motor Arousal Regulation Treatment (SMART) |

Table 4 (A-B): Objectives and main findings of studies included in the review broken down by correlate studied: (A) Neural correlates, (B) Behavioural correlates

**A.**

| Author (year), Country | Objective | Main Findings |
|---|---|---|
| Badura-Brack et al (2015), USA/Canada | Examine the potential differences in somatosensory tactile processing through oscillatory response to non-threatening somatosensory stimuli | Higher levels of PTSD were associated with more abnormal levels of neural activity in all three brain regions. Veterans with PTSD do not perceive nonthreatening stimuli at the same level as veterans without PTSD do suggesting a model of early stimulus categorization to ignore non-threating stimuli |
| Choi et el (2022), USA/Europe | Examine the association between neural correlates of stress and physical symptoms of patients with trauma as compared to healthy controls | During visual stress provocation, trauma patients showed decreased activity in areas involved in self-regulation (pre-frontal regions) and increased activity in regions implicated in emotional dysregulation and reactivity |
| Clancy et al (2017), USA | Investigate the sensory pathology of PTSD and its neural pathophysiology using EEG | Compared to GAD + Healthy controls, patients with PTSD exhibited suppression of posterior alpha activity and bottom-up alpha Granger causality during both the S-RS and M-RS. This pattern of function is in line with sensory hyperactivity leading to excess higher order frontal activity |
| Clancy et al (2020), USA | Investigate whether PTSD is associated with deficient alpha activity in the DMN as well as deficient inhibition of sensory cortical input into the DMN | Concerning alpha power deficits, PTSD showed deficits the visual and DMN ROIs at each state with the visual cortex exhibiting the strongest groups. No significant group effects emerged when comparing S-RS and M-RS. In regard to alpha connectivity, simple contrasts in of S-RS in the PTSD group revealed reduced bidirectional connectivity with the PCC and mafic suggesting disrupted DMN connectivity. In the M-RS condition, the PTSD group showed reduced bidirectional connectivity between the visual cortex, PCC and mafic |
| Harricharan, McKinnon &Lanius (2021), Canada | Provide a brief description of sensory processing and the neurobiological underpinnings of sensory processing in healthy individuals, discuss the neural aberrations among individuals with PTSD and PTSD-DS and present a theoretical framework for sensory processing and its possible relation to symptom profiles observed in PTSD | Individuals with PTSD show increased connectivity with limbic and brainstem structures instead of prefrontal cortex when sensory information is being relayed from the anterior insula. In contrast, individuals with PTSD-DS show increased connectivity with the occipital cortex instead |
| Harricharran et al (2017), Canada | Examine the functional connectivity of the vestibular system in PTSD, PTSD-DS and healthy controls | **PTSD vs. Healthy Controls**<br>Showed greater connectivity between the vestibular nuclei and the right angular and supramarginal gyri<br>**PTSD-DS vs Healthy Controls**<br>Showed minimal functional connectivity of the vestibular insular cortex (posterior insula, supramarginal gyrus) and the dorsolateral prefrontal cortex |
| Lee et al (2018), USA | Report brain network connectivity changes in military services members/veteran with symptoms of military related traumatic stress after the use of allostatic neurotechnology (HIRREM) for auto calibrations of neural oscillations. | Post-intervention group analysis found decreased community structure in the anterior DMN and sensorimotor network. Both the visual cortex and sensorimotor areas showed decreased activity, but the DMN increased in activity post HIRREM intervention |
| Marlatte et al (2022), Canada/ Israel | Investigate the abilities of individuals with and without PTSD to construct a scene within their minds. Additionally, the relationship between neural integrity in gray matter volume and white tract integrity and scene construction abilities were explored | A between-subjects ANOVA found a significant main effect of navigational spatial processing as well as a significant interaction of navigational spatial processing and group such that control more accurately estimated distance and direction than PTSD patients. Additionally, PTSD patients reported significantly fewer spatial details, imagined few entities and provided fewer sensory descriptions and experienced an overall less vivid imagination than controls |

Table 4A Continued

| Author (year), Country | Objective | Main Findings |
|---|---|---|
| Rabellino et al (2018), Canada | Investigate resting state functional connectivity of the cerebellum in PTSD and PTSD-DS as compared to controls | Results found that in the PTSD-DS group there was a profound disconnect across three cerebellar regions, lobule IV-V, Crus I, the anterior vermis, primary sensory cortex and supramarginal gyrus as compared to the PTSD and HC group. Connectivity from the cerebellum to regions responsible for multisensory integration and bodily self-consciousness are diminished. Conversely, increased functional connectivity was observed in the PTSD group between the cerebellum and limbic and cortical regions involved in the integration of external and internal sensory inputs (i.e. Fusiform gyrus, posteriors insula, hippocampus). This could be interpreted as the constant need for those with PTSD to hyper scan their environments for threats. |
| Rabellino et al (2020), Canada | Discuss the current literature on Peri personal Space (PPS) through the following avenues : Define PPS and its characteristics and functions, identify cortical and subcortical structures underlying PPS representation, explore the literature describing the relationship between psychopathology and PPS with a focus on trauma related disorders and lastly, describe the important of studying PPS in trauma related disorders in order to enhance understanding of PPS | Key brain regions (premotor cortex, intraparietal sulcus, putamen, supramarginal gyrus, post-central gyrus, Insula, cerebellum and the vestibular system) are all neural correlates involved in PPS representation and have shown to be altered in PTSD. Therefore, these preliminary relationships give rise to further study about body representation and peri personal space in the aftermath of trauma |
| Terpou et al (2018), Canada | Investigate whether PTSD patients would show reduced pulvinar connectivity with regions involved in integral cognition and self-referential processing as well as investigate whether sympathetic overactivation in PTSD is related to motor agitation and defensive posturing at rest. | Whole brain corrected reductions during resting state were found between the pulvinar nuclei and parietal regions underlying multimodal sensory integration and socio-affective functions in PTSD and PTSD-DS |

**B.**

| Author (year), Country | Objective | Main Findings |
|---|---|---|
| Machorrinho et al (2022), Portugal | Describe embodiment related variables and mental health problems experienced by those with IPV as well as determine the extent which embodiment related variables are related to experience mental health problems | Female victims of IPV show higher levels prevalence of PTSD (especially in the re-experiencing cluster), depression and anxiety. In terms of embodiment, female victims of violence should a weak sense of body ownership and interoception as reported by achieved scores on the HCT and RHI task. Similar results were found on self-report questionnaires |
| Llyod et al (2021), Canada/Germany | Determine the topographical distribution of emotion-related bodily sensations in adults who were exposed to early childhood maltreatment with or without probable alexithymia | The probable alexithymia group displayed a more muted and less distinct activation pattern as compared to the non-alexithymia group across all 17 emotions. Additionally, group difference were not found for amount of sensation but rather for location and intensity of bodily sensation |
| Rabellino et al (2018), Canada | Investigate (1) Body ownership in PTSD during the RHI (2) body ownership in the dissociative subtype of PTSD during the RHI (3) Correlation between body ownership and sense of agency in the whole PTSD sample | As compared to controls and PTSD-DS group, the PTSD group did not show as much of a proprioceptive drift and subjective perception of the illusion indicating a more sustained rigid body image during the RHI. In contrast, as compared to HC and PTSD group, the PTSD-DS group displayed a high variance in both subjective experience and proprioception indicating a more state-dependant body image. |
| Acheson et al (2022), USA | Examine sensorimotor gating and its relation to post-deployment PTSD | Participants with PTSD at 6 months post deployment showed overall reduced PPI. PTSD cases were the least prevalent in the highest performing quartiles of the PPI distribution These results suggest that high levels of PPI may be a PTSD resiliency factor |
| Acheson et al (2022), USA | Build upon the current knowledge in regard to interoception in survivors of sexual trauma and empirically evaluate whether somatic sensitivity are associated with increased PTSD symptoms | Participants with lower PTSD symptoms showed higher levels of IAc (more accurate perception of heartbeat). Both Isac and dissociation were significant predictors of PTSD symptoms in opposite directions but their interaction was not. These finding suggests that IAc may facilitate a heightened awareness in one's heartbeat which is an integral component to many emotions |
| Raingruber & Kent (2003), USA | Increase the understanding of embodied responses that are associated with traumatic clinical events. A second objective was to clarify ways in which the body can help a clinician understand what is most meaningful from a situation in which they experience an intense physical sensation | All groups experienced strong physical sensations when faced with traumatic clinical situations. Participants reported that these strong physical sensations were not pathological in nature but instead oriented them to embodied response that helped alert them to attend and take action to what ever is occurring in their environment |
| Stewart & White (2008), USA | Understand the relationship between sensory filtering disruption and symptoms associated with PTSD and trauma exposure | Participants in the PTSD group reported more disruption in sensory filtering phenomenology, specifically with more disruption in measures of perceptual modulation and distractibility in comparisons to the high and low trauma groups. Interestingly, the high trauma group indicated higher levels of overinclusion and stress fatigue (similar to that of the PTSD group. These findings suggest that trauma symptoms regardless of a PTSD diagnosis are associated with disrupted sensory filtering |
| Kraus et al (2008), Europe | Investigate sensory detection, pain thresholds, and ratings for longer lasting pain stimuli in combat veterans as compared to combat controls and healthy controls | Significant differences in pain thresholds to both heat and cold were found between combat controls and PTSD patients as compared to healthy controls. Although, the PTSD group showed a significantly lower mean incidence of painful stimuli and compared to both control groups. Both veteran populations (with and without PTSD) showed a higher pain threshold to both hot and cold stimuli |
| Zdankiewicz, Odachowska & Tworek (2018), Europe | Investigate the predictive power between traumatic experiences in childhood, higher levels of dissociation and alexithymia on the power of body self. | Individuals who scored higher on the traumatic experience's checklist showed increased alexithymia, dissociation (specifically depersonalization) and overall weaker sense of the body self. The impact of physical activity (both yoga and gym exercises) showed a statistically significant decrease in alexithymia scores |

Table 4B continued.

| Author (year), Country | Objective | Main Findings |
|---|---|---|
| Joon & Bae (2022), Republic of Korea | Investigate whether experiences of childhood trauma effects emotions and sensory processing adolescents as well as determine how different environmental factors affect general school students vs. alternative school students | Participants with more instances of childhood traumatic experiences showed lower registration, lower sensitivity and higher sensory avoidance. |
| Tsur (2020), Israel | Examine the link between childhood maltreatment, complex post-traumatic stress symptoms and post-traumatic orientation to body signals among mothers and their young adult daughters | Significant correlations were found between childhood trauma and C-PTSD symptoms but was not correlated to either of the post traumatic orientation scales for both the mother and daughters. Additionally, C-PTSD symptoms significantly positively mediated the association between childhood trauma - pain catastrophizing , childhood trauma and physical anxiety symptoms and childhood trauma and body vigilance among both mothers and daughters. Taken together, the results indicated that the childhood traumatic experiences of the mother may have detrimental effects on their daughter through transformation of the ability to orient towards their bodily signals. |
| Clancy et al (2020), USA | Examine whether deficient alpha activity compromises sensory inhibition leading to symptoms of trauma-reexperiencing | In the total sample, no effect of alpha power was found on intrusive re-experiencing of trauma symptoms. Additionally, multiple regression analyses found that there was a negative association with alpha connectivity and intrusive re-experiencing in the left hemisphere but not in the right after controlling for depressive symptoms. In the olfactory sub sample, it was found that olfactory trauma memory was associated with greater intrusive re-experiencing symptoms and a decrease in alpha connectivity. Lastly, olfactory trauma memory significantly mediated the association between alpha connectivity and intrusive re-experiencing symptoms |
| Belrose et al (2020), Europe/Australia | Proof of concept of the exploration of the relationship between PTSD severity and Neurological Soft Signs (NSS) | The control group exhibited overall lower NSS average total scores than the PTSD group. Patients with more severe PTSD exhibited the highest symptoms scores, lowest well-being scores and exhibited significant alterations in NSS with the most prominent dysfunction being related to data tic and dynamic equilibrium and motor integration and coordination. When comparing gender, women with PTSD were found to have significantly worse changes in NSS as compared to men int he same group. |
| Pineles et al (2016), USA | Examine the changes in PPI in women with and without PTSD as well as explore the associations between specific types of PTSD symptoms and PPI deficits | Women in the PTSD group exhibited less PPI as compared to the trauma control group. Additionally, it was found there the nature of the trauma (interpersonal vs. not interpersonal) had no effect on the level of PPI deficit. Averaged across the menstrual cycle, PPI deficits were associated with greater reexperiencing, avoidance and overall symptom severity |
| Roca and Freeman (2002), USA | Examine the degree to which psychosensory symptoms are present in a sample of individuals with chronic, combat related PTSD as compared to substance-abusing veteran controls | Within the PTSD sample, psychosensory symptoms as measures by the IIPSS were significantly correlated with measures of overall symptom severity (SCl-90-r GSI), dissociation (DES), PTSD symptoms (PTSD-I), aggression and hostility. These correlations were not found in measures of IQ, age, educational level, combat exposure or symptoms of PTSD avoidance or arousal. Individuals with substance abuse scored significantly lower on measures of IIPSS than the PTSD group indicating the substance abuse was not a factor in increased psychosensory symptoms |
| Skinner et al (1999), USA | Determine whether sensory gating of the P1 potential should abnormalities in female rape victims with PTSD and male combat veterans with PTSD as compared to controls | For both PTSD groups (combat and rape victims), there was no statistical difference between group based on peak amplitude of the P1 potential as compared to their respective control groups. Although, post-hoc analysis showed that the PTSD groups (combat and rape victims) showed decreased sensory gating as compared to their respective control groups. Significant differences occurred at the 250ms interstimulus interval |
| Thomas et al (2022), USA | Study the relationship between peritraumatic stress and threat induced attentional bias immediately after trauma exposure | Preliminary correlational analyses showed that 1-month post experience PTSD symptoms were significantly correlated with PTSD symptoms prior to emergency department admission but not with threat avoidance. Additionally, those with PTSD symptoms at one month may experience higher threat related hypervigilance as opposed to avoidance following trauma exposure |

Table 4B Continued

| Author (year), Country | Objective | Main Findings |
|---|---|---|
| Meteran et al (2018), Europe | Investigate changes in P50 suppression, pre-pulse inhibition, startle reactivity and habituation of the eye blink startle response in a group of refugees with PTSD compared to refugees without PTSD. | Increased amplitude response was found in PTSD patients as compared to healthy refugee controls. When looking at the PPI paradigm specifically, this increase was reflected in the eye-blink startle response. In the P50 paradigm, PTSD patients responded with higher N100 and P200 amplitudes both to T- and C-stimuli. Although, group differences did not meet significance between controls and PTSD patients in this study |
| Llyod et al (2019), Canada | Evaluate the factor structure and psychometric properties of the first self report scale for Tonic immobility Occurring Post-trauma (STOP) | The STOP scale demonstrated robust reliability and good construct validity in measuring of tonic immobility symptoms post-trauma. Additionally, STOP was found to be associated with other dissociative symptoms of PTSD |
| Van't Wout-Franka et al (2019), USA | Investigate whether transcranial direct current stimulation (tDCS) in conjunction with virtual reality (VR) would reduce PTSD symptoms and create meaningful clinical effects as compared to sham | A significant main effect of VR sessions on SCR were found for both the active and sham group as well as a significant VR session by tCDS group interaction in which active over sham was favoured. Additionally, both groups showed clinically meaningful reduction in PTSD symptoms but participants who received tDCS + VR appeared to continue to improve during the 1-month follow up |

Table 5: Therapeutic techniques and efficacy

| Author (Year), Country | Therapeutic Technique | Therapeutic Efficacy |
|---|---|---|
| Angelini (2006), Europe | Sensorimotor psychotherapy uses the following techniques to help clients regulate themselves : (1) Make clients aware of breathing patterns and incorporate breathing exercises (2) Orient thoughts about the body into core support (pelvis , spine) and peripheral support (arms, legs) systems (3) Ask clients to oscillate between negative and positive feelings (4) Identify and track precursors of arousal (5) Work on somatic sense of boundaries (too far and too close) (6)Explore actions such a pushing, pulling, kicking etc. (7) Use props in the room to represent others and reactions to them (8) Recognize incomplete actions cause by trauma and complete them in the here and now. | No experimental efficacy reported |
| Champagne (2009), USA | The SMP has 4 main therapeutic goals in conjunction with sensory diet (a routine that specifically creates a sensory supportive environment through sensory resources): (1) Increase self-awareness through self-expression, (2) Self-shaping though planning and practising varied sensory modulation interventions, (3)Self regulation and positive change, (4)ongoing transformation through repertoire expansion | After one month, the participant noticed a significant difference in the ability to feel grounded and was able to fall asleep faster and concentrate for longer periods of time. Additionally, through consistent use of their sensory diet, they reported feeling more present with clients at work and less over stimulated within their work environment. |
| Classen et al (2021), Canada | Trauma and Body group therapy focuses on the integrative nature of sensorimotor , cognitive and emotional processing described in sensorimotor psychotherapy. Primary focus was aimed on drawing participants into the present moment to witness their own somatic experiences through a non-judgemental lens | Participants in the treatment group successfully increased their somatic awareness compared to waitlist control group but did not reduce the use of dissociation to disconnect from bodily experiences. Additionally, participants in the treatment group as showed a strong treatment effect for soothing receptivity |
| Coetzee and Regal (2005), Europe | Eye movement desensitization and reprocessing therapy primarily focuses traumatic images, and the negative thoughts and emotions associated with them. The main therapeutic goal of EDMR is to (1) disentwine the individual to these emotional responses and (2) begin to reprocess these traumatic images with positive cognition and emption through the use of saccadic eye movements | In one analysis of the results of 61 treatment-outcome trials for PTSD, psychological therapies (EDMR and behavioural therapies) have significantly lower drop out rates that pharmacotherapies. In another review, it was found that the more rigorous the methodology of the EDMR protocol, larger the effect size in favour of EMDR for PTSD. Conversely, in a direct comparison of trauma focused CBT and EMDR, it was found that none has a significant advantage over the other in terms of therapeutic changes |
| Fisher (2011), USA | Sensorimotor therapy stems from approaches used in psychodynamic psychotherapy, gestalt therapy, cognitive-behavioural treatments and the Hakimi method of body psychotherapy. Its principles stem from findings from neuros science research and how the brain and body give attention to autonomic arousal and perceived adaptive responses. | No experimental efficacy reported |
| Fisher (2018), USA | Sensorimotor psychotherapy focusses on observing bodily sensations that take place during traumatic memory with mindful attention. This type of attention activates the mPFC which is thought to be implicated in interoceptive experience and overall internal awareness | In a 10-patient hospital based outpatient group, patients reported improvement in dissociative symptoms, internal awareness and receptiveness to soothing following the end of sensorimotor psychotherapy group treatment and at their 6 month follow up. Additionally, in a 12-session sensorimotor psychotherapy group protocol that incorporated psychoeducation, 20 subjects reported decreases in depressive and PTSD symptoms and overall increase in health and social measures |

Table 5 Continued.

| Author (Year), Country | Therapeutic Technique | Therapeutic Efficacy |
|---|---|---|
| Flehr et al (2019), Australia | Current pain literature has indicated a strong link between chronic pain and traumatic stress. This is hypothesized to occur because of the implication of autonomic dysregulation on the maintenance of chronic pain feedback loops. Current therapies aimed at reducing autonomic dysregulation brought on by traumatic stress use a bottom-up sensory approach to bring back the "mind-body" connection but little has been investigated on how this approach may help those who experience chronic persistent pain brought on by traumatic stress | Both experimental groups showed a statistically significant improvement in heart rate variability as well as an overall reduction in scores on the Brief Pain Inventory (BPI). Group differences were negligible. Women in the BY group achieved significant improvements in self report measurements of physical functioning and mental as compared to the HIIT group. As a whole, women in the study did achieve statistically significant improvement in persistent pain levels but it could not be determined if this was cause by vigorous exercise as group differences were not larger enough to make conclusions |
| Hetherington & Gentile (2022), Italy | Sensorimotor Art Therapy is a modified version of sensorimotor therapy in which the client processes their trauma through various forms of art (i.e.: drawing, painting.etc.). Clients are encouraged to focus on their body and motor responses to their trauma while they are engaging in a particular form of art | Direct Quote: "Initially, I thought art therapy sessions were useless, I really didn't want to go…after a year I began making great strides. I started to open up more to others, be more emotional and express my ideas. I began to see my life in colour, instead of just grey. I am more controlled now" |
| Joesphs (2017), USA | Treatment approach consists of primarily providing patients with guided exercises that focus on increasing self-awareness of body language and body sensation and work towards altering the body towards more adaptive movements (i.e. Altering posture, walking and breathing). The therapist primarily acts as an external regulator of the patients' bodily experiences to help keep them in the "window of tolerance" by reminding them of this guided exercise. | No experimental efficacy reported |
| Jones et al (202), Canada | Clients are delivered 3MDR in an immersive Computer Assisted Rehabilitation Environment (CAREN). CAREN is a 3D VR-system with a centrally located treadmill surrounded by 240-degree floor to ceiling screen with motion capture technology. Each session is 90 minutes long and consists of repetitive cycles of: (1)Warm-up phase where the client listens to self-selected music while they reminisce of their military deployment, (B) a series of 2-5 cycles of active therapy where 1-7 images are shown to clients and they are asked to describe the physical sensations , emotions and though that these scenarios cause (C) post platform phase where the client is given the opportunity to review the session and discuss new insights | Results demonstrated significant reductions in PTSD symptom severity and number of symptoms in the experimental group as compared to controls. Notably, 27% of participants no longer met criteria for PTSD at the 3-month follow up |
| King et al (2016), USA | Participants in the MBET groups received 16- week intervention that consisted of 4 modules: (1) PTSD psychoeducation and relaxation, (2) Mindfulness of body and breath exercises with in-vivo exposure (3)Mindfulness of emotion in Vivi exposure and (4) Self-compassion training. Class were 2hrs each with assigned homework at the end | The MBET post-> pre contrast revealed increased connectivity in the DMN to areas in the frontal cortex and the anterior cingulate cortex. Additionally, increased connectivity was found between posterior cingulate cortex with the dorsolateral prefrontal cortex as well as between the left amygdala and left hippocampus. These findings are consistent with the concept that mindfulness-based training can help those with trauma exposure shift to self-referential attention in which they can experience more interoceptive and environmental sensation |

Table 5 Continued

| Author (Year), Country | Therapeutic Technique | Therapeutic Efficacy |
|---|---|---|
| Lanius (NA), Canada | Prior to starting EDMR, the therapist encourages the client to track physiological sensation to allow them to be mindful in the present. The therapist actively uses their voicing during the session to keep the participant grounded. When EDMR beings, the participant continues to process sensory information prior to moving into the thoughts and emotions associated with their memories | Clients have reported an increase to their emotional tolerance by switching their focus to somatic sensations before and during their EDMR session |
| Leavitt (2006), USA | Clients may be asked to think about their traumatic event or at least something that stress them out. Instead of focusing on the emotional or cognitive response to this memory, the client will focus on the bodily sensations associated with the memory (i.e. heart racing, sweaty palms.etc....). In Phase 1 of treatment: developing somatic resources for stabilization, clients learn to oscillate between attention on calm body areas and body areas in which pain or discomfort are occurring. This is to ensure they remain within their window of tolerance. In Phase II and Phase IIi, client work on restoring acts of triumph and integration and success info normal life | "I used the techniques taught in the treatment section on myself as I wrote this review. They worked! I tend to get anxious when I have to write for publication...I thought about needing to write this review so as to activate the issue. I found the discomfort in my body, dropped the ‘‘story’’ about writing, and began ‘‘body reading...I felt grounded. My level of discomfort stayed within the window of tolerance. I had connected to my core’’ (Leavitt, 2006) |
| Lee (2007), USA | The book breaks down sensorimotor psychotherapy into three different phases of treatment:<br>Phase 1: Establishing a sense of safety and security through self-care. The primary focus of this phase is to teach somatic resources and physical actions establish this security<br>Phase 2: Processing traumatic memory and restoring acts of triumph through somatic integration of dissociated and non-verbal memory fragments<br>Phase 3: Integration and Success in Normal Life though focusing on expanding a client’s social support, overcoming fears in daily life and creating occupational needs and goals | Efficacy not reported |
| Lohrasbe & Ogden (2017), Canada/USA | The therapist aims at providing somatic resources to track and attend to physical components of dysregulation. Some examples are spinal alignment (straightening the back when in a dysregulated state, breathing and grounding (slowing one’s breath in a moment of panic). Resources must be embodied by placing emphasis on the sense being felt through its movement and phycological components. Once the body ahs been downregulated, the cognitive qualities of the sensation can be integrated effectively | Efficacy not reported |
| Murphy (2016), USA | The primary aim of the therapist was to teach strategies to enable clients to be more aware of their body sensations. Each group session consisted of six main components: (1) Mindfulness activity (2) previous week check in (3) educational component, (4)experiential component, (5)discussion of the homework assignment for the following week, (6)closing activity | Results indicated participation in the SP intervention reduced overall symptoms, increased mindfulness and social connectedness. There was no statistically significant relationship between SP and post-traumatic growth. These results remained stable at the 1 month follow up |
| Ogden (Unknown), USA | The therapist pursues completing incomplete actions through direct work with body movement and the sensation itself. Clients may recall traumatic memories in which they were trying to push away. The therapist helps the patient separate this action from the past, bring it into the present and process the feelings associated with the incomplete action to reach completion to elucidate feelings of triumph over the event/accompanying sensation | Anecdotes provided by clients have reported feelings of "aliveness", physical pleasure and satisfaction with reconnection with sensations |

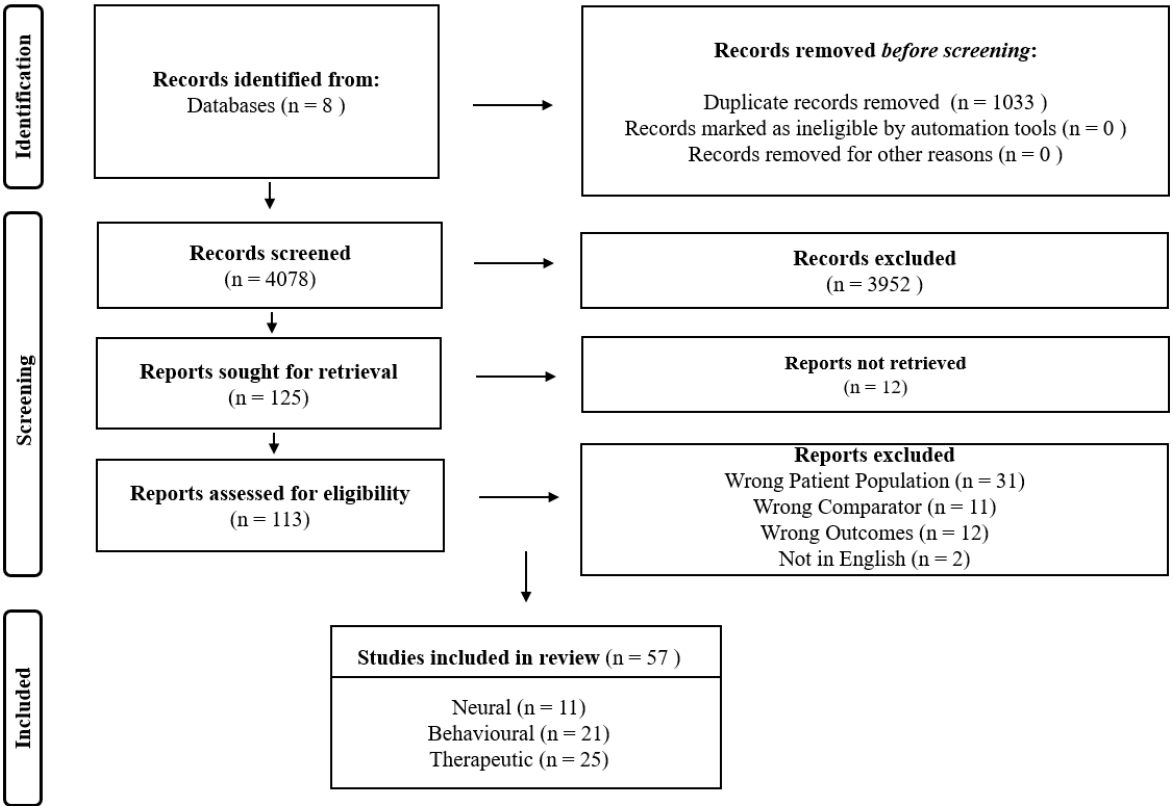
Table 5 Continued

| Author (Year), Country | Therapeutic Technique | Therapeutic Efficacy |
|---|---|---|
| Ogden & Minton (2000), USA | Clients are asked to mindfully track the sequence of physical sensations as they progress throughout the body and disregard and emotion or cognition that arise until body sensations reaches a point of rest and arousal is returned to normal. The therapist must help the client to find an acute awareness of their inner body sensations first via client-therapist interaction and seconds as the client themselves notices their inner body sensations | Sensorimotor psychotherapy itself was found to not be sufficient on its own and requires integration of all three levels of processing: sensorimotor, emotion and cognition in order for recover to occur. Anecdotal reports from both clients and therapist have both found this method of therapy reduces PTSD symptoms and increased the client's ability to remain the present |
| Ogden & Minton (2002), USA | Clients are asked to mindfully track the sequence of physical sensations and impulses and disregard any emotion or cognition as they arise while experiencing a traumatic memory. The therapist must act as an "auxiliary cortex" for clients through observation and description of their sensorimotor experience until they are able to do it effectively themselves. To induce mindfulness, clients are also asked to track and describe their sensory experience as it adapts and changes through their experience of their traumatic memory | Professionals who have learned Sensorimotor psychotherapy have reported that their clients experience reduced PTSD symptoms such as nightmares, panic attacks, aggressive outburst and hyperarousal following a sensorimotor psychotherapy protocol |
| Ogden, Minton & Clare (2006), USA | The client is told to focus on a tracking physical feeling. These signs can be signs of wellbeing or malfunctioning. The therapist works to look for patterns of movement that may be correlated to longstanding beliefs and emotional tendencies that stems from traumatic experiences and reactions. For example, while recalling her traumatic experiences, the client Jennifer noticed tension in her body and was encouraged to find a physical action that felt right in the moment. This led to Jennifer noticing an impulse to make wide circulations motions with her arms to delineate "her space" and to "stay out of it" | As Jennifer practised these impulse movements and setting of her personal boundaries through sensorimotor psychotherapy, she was able to keep herself within her window of tolerance and become more social and less prone to freeze when though to be around a threat |
| Reuille-Dupont (2021), USA | Somatic psychology practitioners use the body as a primary source of information from their client. Information flows from sensation awareness, into movement and then affect and cognitive meaning are added. Treatment primarily focuses on bring felt sensations into conscious awareness and use movement to help resonate with emotions. Examples of this would be pushing, pulling and running. Movements were practised in conjunction with the therapist, the therapist mirror embodiment to the client or the client preforming the movements on their own. | In all case examples, the therapists identified an incongruent or "unfinished movement" within their clients. They reported that once this movement was identified, they worked with their clients through the use of somatic regulation techniques to get them to open up and share their experiences more freely with them |
| Scagnetto, Benedetti &Notari (2021), Europe | The sensorimotor psychoeducational protocol was derived from theory and exercises created by Ogden and Fisher to be used with or without the dog variable. The protocol consisted of 6 interventions with the dog (intervention group) and 6 interventions without the dog (control group. Each session lasted 60 minutes. The dogs chosen were a male Cavalier Kin Charles and a male crossbreed between a Cane Corso and a Pitbull terrier as they have opposite morphological and character characteristics. | Results indicated that there was no significant difference in the level of emotional dysregulation, pre and post intervention, in both the interventional and control group. When looking specifically at depressive and post-traumatic stress symptoms, the intervention group showed more consistent pattern of emotional stabilization from pre to post intervention |
| Spinazzola et al (2011), USA | Hatha yoga consists of the practise of physical postures and breath work to engage in meditation. Yogic breathwork involves controlling both the depth and rate of one's breathing during the practise. are also encourages to practise illustration within their own body. This refers to the exploration of their body movements and the associated physical sensation's as well as self-awareness of the duration, speed of intensity of actions to increase overall self relaxation and care | Yoga breath interventions have shown to have clinically significant benefits in a variety of studies. For example, in yoga tested among survivors of the 2003 Southeast Asia tsunami, results found a significant reduction of symptoms of PTSD Ans depression. In the first case study (Samantha), staff at her facility reported nearly a 50% reduction in the number of behavioural incidents caused by her within the first 3 months of practising yoga. As for Danny, he reported feeling more aware of his body and physical sensations at the end of his classes when prompted by the Yoga teacher |

Table 5 Continued

| Author (Year), Country | Therapeutic Technique | Therapeutic Efficacy |
|---|---|---|
| Warner et al (2004), USA | Sensory Motor Arousal Regulation Treatment (SMART) is a trauma based somatic psychotherapy that aims at regulating children/adolescents, who are traumatized, through the use of basic sensory motor input tools and therapist skills. SMART therapist utilizes the use of sensory rooms that include items such as physio balls, mini trampolines, low balance beams, stepping stones, blankets.etc.... Clients are encouraged to utilize the tools that help the most with their own regulation. While the client is utilizing these tools their therapist works towards having their client become comfortable expressing their feelings about their traumatic experience | Efficacy not reported |
| Warner et al (2013), USA | Occupational therapists (OT) meet with each resident individually to develop a unique "sensory diet" to determine which senses may help improve the residence sense of groundless in the body. Residents are then provided a safe environment where they can practise and rehearse these down-regulation skills using items geared towards to the five sense (i.e. Touch- manipulative hand held games, lotions , visual- lighting changes..etc....) | In one residential program, A 68 % reduction in restraints was observed from fiscal year 2005 to 2006, a 26 % reduction from fiscal year 2006 to 2007 and a 3 % reduction from fiscal year 2007 to 2008 after the implementation of a smart room. In another program, almost immediately, with the addition of sensory strategies, the use of restraints was decreased by 80 to 90 %. The positive changes in student behavior reported by the staff |

Figure 1. Flow diagram of scoping review article selection



# CHAPTER 3: SENSORY SENSITIVITY IN PTSD: A QUESTIONNAIRE STUDY INVESTIGATING THE RELATIONBETWEEN SYMPTOMOLOGY, FUNCTIONAL IMPAIRMENT, AND SENSORY SENSITIVITY

**Abstract**

**Objective:** Sensory sensitivity refers to a sensory process by which individuals are more acutely aware of the experience of sensation. It can be further categorized into raw sensory sensitivity (a decrease in the threshold of detection of sensory stimuli) and affective sensory sensitivity (integration of heightened emotional response to sensory experience). Despite recent interest in the understanding of how sensory processing is altered in post traumatic stress disorder (PTSD), a paucity of research exists pertaining to how sensory sensitivity affects daily function among individuals who are trauma-exposed/ diagnosed with PTSD. Accordingly, we examined the presence and severity of raw and affective sensory sensitivity and its relation to dissociation and overall functional impairment within a population of trauma-exposed individuals,

**Method:** Individuals reporting trauma exposure and meeting criteria for a probable diagnosis of PTSD completed a battery of seven questionnaires via Redcap (online survey platform): the PTSD Checklist for DSM-5 (PCL-5), World Health Organization Disability Assessment Scale (WHODAS 2.0), Highly Sensitive Person Scale (HSP), Sensory Perception Quotient-35 Item (SPQ-35), Adverse Childhood Experience (ACE), Multiscale Dissociation Inventory (MDI) and Difficulties in Emotion Regulation Scale (DERS). All questionnaires were completed at one timepoint.

**Results:** Significant moderate correlations were found between functional impairment, dissociation, and both measures of sensory sensitivity. No measure of sensory sensitivity was associated with exposure to adverse childhood events. Interestingly, when controlling for dissociative symptoms, increased raw sensory sensitivity, as measured by the SPQ, was a significant predictor of increased functional impairment; no such effect emerged for affective sensitivity as measured by the HSP. Lastly, neither measure of sensory sensitivity was a

significant mediator or moderator of the relation between dissociation and functional impairment.

**Conclusion:** Higher levels of raw and affective sensory sensitivity are associated with elevated levels of dissociation and of functional impairment among trauma-exposed individuals. After controlling for dissociation, only raw sensory sensitivity predicted functional impairment. These findings highlight the need for further exploration of the impact of sensory sensitivity on the expression of PTSD and the downstream influence of this condition on functioning in the everyday world.

**Key words:** Sensory sensitivity; functional impairment; dissociation; posttraumatic stress disorder

**Significant Outcomes**

- More severe symptoms of both raw and affective sensory sensitivity were associated with more severe symptoms of functional impairment and elevated levels of dissociation among a trauma-exposed sample
- After holding dissociation constant, only raw sensory sensitivity remained a significant predictor of increased levels of functional impairment in this sample

**Limitations**

- Participants in this sample were trauma exposed and met criteria for a probable diagnosis of PTSD following self-report of symptom profile. Semi-structured clinical interviewing would assist in establishing a definitive diagnosis of PTSD in subsequent studies.
- The Highly Sensitive Person scale (HSP) was not intended to be used a diagnostic tool and should be interpreted cautiously.

- The Sensory Perception Quotient (SPQ) was validated in a population with adults with autism spectrum disorder (ASD) as compared to age- and sex-matched healthy controls. The scale is not validated in trauma populations and thus may not capture the extent to which individuals with PTSD experience sensory sensitivity

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## Introduction

Posttraumatic stress disorder is a debilitating mental illness that may develop after exposure to one or more traumatic events. It is often categorized by symptoms of re-experiencing, hypervigilance and hyperarousal, emotional dysregulation and, in some cases, emotional shut down (Powers et al., 2014; Bradley et al., 2011). Regardless of symptom profile, research has found an overwhelmingly strong relationship between PTSD symptomatology and functional impairment in one's daily life (Westfal et al. 2011; Jellestad et al., 2021). Here, we explore sensory sensitivity among individuals with a provisional diagnosis of PTSD, placing particular emphasis on its effects on functional impairment. Here, previous research points towards a strong link between sensory sensitivity and adverse outcomes such as negative affect (Van Reyn, Koval & Bastian, 2022), dissociation (Melfsen et al., 2021), and overall functional impairment (Fischer et al., 2010) across a variety of study populations. Accordingly, we hypothesized that individuals with a probable diagnosis of PTSD would show higher levels of sensory sensitivity that were associated with elevated levels of dissociation and functional impairment. Given the role of dissociation in predicting functional impairment among individuals with PTSD, we explored whether sensory sensitivity mediated any potential relation between functional impairment and dissociation.

The ability to interact with the outside world is strongly dependent on the ability to effectively integrate incoming stimuli and execute context-appropriate behavioural responses. In the aftermath of trauma, this detection system may become dysregulated, thus affecting the ability to distinguish between threatening and nonthreatening stimuli (Fleming, Harnett & Ressler, 2024). Consequently, individuals may experience heightened sensitivity to incoming internal and external stimuli (Warner et al., 2020). Sensory sensitivity, a possible result of

sensory dysregulation, is defined as neurobiological disposition to being sensitive to subtle stimuli (Warner et al., 2020). In the general population, clinically significant sensory sensitivity is described as a symptom of Sensory Processing Disorder (SPD). In the context of PTSD, research points towards overlapping psychological characteristics among those diagnosed with SPD and those diagnosed with PTSD. Most commonly, this overlap occurs in the emergence of extreme response to stimuli from both the body and the external environment (Engel-Yeger, Palgy-Levin & Lev-Wiesel, 2013). This symptom presentation is even more pronounced if the stimuli is associated with memories and emotions of the traumatic event (Engel-Yeger et al., 2013)

Here, sensory sensitivity refers to sensitivity too affective and too raw sensory patterns. Specifically, whereas raw sensory sensitivity occurs when the threshold of sensory experience is decreased leading to conscious awareness of subtle stimuli (Tavassoli, Hoekstra & Baron-Cohen, 2014), affective sensory sensitivity occurs when heightened feelings and emotions are integrated into the experience of sensory sensation (Aron & Aron, 1997).

Regardless of the type of sensory sensitivity occurring, the detection of subtle and irrelevant stimuli, especially in the aftermath of trauma, can lead to experiences of sensory overload. Indeed, sensory overload is a hallmark symptom of sensory sensitivity. Here, research has linked experiences of sensory overload to negative affect and overall feelings of distress (Aron, Aron & Davies, 2005; Benham, 2006). Classically, dissociation (a feeling often associated with not being present in one's own body or in the surrounding world) may emerge as a coping mechanism when faced met with an overwhelming number of stimuli, thus increasing ability to tolerate (or to survive) the stress of the environment (Melfsen et al., 2021). Despite increased understanding of sensory overload in response to sensory sensitivity in the aftermath of

trauma, there remains a gap in understanding of the impact of this relation on overall functioning in daily life.

Accordingly, the primary aim of the present study was the investigate the relation between raw and affective experiences of sensory sensitivity, functional impairment, and dissociation in a sample of individuals who are trauma-exposed with a presumptive diagnosis of PTSD as defined by a cut-off score of 33 on the PTSD Checklist for DSM-5 (PCL-5). This aim was explored by: (1) determining correlational relations between measures of dissociation (Multiscale dissociation inventory (MDI)), functional impairment (World Health Organization Disability Assessment Scale (WHODAS) and sensory sensitivity (Highly Sensitive Person Scale (HSP) and Sensory Perception Quotient (SPQ);) (2) determining the extent to which sensory sensitivity predicts dissociation and functional impairment; and (3) investigating whether sensory sensitivity mediates the relation between dissociation and functional impairment. As hyperarousal to stimuli and dissociation have been well documented as symptomology in PTSD (Frewan & Lanius., 2006; Weston et al., 2014), it was hypothesized that increased sensory sensitivity would be associated with negative symptom outcomes of functional impairment and dissociation in this population.

## Materials and methods

### *Participants*

One hundred and sixty-six participants were recruited to participate in this study. One hundred forty-six participants were included in analysis as 20 participants were missing significant amounts of data that could not be imputed.  and subsequently removed. To ensure that the population being analyzed met a probable diagnosis of PTSD, a PCL-5 cut-off criterion of

33, as recommended by Weather et al (2013) was used. Thirty-three respondents did not meet this criterion and one outlier was removed from the data, leaving a final sample size of n=112. Individuals who self-identified as trauma exposed and having a diagnosis of PTSD were recruited through social media advertisements (e.g., Facebook, Instagram, LinkedIn, Kijiji) or Amazon Mechanical Turk (Mturk). All participants were in either Canada or the United States. A demographic summary is provided in Table 1.

Inclusion criteria for this study included a self-report of trauma exposure and a self-reported diagnosis of PTSD, ability to provide written informed consent, and aged between 18 years old to 65-year-old. Exclusion criteria was this study included the inability to read, write, or communicate in English, currently receiving treatment with anti-cholinergic or anti-psychotic medication or psychostimulants, use of benzodiazepines in the past 24 hours, had ECT within the past year, diagnosis of substance dependence or abuse in the past 6 months, a recent history (within the past 12 months) of medical disorders known to adversely affect cognition (e.g. Alzheimer's , Attention Deficit/hyperactivity Disorder. Dementia with Lewy bodies disease, Epilepsy, Primary progressive aphasia, Multiple Sclerosis, Parkinsons), a history of traumatic brain injury and/ or loss of consciousness lasting more than 60 seconds and lastly, have a history of neurological or neurodevelopmental disorders.

*Online Questionnaire Battery*

All participants completed a battery of seven online self-report questionnaires via Redcap survey platform in the following order:

*PTSD Checklist-5 (PCL-5; Weathers et al., 2013)*: A 20-item questionnaire used to evaluate PTSD symptom severity informed by the Diagnostic and Statistical Manual of Mental Disorders,

5th Edition (DSM-5). The questionnaire has excellent internal consistency (α = .94) and good test-rest reliability (r = .82)

*Highly Sensitive Person Scale (HSP, Aron & Aron, 1997):* A 27-item questionnaire used to evaluate the affective nature of sensory processing sensitivity in the general population. The HSP has good internal consistency (α = .87) and moderate convergent validity (r = .64).

*Sensory Perception Quotient-35 Item (SPQ-35, Tavassoli et al., 2014*): A 35-item questionnaire used to evaluate basic/raw sensory processing hypersensitivity in a population of adults with ASD. Good internal consistency was found (α = .93).

*World Health Organization Disability Assessment Schedule* (WHODAS 2.0; Üstün et al., 2010): A 36-item measure of disability and health across the six domains of: Cognition, Mobility, Self-Care, Getting Along, Life Activities and Participation. The WHODAS has overall great test-retest reliability (α = .98) and High Internal consistency at the domain level (0.52-0.94)

*Adverse Childhood Experience Questionnaire* (ACE; Felliti et al., 1998): A 10-item questionnaire used to measure the impact of traumatic experience that occurred during an individual's childhood through domains such as neglect, abuse, or overall household dysfunction. The questionnaire has good internal consistency (α = .88)

*Difficulties in Emotion Regulation Scale (DERS; Gratz & Roemer, 2004)*: A 36-item questionnaire use to measure emotion regulation difficulties across the six domains of awareness, clarity, nonacceptance, strategies, impulsivity and goals. The DERS has great internal consistency (α = 0.96) and good test-retest reliability (Ω = .88),

*Multiscale Dissociation Inventory (MDI; Brière, 2002)*: A 30-item questionnaire used to measure the frequency of dissociative symptoms across the six domains of depersonalization,

derealization, disengagement, emotion constriction, identity dissociation and memory disturbances. The MDI shows great internal consistency Internal consistency ($\alpha = 0.96$) and overall god reliability

*Statistical Analysis*

Prior to any analysis, data were checked for normality using the Shapiro-Wilk test of normality and for outliers using the Grubbs' test for outliers. Data was found to be not normal for all measures therefore non-parametric tests were used. All analyses were completed using R Studio RStudio 2023.06.2+561. To ensure that data collected from recruitment avenues of Amazon Mechanical Turk (Mturk) and social media were consistent with each other, preliminary correlations were performed. Each data set was found to show similar levels of association and therefore were collapsed into one data pool. The data frame was further isolated into participants that met a cut-off of a score of 33 on the PCL-5 leaving a final data set of 113 participants. All questionnaires used were scored according to clinical interpretation as noted within their respective psychometric validation literature. To note, the SPQ is reversed scored meaning that lower scores correspond to higher sensory sensitivity and higher scores correspond to lower scores of sensory sensitivities. For the purposes of this study, the subscales of depersonalization and derealization were combined and used as a measure of dissociation.

To account for non-normality, Spearman's correlations were conducted on WHODAS total scores (scored via complex scoring (Üstün et al., 2010), PCL-5 total scores, DERS total scores, ACE total scores, HSP total scores, SPQ total scores and MDI depersonalization + derealization subscale (scored via t-scores, Brière et al, 2005) to determine basic relationships between variables. Results of this analysis can be found in Figures 1, 2 and 3. To measure the extent to which sensory sensitivity and dissociation predicted levels of functional impairment,

robust regression analyses were conducted. To further investigate the effects of sensory sensitivity on the relationship between dissociation and functional impairment, mediation analysis using the PROCESS macro (Model 4) designed by Andrew F. Hayes (2022) was performed.

## Results

### *Clinical and demographic characteristics*

The clinical and demographic characteristics of the sample are displayed in Table 1 and Table 2. The sex of the sample was predominately female (73.4%) followed by male participants (10.1%) followed by intersex respondents (0.7%). The mean age of the sample was 35.9 years old (SD=12.6). Interestingly, of the occupations listed, the most common reported occupation was first responder/public safety personnel (33%) followed by other (7.9%). The majority of participants reported that they had completed university/college and were married. Regarding clinical measures, the study sample reported an average weighted score of 16.3 (SD =3.43) on the WHO-DAS 2.0 which corresponds to a percentile range of 78.4% to 82.7% as compared to the general population, indicating overall moderate functional impairment. The highest functional impairment scores were found to be from the life activities subscale of the WHO-DAS 2.0, defined as domestic responsibilities, work and leisure, amongst the study population. On average, participants reported higher scores on the HSP (Mean=141.59 (SD = 21.55) and lower scores on the SPQ (Mean = 75.80 (SD = 11.98)) indicating overall higher affective and raw sensory sensitivity. Interestingly, dissociation scores were the highest on the subscale of depersonalization (t-score (avg) =112.0 (SD=38.7)).

### *Correlational Relations*

In line with our hypotheses, both measures of heightened sensory sensitivity correlated with the majority of variables of interest analyzed (see Figures 1-4). Most notably, individuals with a presumptive diagnosis of PTSD exhibited a positive relation between sensory sensitivity and measures of functional impairment (HSP: $\rho$ =0.274, $p$ =.003: SPQ: $\rho$ =-0.309, $p$ = < .001) and dissociation (HSP: $\rho$ =0.304, $p$ =.004: SPQ: $\rho$ =-0.286, $p$ =.007). Higher levels of sensory sensitivity were also significantly correlated with PTSD symptom severity as measured by the PCL-5 (HSP: $\rho$ =0.43, $p$ = < .001): SPQ: $\rho$ = -0.27, $p$ =.002). Despite significant correlations between symptom severity, dissociation and functional impairment, non-significant correlations appeared between sensory sensitivity and measure of emotion dysregulation and instances of childhood exposure to adverse events.

*Regression Analyses*

Given that this dataset was found to have non-normal data, robust regression techniques were employed to ensure reliability of our findings. Each test was performed to investigate the predictive value of sensory sensitivity on functional impairment while holding dissociation constant. In all cases, dissociation was found to be a significant positive predictor of functional impairment when holding sensory sensitivity constant ($p < 0.05$). For each measure of sensory sensitivity, however, a conflicting pattern of results were found. Specifically, when HSP sensory sensitivity scores were used as a predictor of functional impairment, holding dissociation constant, a non-significant relation was found ($\beta$ =3.14e-04, $p$ = .07), albeit approaching the threshold of significance. By contrast, sensory sensitivity as captured by the SPQ was a significant positive predictor of functional impairment when holding dissociation constant ($\beta$ =-6.47e-04, $p$ =.03). Interactions between sensory sensitivity measures and dissociation were added to the model and found to be non-significant and therefore not reported,

*Mediation Analyses*

To control for non-normality of data, 5000 bootstraps samples were used for each mediation analysis. Using the SPQ as a mediator, results found both a significant total (β =0.0005, $p < .001$) and direct effect (β =0.0005, $p < .001$) of dissociation and functional impairment indicating a non-significant mediation effect. Confidence intervals of the indirect effect of SPQ on the relation approached threshold of partial mediation (BootLLCI= -0.0003, BootULCI=0.1371). When HSP was entered as mediator of relation between dissociation and functional impairment, analysis revealed a significant total (β =0.0001, $p < .001$) and direct effect (β =0.0001, $p < .001$), indicating a non-significant mediation effect. In line with the results from the SPQ, confidence intervals of the indirect effect of SPQ on the relation approached the threshold of partial mediation (BootLLCI= -0.0009, BootULCI=0.1353)

**Discussion**

To our knowledge, this is the first study to investigate raw and affective sensory sensitivity in relation to symptom severity, functional impairment, and dissociation in a population of individuals who have been exposed to trauma and meet criteria for a probable diagnosis of PTSD. As expected, more severe symptoms of PTSD were associated with elevated increased levels of raw and affective sensory sensitivity. In turn, participants with more severe sensory sensitivity displayed increased levels of both dissociation and functional impairment. Interestingly, after holding dissociation constant, whereas raw sensory sensitivity was a significant predictor of functional impairment, affective sensory sensitivity was not. Finally, both measures of affective and raw sensory sensitivity approached marginal significance in partially mediating the relation between dissociation and functional impairment

Although the SPQ was designed to capture sensory perception independent of social or affective response, this finding was unexpected (Tavassoli et al., 2014). Previous research on children/adolescents with psychiatric symptomology have found that, in the presence of overwhelming stimuli and problematic sensory processing patterns, emotional dysregulation increased (Cheng & Boggett-Carsjen, 2005; Sperati et al., 2024). In our sample, however, no such significant relation emerged between raw sensory sensitivity and emotion dysregulation. Taken together, these findings suggest that emotional dysregulation may be more pronounced in the face of sensory overload among children as compared to adults Perhaps more probable, however as defined with the SPQ-35, do not capture fully the type of sensory events that lead to negative changes in affect. Further research is warranted to examine more specifically the effects of raw sensory sensitivity in emotional dysregulation in adults with and without PTSD and other psychiatric disorders.

Surprisingly, sensory sensitivity was not associated with exposure to adverse childhood events despite earlier investigations that point towards alterations in the neuronal functioning of individuals exposed to childhood trauma, particularly in areas critical to somatosensory processing, sensory integration, and motor output (Van der Kolk.,2005; Holland & May-Benson, 2014). These early results suggest strongly that childhood trauma has a profound effect on one's ability to effectively integrate sensory stimuli, a pattern that persists into adulthood. In the present study, it was unclear whether participants were exposed to childhood or to adult trauma, either of which has the potential to alter sensory processing. In line with this hypothesis, significant relations emerged between sensory sensitivity and the overall severity of PTSD symptoms among respondents,

We further examined the relation between sensory sensitivity and functional impairment. We hypothesized that sensory sensitivity would be a significant predictor of functional impairment, even with the effects of dissociation held constant. The regression analysis revealed that whereas raw sensory sensitivity was a significant predictor of functional impairment (β = -6.47e-04, $p$ = .03), affective sensory sensitivity was marginally not significant (β = 3.14e-04, $p$ =.07). Here, whereas the regression analysis performed for affective sensory sensitivity explained only 13% of the variance in the model, the analysis for raw sensory sensitivity explained 33% of the model variance. As expected, on both regression analysis, dissociation was a strong significant predictor of functional impairment. Together, these results suggest that both raw sensory sensitivity and dissociation (for a similar pattern of findings, see Boyd et al., 2020) contribute to functional impairment among individuals with PTSD.

Here, previous research has revealed robust alterations evidence that emotionality plays a distinct role in one's ability to accurately discriminate amongst incoming sensory stimuli. For example, one study investigating visual learning in healthy adults reported processing and discrimination of neutral stimuli was impaired after their association with adverse stimuli (Shalev, Paz & Avidan., 2017). Discrimination of threatening versus non-threatening stimuli also plays a crucial role in in one's ability to function within their everyday environment (Keefe et al., 2022) (Blekić et al, 2021). The present study contributes to this body of literature by revealing that raw sensory sensitivity has a more significant impact on functional impairment in PTSD than does affective sensory sensitivity, thus improving understanding of the dysregulation in sensory processing that appears to characterize PTSD.

Finally, the current study aimed to investigate whether raw and/or affective sensory sensitivity mediated the relationship found between dissociation and functional impairment. We

hypothesized that individuals who experienced higher levels of dissociation would experience higher levels of sensory sensitivity which would in turn lead to higher levels of functional impairment. For both raw and affective sensory sensitivity, regression analysis found both a significant indirect and direct effect indicating a strong relationship between dissociation and functional impairment sensory sensitivity is not a full mediator of the relation between dissociation and functional impairment. Nevertheless, confidence intervals from both analyses were just below statistical threshold, suggesting that sensory sensitivity may emerge as a partial mediator of this relation in larger sample sizes.

Our findings are consistent with prior research that identified a strong relation between dissociation and functional impairment (Boyd et al., 2017; Boyd et al., 2020). Although not significant in this sample, the possible marginal partial mediation effect that both raw and affective sensory processing have the on the relation between dissociation and functional impairment aligns with studies suggesting that changes in sensory processing, such as sensory sensitivity, contributes to experiences of dissociation in trauma-exposed populations (Kearney & Lanius ,2022)

The results of the current study must be considered within a framework that considers its strengths and limitations. One potential strength is that data were collected through anonymous self-report questionnaires, thus having the potential to minimize any response bias that occurs during face-to-face assessment. Nevertheless, semi-structured clinical interviews are necessary to confirm diagnoses of PTSD in this sample. With respect to limitations, this current study has number of notes. Firstly, data was collected in a cross-sectional format without a control group present. This meant that conclusions could not be definitively made surrounding changes over time nor cam we confidently establish a cause-and-effect relation between sensory sensitivity

and the variables of interest. With respect to the measures used to capture sensory sensitivity, The HSP was not intended to be used a diagnostic tool and should be interpreted cautiously. In addition, the SPQ was validated in a population of adults with autism spectrum disorder as compared to age- and sex-match healthy controls. The scale is not validated in trauma-exposed populations and therefore may not capture the extent to which those with PTSD experience sensory sensitivity. The creation of trauma-informed sensitivity scale is warranted.

These results provide nascent information only concerning the role that sensory sensitivity has on symptom experience among individuals exposed to trauma and diagnosed with PTSD. Instead, these findings provide preliminary evidence of the association that sensory processing sensitivity has on dissociative symptomology and in turn, functional impairment. Given the limitations identified above, the present findings must be interpreted with caution. Future research may also identify additional factors associated with sensory sensitivity, such as emotional dysregulation and social support, that might influence further the relation between dissociation and functional impairment further. Finally, a longitudinal study examining changes in sensory sensitivity over time following a traumatic event has the potential to identify casual mechanisms surrounding the overall impact of sensory sensitivity on PTSD, dissociation, and related functional impairment.

**Acknowledgement**

None.

**Declaration of Interest**

None.

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**Tables and Figures**

Table 1: Demographic characteristics of study sample

| Characteristic | |
|---|---|
| **Age (Mean (SD))** | 35.86 (2.59) |
| **Sex (N)** | |
| o Male | 14 |
| o Female | 102 |
| o Intersex | 1 |
| o Not specified | 1 |
| **Race (N)** | |
| o Aboriginal | 10 |
| o Black | 3 |
| o South/East/Southeast Asian | 10 |
| o Hispanic | 4 |
| o Middle Eastern | 2 |
| o White | 96 |
| o Other | 3 |
| **Education level completed (N)** | |
| o Some high school | 1 |
| o Completed high school | 13 |
| o Some college/university | 32 |
| o Completed college/university | 40 |
| o Some graduate level education | 12 |
| o Completed graduate degree | 16 |
| **Marital Status (N)** | |
| o Single | 56 |
| o Married/Common-law | 29 |
| o Separated/Divorced | 20 |
| o Long-term relationship | 11 |
| o Other | 1 |
| **Employment Type (N)** | |
| o Active military member | 1 |
| o Veteran | 1 |
| o First responder/Public safety worker | 6 |
| o Healthcare Provider | 16 |
| o Not Currently Employed | 39 |
| o Other | 52 |

Table 2: Clinical characteristics of study sample

| Characteristic | Mean (SD) |
|---|---|
| **PCL-5 Total** | 51.55 (11.35) |
| **WHODAS** | |
| o Cognition | 11.54 (2.83) |
| o Mobility | 11.26 (4.25) |
| o Self-care | 14.05(4.67) |
| o Getting along | 14.33 (4.32) |
| o Life activities | 19.80 (5.62) |
| o Participation | 9.70 (2.50) |
| WHODAS Total | 16.28 (3.43) |
| **HSP Total** | 141.59 (21.55) |
| **SPQ Total** | 75.80 (11.98) |
| **ACE Total** | 4.98 (2.17) |
| **MDI*** | |
| o Disengagement | 83.79 (17.72) |
| o De**p**ersonalization | 112.04 (38.70) |
| o Derealization | 88.97 (28.19) |
| o Emotion constriction | 83.56 (22.29) |
| o Identity dissociation | 73.55 (39.37) |
| o Memory disturbances | 83.53 (28.36) |
| o Depersonalization + Derealization | 172.65 (42.98) |
| **DERS Total** | 105.84 (22.62) |

*MDI scores have been t-scored for analysis as required by Brière, Weathers and Runtz, 2005

Table 3(A-B): Robust Regression analysis of functional impairment with predictors of dissociation and sensory sensitivity. Significance was measured at *a=0.05*. (A- HSP scores B- SPQ scores)

**A.**

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 4.01e-02 | 2.42e-02 | 1.67 | 0.09 | 0.13 |
| *HSP* | 3.14e-04 | 1.726e-04 | 1.82 | 0.07 | |
| *Dissociation* | 4.65e-04 | 8.80e-05 | 5.28 | 9.37e-07 | |

**B.**

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 1.35e-01 | 3.05e-02 | 4.43 | 2.74e-05* | 0.33 |
| *SPQ* | -6.47e-04 | 2.93e-04 | -2.20 | 0.03* | |
| *Dissociation* | 4.57e-04 | 8.58e-05 | 5.33 | 7.91e-07 | |

Figure 1: Heatmap correlational matrix for all variables of interest (VOI)

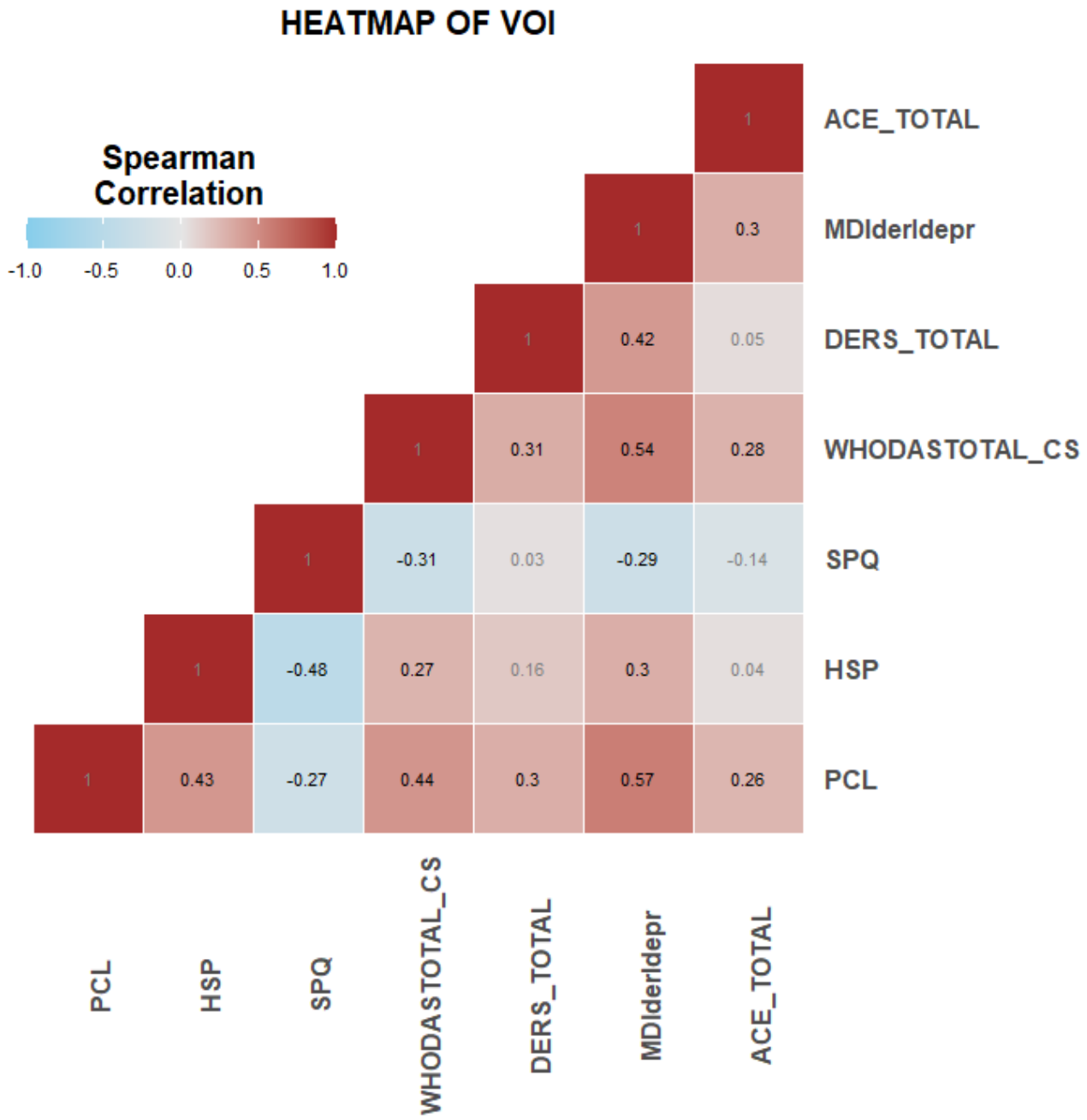


Figure 2: Scatterplot of WHODAS total scores and MDI derealization + depersonalization subscale ($\rho$=0.546, $p$ <.001)

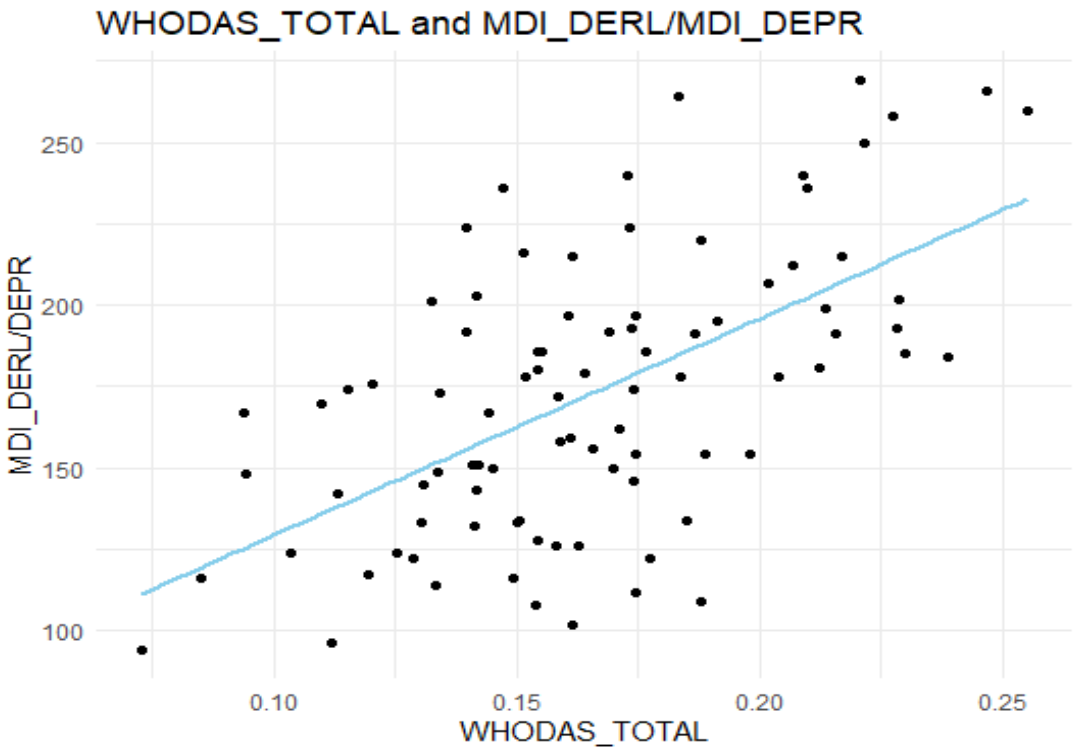


Figure 3(A-B): Scatterplots of WHODAS total scores and HSP/SPQ scores. (A) WHODAS Total scores and HSP scores (ρ=0.274, $p$ = .003) (B) WHODAS Total scores and SPQ scores (ρ= -0.309, $p$ <.001)

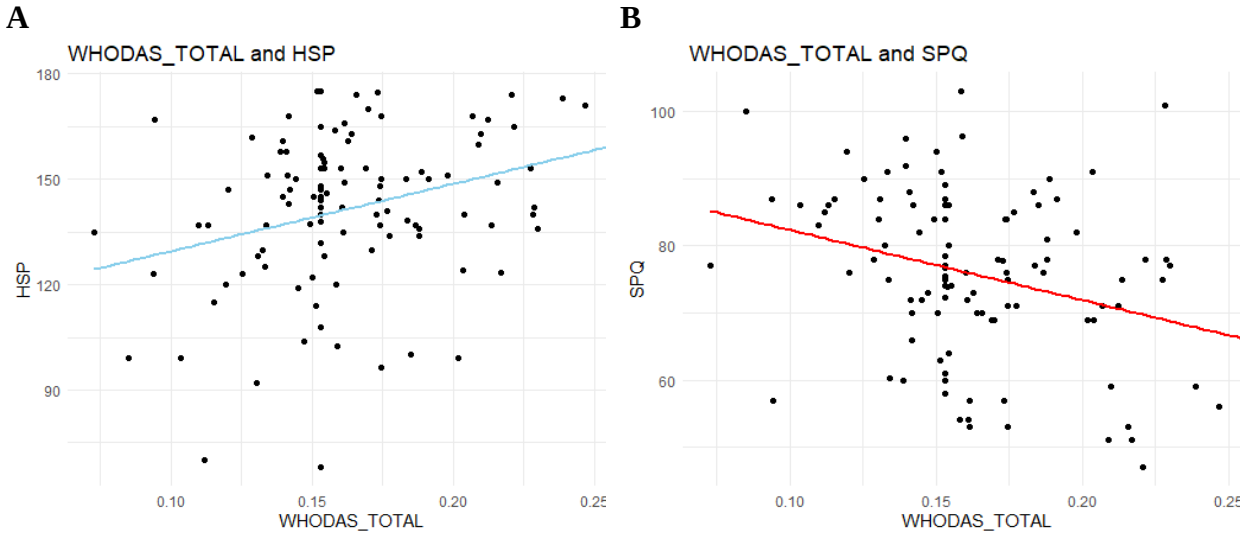


Figure 4(A-B): Scatterplots of and MDI derealization + depersonalization subscale and HSP/SPQ scores. (A) and MDI derealization + depersonalization subscale and HSP scores (ρ=0.304, *p*= .004) (B) and MDI derealization + depersonalization subscale and SPQ scores (ρ= -0.*286 p* = .007)

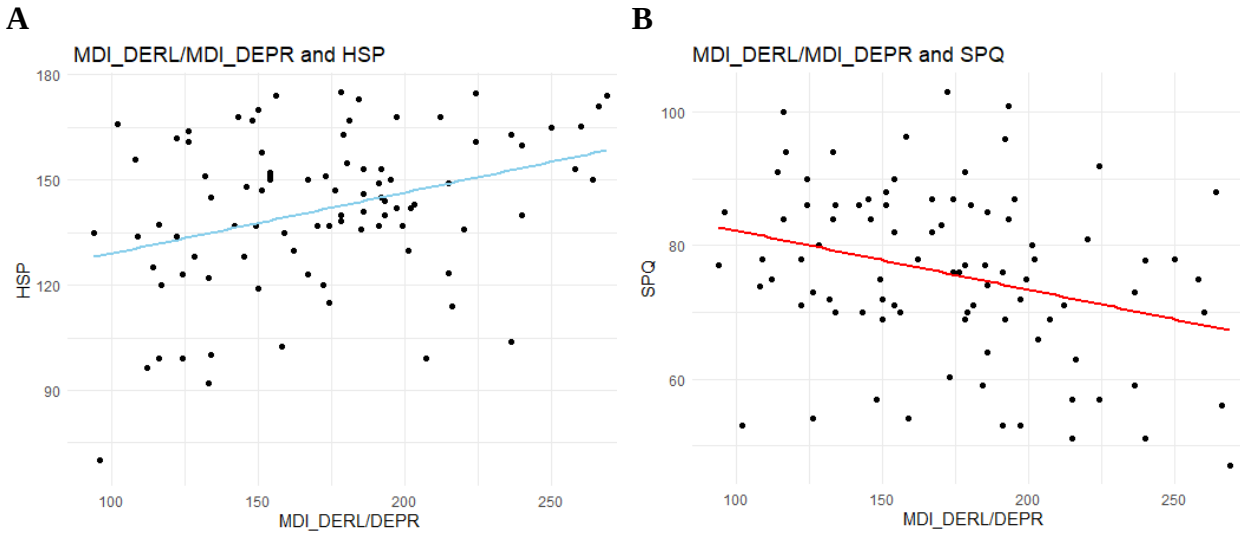
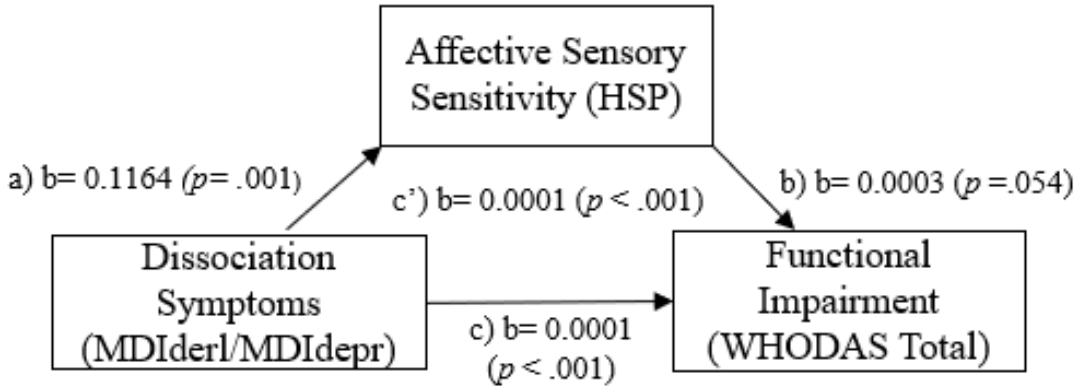


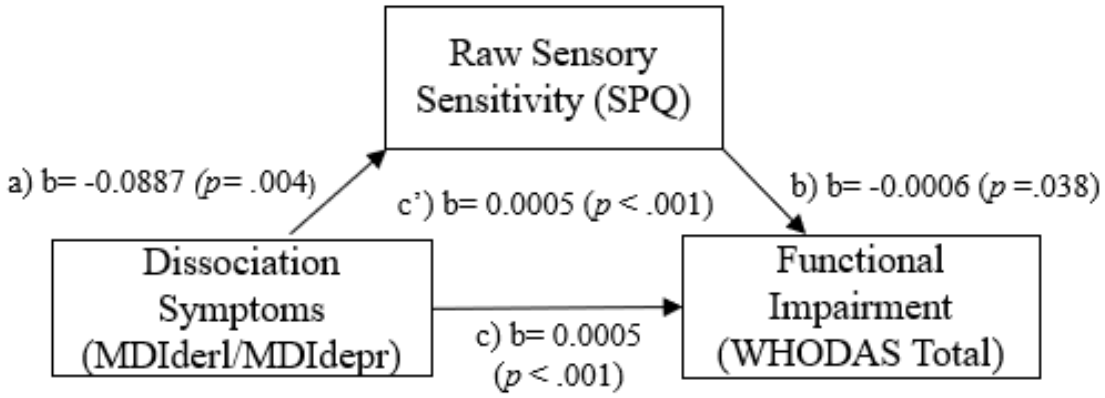
Figure 5 (A-B): Mediation analysis of sensory sensitivity measures on the relationship between dissociation and functional impairment. (A) HSP scores as a mediator (B) SPQ scores as a mediator

**A.**




b = unstandardized coefficients; a = effect of Midler/MDIdepr on change in HSP, b) effect of HSP on change in WHODAS Total; c = the total effect; c' = the direct effect. HSP (Highly Sensitive Person scale), MDIderl/MDIdepr (Multiscale Dissociation Inventory) WHODAS, World Health Organization Disability Assessment Schedule 2.0

**B.**




b = unstandardized coefficients; a = effect of MDIderl/MDIdepr on change in SPQ, b) effect of SPQ on change in WHODAS Total; c = the total effect; c' = the direct effect SPQ (Sensory Perception Quotient), MDIderl/MDIdepr (Multiscale Dissociation Inventory) WHODAS, World Health Organization Disability Assessment Schedule 2.0

# CHAPTER 4: THE RELATIONSHIP OF TEST PERFORMANCE ON SENSORY-BASED COGNITIVE ASSESSMENTS ON FUNCTIONAL IMPAIRMENT AND DISSOCIATION IN A SAMPLE OF PUBLIC SAFETY PERSONNEL

**Abstract**

**Objective:** Public safety personnel (PSP) are exposed to demanding, and at times, traumatising, environments that require both adequate sensory processing and effective cognitive performance to engage in. Although a substantial body of evidence points towards deficits in cognitive functioning among individuals with posttraumatic stress disorder (PTSD), little investigation has occurred to examine the interplay of between sensory processing and cognitive performance in this population. Here, I examined test performance on sensory-based cognitive assessments in relation to functional impairment and experience of dissociation in a sample of trauma-exposed public safety personnel.

**Method:** PSP completed three questionnaires: the PTSD Checklist DSM-5 (PCL-5), the World Health Organization Disability Assessment Scale 2.0 (WHODAS 2.0), and the Multiscale Dissociation Index (MDI). In addition, participants completed computer-based tasks assessing cognitive performance that relied in part on the processing of sensory information or completion.

**Results:** Among trauma-exposed PSP, significant correlations were found between cognitive task performance, as measured by Rotations and Polygons, and emotion constriction subscales of dissociation. Additionally, decreased performance on Rotations (a task reliant on visuospatial processing, spatial manipulation and spatial working memory) was associated with elevated levels of functional impairment. This relation held even after holding dissociation constant. The interaction between Rotations and dissociation was not a significant (a=*0.95)* predictor of functional impairment. Finally, marginal significance was found for a partial mediation of cognitive performance, as measured by Rotations, on the relation between dissociation and functional impairment.

**Conclusion:** Deficits on a cognitive task reliant on visuospatial processing, spatial manipulation, and spatial working memory predicted overall functional impairment among PSP with a presumptive diagnosis of PTSD. Cognitive dysfunction on tasks heavily reliant on visual spatial processing may contribute to functional impairments seen commonly in this condition.

**Key words:** Posttraumatic Stress Disorder; Sensory processing; Cognitive performance

**Significant Outcomes**

- Rotations, a cognitive task used to measure visuospatial processing, spatial manipulation and spatial working memory, was a significant predictor of functional impairment when holding measures of dissociation constant. Additionally, the interaction between Rotations and dissociation was found to be a significant predictor of functional

**Limitations**

- The cognitive battery used during data collection does not include cognitive tasks that require processing in the auditory, proprioceptive or olfactory modalities.
- The study was under powered. Further exploration with a larger sample size is warranted.

**Funding Information:** No external funding to be declared for this chapter.

## Introduction

In Canada, the term “Public Safety Personnel (PSP)” encompasses a large group of individuals that protect the safety of the population. This includes occupational titles such as first responders (e.g., police officers, paramedics, firefighters). PSP are amongst one of the largest groups susceptible to exposure to traumatic events, reporting higher rates of severe mental illness (Edgelow et al., 2023). One of the most prevalent mental disorders among the PSP population is posttraumatic stress disorder (PTSD). PTSD is associated with chronic and debilitating symptomology such as hypervigilance, irritability and issues with cognitive performance in domains such as executive functioning and memory (Bryant et al., 2011).

Cognitive performance has been widely studied within PTSD populations in the hopes of uncovering associated cognitive decline. In one study focused on Vietnam Veterans with PTSD, more severe symptoms of PTSD correlated significantly with decreased cognitive performance in the domains of attention and memory (Prieto et al., 2023). Moreover, in a metanalysis aimed at identifying neurocognitive dysfunction in PTSD, the largest effect sizes emerged for deficits in verbal learning, information processing, working memory and verbal memory (Scott et al., 2015). Although not widely defined in the literature, cognitive performance can be further partitioned into lower order sensory-based cognition and higher order integrative cognition (Lemons & Lemons., 2013). More specifically, lower order sensory-based cognition can be defined as cognitive processes that require a heavy emphasis on the integration of incoming stimuli to subsequently formulate appropriate decisions and corresponding actions (Bloom et al., 1956).

In the fast-paced operational theatre, PSP rely heavily on higher-order cognitive systems involved in attention, movement and executive function, that derive their function from lower-

order sensory processing and effective multisensory integration. Sensory processing refers to the ability to process incoming interoceptive and exteroceptive stimuli into subconscious awareness via subcortical brain regions (Alkire, Hudetz &Tononi, 2008). It has been postulated that the both the posterior and anterior insula may serve as gates through which conscious access to sensory information is granted to higher-order brain regions such as the prefrontal cortex (Huang et al., 2021). Once sensations have reached conscious awareness, sensory inputs are combined to create a cohesive experience from which one can make sense of their surroundings and react accordingly (Huang et al., 2021; Mashour, Roelfsema & Changeux, 2020). When this process becomes dysregulated, it becomes increasingly difficult for one to accurately form a cohesive understanding of their environment, thus leading to disordered and inappropriate action (Siemann, VanderWeele & Wallace, 2020). This integration is particularly relevant in an occupational context where an individual relies on accurate perception and action to effectively navigate potentially life or death situations. Despite the sizeable understanding of the effects of PTSD on overall cognitive performance, there remains a gap in the research concerning the relationships of sensory-based cognitive performance on the experiences of dissociation and overall functional impairment

Therefore, the primary aim of the present study was to investigate the relation between sensory-based cognitive deficits, functional impairment, and dissociation in a sample of trauma-exposed PSP with a presumptive diagnosis of PTSD. Given the established relation between dissociation and decreased performance on a variety of neurocognitive tests (Prieto et al., 2023), we hypothesized that poorer performance on cognitive tasks reliant on visuospatial processing be associated with higher levels of functional impairment and of dissociation. Additionally, we

examined whether cognitive performance on spatial processing tasks mediated the established relation between dissociation and functional impairment (Boyd et al., 2020).

## Materials and methods

### *Participants*

Eighty self-identified public safety personnel (PSP) (*N=80)* were recruited to participate in this study. All participants had a self-reported diagnosis of current PTSD [mean age 44.69, SD 8.44]. PSP with PTSD were recruited from the community using target social media advertisements, informational letters and PSP organizations within Ontario, Canada). Inclusion for the study included a self-reported diagnosis of PTSD by a registered health care professional (confirmed to be either PTSD or subthreshold symptoms of PTSD following exposure to a Criterion A event through the administration of the Clinician-administered PTSD scale for DSM-5 (CAPS-5), occupational history as a public safety personnel/ first-responder as defined by the Worker's Safety Board of Ontario Operational Policy Manual (2018), permanent residency in Ontario, and reliable access to a computer and internet connectivity. Exclusion criteria for this study included treatment with anti-cholinergic or anti-psychotic medication, psychostimulants, electroconvulsive therapy (ECT) within the past year, head trauma paired with more than one minute of loss of consciousness, traumatic brain injury, neurological and/or neurodevelopmental disorders or a diagnosis of psychotic disorder for bipolar disorder.

### *Cognitive Test Battery*

Cognitive task used in the current study were completed via the online cognitive testing platform, Creyos (formerly known as Cambridge Brain Sciences; https://creyos.com/) using paradigms from neuropsychological literature. Due to Covid-19 restrictions, participants

completed these tasks via Zoom for Healthcare with a trained facilitator to oversee and technical difficulties that may arise. Participants completed a battery of five tests: (a) Double Trouble, a measure of visual processing and response inhibition; (b) Spatial Planning, a measure of visual spatial processing and planning; (c) Polygons, a measure of visuospatial processing; (d) Rotations, a measure of visuospatial processing and mental rotations; and (e) Monkey Ladder, a measure of visuospatial memory. A more detailed description of each cognitive test can be found in Table 2.

*Self-Report Questionnaires*

*PTSD Checklist for DSM-5 (PCL-5; Weathers et al., 2013):* A 20-item questionnaire assessing PTSD symptom severity created with the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) criteria for PTSD in mind. The question shows good test-retest reliability and convergent validity.

*World Health Organization Disability Assessment Scale (WHODAS 2.0; Üstün et al., 2010)*: A measure of health and disability across six domains of functionality: Cognition, Mobility, Self-care, Getting along, Life activities and Participation. The WHODAS has high test-retest reliability (intra-class coefficient = .93 to .96 at the domain level) as well as internal consistency ($\alpha$ = .94 to .96).

*Multiscale Dissociation Inventory (MDI; Brière, 2002)*: A 30-item measure used to examine the frequency of dissociative symptoms across sic different subscales including disengagement, depersonalization, derealization, emotion construction, identity dissociation and memory disturbances. The MDI demonstrates internal consistency ($\alpha$ = 0.96) and good convergent validity.

*Statistical Analysis*

Prior to any analysis, data were checked for normality using the Shapiro-Wilk test of normality and for outliers using the Grubbs' test for outliers. Data were found to be not normal for all measures therefore non-parametric tests were used. Effect sizes were estimated using Cohen's d. All analyses were completed using R Studio RStudio 2023.06.2+561. All questionnaires used were scored according to their respective clinical interpretation. For the purposes of this study, the subscales of depersonalization and derealization were combined and used as a measure of dissociation. A correlation matrix was created via spearman correlation (two-tailed; $\alpha = 0.05$) of all five cognitive tests (Double Trouble, Spatial Planning, Rotations, Polygons and Monkey Ladder), PCL-5 Total summed score, WHODAS summed score, 6 subscales of the MDI (disengagement, depersonalization, derealization, emotion constriction, identity dissociation and memory disturbances and this study's measure of dissociation. To measure the extent to which test performance on sensory-based cognitive assessments and dissociation predict levels of functional impairment, robust regression analyses were conducted. To further investigate the effects of sensory-based-cognitive assessments on the relationship between dissociation and functional impairment, mediation analyses were conducted on cognitive tests that were deemed significant predictors of functional impairment in the previous regression analyses

**Results**

*Clinical and demographic characteristics*

The clinical and demographic characteristics of the sample are displayed in Table 1 and Table 2. The sample was approximately evenly split between male and female participants with a mean

age of 22.7 years (SD=8.4). Mean scores of each subscale of the MDI did not reach clinical significance as described by Brière et al (2002) and overall mean scores of WHODAS indicated moderate functional impairment with a score of 13.90 (SD=7.88).

*Correlational Relationships*

PTSD symptom severity (PCL-5), functional impairment (WHODAS 2.0) and dissociation (MDI) were all moderately positively correlated to each other ($\rho$ =0.34 – 0.73). Of the cognitive test examined, only test performance on Polygons and Rotations was significantly correlated to self-report measures. More specifically, Rotations performance was negatively correlated to the PCL-5 ($\rho$ = -0.29), WHODAS ($\rho$ = -0.35), MDI-identity dissociation subscale ($\rho$ =-0.37) and MDI-emotion constriction subscale ($\rho$ =-0.25) and Polygons performance was negatively correlated to the PCL-5 ($\rho$ = -0.24) and MDI-emotion constriction subscale ($\rho$ = -0.23).

*Regression Analyses*

Given the presence of non-normal data, robust regression techniques were employed to ensure reliability of our findings. Each test was performed to investigate the predictive value of test performance on functional impairment while holding dissociation constant. In all cases, dissociation was found to be a significant positive predictor of functional impairment when holding test performance constant ($p < 0.01$). Test performance on Double Trouble, Spatial Planning, Polygons and Monkey ladder failed to predict functional impairment when dissociation was held constant. (Double Trouble ($\beta$ = 3.75, p= .23), Spatial Planning ($\beta$ =3.76, $p$ =.48), Polygons ($\beta$ = 5.30, $p$ = .41), Monkey Ladder ($\beta$ = -4.18, $p$ =.49). Conversely, test performance on Rotations was a significant negative predictor of functional impairment ($\beta$ = -9.47, $p < 0.01$).

To investigate this relation further, the interaction of Rotations and dissociation on functional impairment was added to the model. The interaction approached significance (β =0.11, p=.05).

*Mediation Analyses*

As Rotations was the only sensory-based cognitive tests that was significantly correlated with clinical measures (WHODAS 2.0, MDI), a mediation analysis was performed for this cognitive task only. The PROCESS macro (Model 4) designed by Andrew F. Hayes (2022) was used to investigate whether sensory-based cognitive test performance on Rotations mediated the relation between dissociation and functional impairment. To control for non-normality of these data, 5000 bootstrap samples were used to estimate the indirect effect and its confidence intervals. There was a significant total (β =0.0510, $p$ =.0021) and direct effect (β =0.0411, $p$=.0103) of dissociation and functional impairment, indicating a non-significant mediation effect. Nevertheless, confidence intervals of the indirect effect of Rotations on this relationship approached threshold of partial mediation (BootLLCI= -0.0124, BootULCI=0.1904).

**Discussion**

To our knowledge, this is the first study to investigate cognitive processing in a population of PSP through a sensory processing lens. Here, we administered an online, "gamified" cognitive task battery on a sample of trauma-exposed public safety personnel (PSP) to evaluate the relation between spatially based cognitive task performance, dissociation, and overall functional impairment. An additional aim was to determine if the relation between dissociation and functional impairment is mediated, in part, by cognitive task performance on measures assessing spatial processing.

Averaged scores of cognitive task performance across the study sample showed a range of the 53 to 75 percentile scores indicating average to above average performance as compared to the non-trauma exposed general population (Creyos, n.d). In terms of functional impairment and dissociation, the study population showed mild functional impairment and although subclinical, increased levels of dissociation as compared to the general population (Brière et al., 2005; Üstün et al., 2010. These findings were expected of our PSP population as these individuals require a higher level of functionality and cognition to meet their occupational demands (Ricciardelli et al., 2020), such that average cognitive performance may represent a performance decline over previously above average performance in occupation-relevant cognitive domains (e.g., spatial processing; fine motor control).

In line with our hypothesis, spatial task performance on two measures was associated with elevated levels of PTSD symptom severity and functional impairment, and with higher levels of dissociative processing across subdomains of dissociation. More specifically, poor performance on Rotations (a measure of visuospatial processing and spatial working memory) and Polygons (a measure of goal directed visual search) were associated with greater severity of PTSD symptoms and elevated levels of dissociation. Interestingly, decreased performance on Rotations was the only cognitive task to significantly correlate to higher severity of functional impairment. The remaining three spatially based cognitive measures did not predict clinical levels of PTSD; these findings contrast with earlier reports that have linked traumatic and occupational stress in PSP to cognitive deficits in working memory, lexical access, verbal learning and memory (Gutshall et al., 2017; Desrochers et al., 2021), suggesting that the measures administered here assayed dissociable aspects of cognitive processing over those assessed previously. Importantly, and in line with our findings, previous work has revealed a

robust association between spatial working memory deficits and re-experiencing symptomology in PTSD (Mathew et al, 2022; Mirabolfathi, Moradi, & Bakhtiari, 2016). It is notable here that performance on Rotations, a measure of visuospatial processing and mental rotations, is thought to be related on three inter-related aspects of spatial processing that include visuospatial processing, spatial manipulation and spatial working memory. Like any cognitive task, therefore, performance relies on the integration of multiple aspects of cognitive processing that together contribute to task performance.

To investigate further the relation between functional impairment, dissociation, and spatial task performance, multiple regression analysis was preformed. In a model containing Rotations, dissociation, and their interaction as predictors of functional impairment, Rotations remained a significant predictor even when holding dissociation constant. More specifically, higher performance on Rotations was associated with lower levels of functional impairment. In addition, when holding percentile scores of Rotations constant, dissociation was found to be a positive predictor of functional impairment. These results were as expected given the significant correlations found between clinical and cognitive variables described in Figure 1. When examining the predictive power of the interaction of Rotations and dissociation on functional impairment, the relation was found to be marginally significant at the alpha significance level of 0.05 ($\beta = 0.11$, SE = 0.06, t = 1.96, $p$=.05). This suggests that the negative effect of Rotations on functional impairment becomes less pronounced as dissociation increases.

These findings align with previous research showing that individuals with higher dissociation in the aftermath of trauma experience more limited performance in visuospatial processing and working memory leading to functional impairment (Rivera-Vélez et al., 2014; Bruce et al, 2013; McKinnon et al., 2016). This may occur because visuospatial working

memory and visual search are implicated in scanning and planning within one's environment, particularly in the presence of trauma-related stimuli. When faced with negative stimuli, individuals with PTSD tend to use more attentional resources, leading to overall slower visual search speeds and overall increase in visuospatial processing (Olatunji et al., 2012). When met with neutral stimuli, sustained visuospatial attention can impair the individual ability to process the cues in their environment effectively (Evan et al., 2022). As the tasks in the current study have been "gamified" and are neutral in nature, the observed deficit in performance when correlated with higher levels of dissociation and impairment is in line with previous findings.

Lastly, we were interested in examining whether cognitive performance on Rotations mediated the confirmed relationship between dissociation and functional impairment. Rotations was chosen as the only cognitive task to use as a mediator as, in the study sample, this was the only cognitive task to be a significantly correlated to functional impairment and dissociation as well as a significant predictor of functional impairment. Despite marginal significance, Rotations failed to emerge as a partial mediator of this relation.  R This finding provides critical insight into understanding of how ability to perceive information and mentally manipulate in visual space may underly one's ability to stay grounded in their environment. Deficits in this ability may stem from the diminished capacity to experience one's environment effectively (Holland, Jun &Sloan, 2017). Currently, there is limited research investigating the mediating effects of cognitive performance on impairment and symptom outcomes. Although there is emerging evidence suggesting that sleep disturbances, another hallmark symptom of PTSD, and cognitive dysfunction may be a significant mediator of the relationship of impairment and overall PTSD symptomology (Verfaellie et al., 2017). These findings paired with our findings of a marginally significant partial mediation relationship suggest there may be more complex relations

underlying the effects of cognitive performance on the relationship of functional impairment and dissociation in PSP populations.

With respect to study limitations, several point must be considered. Firstly, as sensory processing is a crucial early step to multisensory integration and cognitive performance, it is nearly impossible to tease the two apart. Results from the current study are therefore taken with caution when concluding that sensory processing deficits experienced during cognitive testing are at primary fault for poorer performance. Secondly, the cognitive tasks chosen for analysis in the current study primarily focused on the visual sensory modality leaving out sensory processing from other modalities such as olfaction, audition and proprioception. The lack of findings from other sensory modalities funnels the conclusions that can be made in regard to sensory processing and cognition. Lastly, the current study was underpowered, which may have led to marginally significant findings. Future research investigating cognitive tasks such as the Go-No Go task, or signal detection tasks that require less resources from higher order cognitive process may be warranted to come to a more robust conclusion on sensory processing deficits in cognitive performance.

In summary, the findings reported demonstrate that, among trauma-exposed PSP, not only is performance on two measures of assessing visual search (a possible proxy of selective and sustained attention) and visual mental rotation associated with elevated levels of PTSD symptom severity and dissociation but also cognitive performance on a visuospatial task highly reliant on mental rotation, visuospatial processing, spatial manipulation and spatial working memory is associated with functional impairment, even after holding dissociation constant. The ability to actively perceive visual information and then manipulate it mental visual space is a critical function that PSP require to accurately perceive their environment and create a spatial

understanding of where people or objects may be. Although further research is required investigate this relation further, these findings suggest that deficits in visual sensory processing in conjunction with spatial working memory may be an important avenue to research to understand the impact of dissociation and functional impairment further in PSP. Moreover, these findings further the characterization of alterations in visual spatial processing among trauma-exposed individuals, with potential implications for symptom expression and neuronal functioning in PTSD and other trauma-related conditions.

**Acknowledgement**

None.

**Declaration of Interest**

None.

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**Tables and Figures**

Table 1: Demographic characteristics of study sample

| Characteristic | |
|---|---|
| **Age** | Mean 22.69 (8.44) |
| **Sex** | |
| o Male | 37 |
| o Female | 40 |
| o Not Reported | 3 |
| **Race** | |
| o Aboriginal | 4 |
| o Black | 0 |
| o South/East/Southeast Asian | 3 |
| o Hispanic | 0 |
| o Middle Eastern | 2 |
| o White | 71 |
| o Other | 1 |
| **Education level completed** | |
| o Some high school | 0 |
| o Completed high school | 4 |
| o Some college/university | 14 |
| o Completed college/university | 55 |
| o Some graduate level education | 0 |
| o Completed graduate degree | 4 |
| **Marital Status** | |
| o Single | 14 |
| o Married/Common-law | 47 |
| o Separated/Divorced | 10 |
| o Long-term relationship | 5 |
| o Other | 0 |
| **Employment Type** | |
| o Active military member | 1 |
| o Veteran | 3 |
| o First responder/Public safety worker | 47 |
| o Nursing | 12 |
| o Other | 11 |

Table 2: Clinical characteristics of study sample

| Characteristic | Mean (SD) |
|---|---|
| **PCL-5 Total** | 42.77 (16.41) |
| **WHODAS Total** | 13.90 (7.88) |
| **MDI** | |
| o Disengagement | 77.61 (18.64) |
| o Depersonalization | 69.49 (32.23) |
| o Derealization | 64.81 (22.94) |
| o Emotion constriction | 67.09 (22.29) |
| o Identity dissociation | 50.71 (10.94) |
| o Memory disturbances | 71.40 (25.53) |
| o Depersonalization/ Derealization | 134.30 (53.55) |
| **Sensory-based Cognitive Tests (Percentile, rounded)** | |
| o Double trouble | 53rd Percentile |
| o Spatial planning | 70th Percentile |
| o Polygons | 65th Percentile |
| o Monkey Ladder | 75th Percentile |
| o Rotations | 60th Percentile |

*MDI scores have been t-scored for analysis as required by Brière, Weathers and Runtz, 2005

Table 3: Explanation of Cognitive test of interest used in the study

| Cognitive Task | Task Information | Primary Outcome Measure | Sensory ability tested | Cognitive ability tested |
|---|---|---|---|---|
| **Double Trouble** | Participants are asked to indicate which of the two-coloured words at the bottom of the screen (ignoring the colour of those words) correctly describes the colour that the word at the top of the screen is written in. | Overall score, calculated by subtracting the number of moves made from twice the minimum number of moves required. | Visual processing, Tactile response inhibition | Response inhibition, focused attention |
| **Spatial Planning** | Participants are met with a tree-shaped frame and beats with numbers in them. The goal is that participants must reposition the beads, so they are configured in ascending numerical order in as few moves as possible | Overall score, calculated by subtracting the number of moves made from twice the minimum number of moves required. | Visuospatial processing | Spatial planning |
| **Rotations** | Two grids of coloured squares are displayed on either side of the screen. One of the grids is rotated by a multiple of 90 degrees. Participants must indicate whether or not these grids are identical | Overall score - the sum of the difficulties of all successfully answered problems, minus the sum of the difficulties of all incorrectly answered problems. | Visuospatial processing, | Spatial manipulation, Spatial working memory |
| **Polygons** | A pair of overlapping polygons are displayed. Participants are required to indicate whether a polygon located on the right side of the screen is identical or not to the polygon on the left side. | Overall score - the sum of the difficulties of all successfully answered problems, minus the sum of the difficulties of all incorrectly answered problems. | Visuospatial processing (Goal directed visual search) | Object recognition, reasoning |

Table 3 Continued

| Cognitive Task | Task Information | Primary Outcome Measure | Sensory ability tested | Cognitive ability tested |
|---|---|---|---|---|
| Monkey Ladder | Participants are shown sets of numbered squares in random locations on the screen. After a variable amount of time, the numbers disappear from the squares. Participants are required to click the squares in ascending numerical sequence to complete the task. | (i) maximum level completed (e.g. the problem with the highest number of boxes that the user successfully completed) and (ii) average score: the sum of the number of boxes in all successfully solved problems, divided by the number of successfully completed problems. | Visuospatial processing | Working memory |

Table 4(A-E): Robust Regression analysis of functional impairment with predictors of dissociation and cognitive test performance, (A- Double Trouble, B- Spatial Planning, C- Polygons, D-Monkey Ladder, E-Rotations). Significance was measured at *a=0.05*.

A.

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 4.08 | 3.16 | 1.29 | 0.20 | 0.13 |
| *Double Trouble* | 3.75 | 3.13 | 1.20 | 0.23 | |
| *Dissociation* | 0.06 | 0.02 | 3.21 | 0.00* | |

B.

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 4.30 | 4.48 | 0.96 | 0.34 | 0.12 |
| *Spatial Planning* | 3.76 | 5.30 | 0.71 | 0.48 | |
| *Dissociation* | 0.05 | 0.02 | 2.75 | 0.01* | |

C.

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 0.79 | 6.24 | 0.12 | 0.90 | 0.11 |
| *Polygons* | 5.30 | 6.33 | 0.84 | 0.41 | |
| *Dissociation* | 0.07 | 0.03 | 2.62 | 0.01* | |

D.

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 10.23 | 5.51 | 1.86 | 0.07 | 0.12 |
| *Monkey Ladder* | -4.18 | 6.04 | -0.69 | 0.49 | |
| *Dissociation* | 0.05 | 0.02 | 2.89 | 0.01* | |

E.

| ***Predictor*** | ***Coefficient (B)*** | ***Standard Error (SE)*** | ***t-value*** | ***p-value*** | ***Multiple $R^2$*** |
|---|---|---|---|---|---|
| *Intercept* | 13.27 | 3.59 | 3.70 | 0.00* | 0.25 |
| *Rotations* | -9.47 | 3.49 | -2.72 | 0.00* | |
| *Dissociation* | 0.05 | 0.02 | 2.52 | 0.01* | |
| *Rotations*Dissociation* | 0.11 | 0.06 | 1.96 | 0.05 | |

Figure 1: Heatmap correlational matrix for all variables

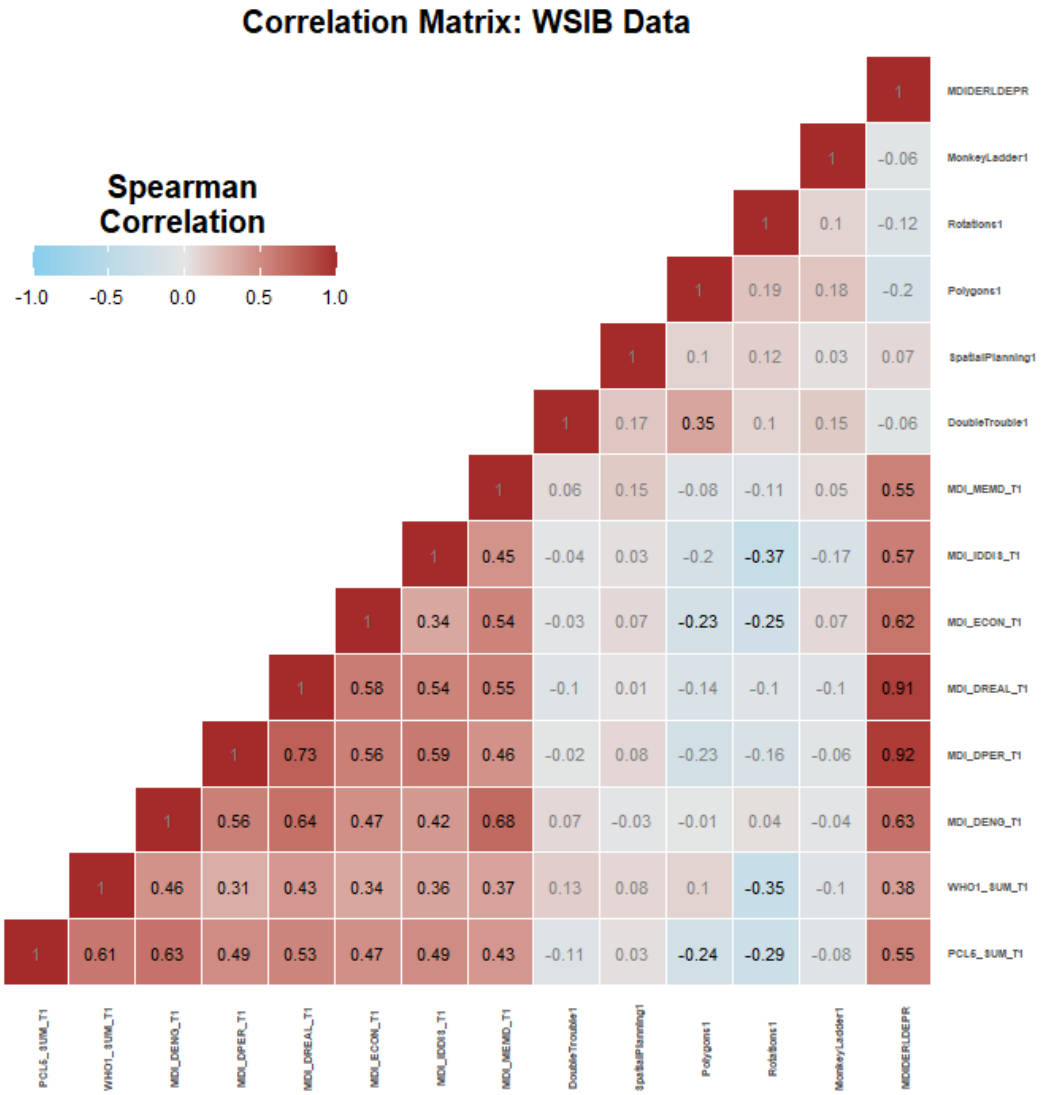
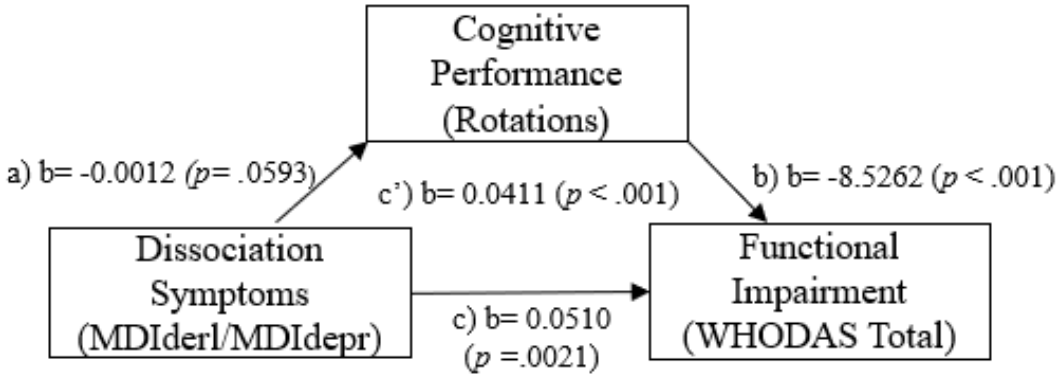


Figure 2. Mediation analysis of cognitive test performance (Rotations,), on the relationship between dissociation and functional impairment




b = unstandardized coefficients; a = effect of dissociation (MDI) on change in Rotations, b) effect of Rotations on change in functional impairment (WHODAS); c = the total effect; c' = the indirect effect of Rotation on the relationship between dissociation and functional impairment, MDI (Multiscale Dissociation Inventory) WHODAS, World Health Organization Disability Assessment Schedule 2.0

# CHAPTER 5: AFTERWORD

**Afterword**

The goal of this thesis was to investigate whether individuals exposed to psychological trauma/ diagnosed with PTSD experience sensory processing deficits as part of their overall symptom profile. Results from our scoping review outlined in Chapter 2 conceptualizes the neural and behavioural deficits experienced by those with trauma exposure/a diagnosis of PTSD as well as provide valuable insight into the current somatic based therapeutics available. In addition, results derived from the experimental studies suggest that domains of sensory processing explored here, specifically sensory sensitivity and sensory-based cognitive performance, are altered in individuals who are trauma exposed/ diagnosed with PTSD. This thesis provides a collection of novel investigation that explore sensory processing symptomology in individuals with PTSD and provide new insight in terms of altered sensory processing can impact the ways in which the world is perceived and how one may react to it.

In Chapter 2, we found evidence supporting the notion that alterations in sensory processing are an integral part of classic symptomology in PTSD. When looking particularly at behavioural and neural correlates, out results found overlapping trends in symptom outcomes caused by alterations in sensory processing. More specifically, it was found that individuals who were exposed to trauma/ diagnosed with PTSD with either self-reported/experimentally concluded sensory processing alterations experienced increased levels of hypervigilance and weakened levels of self-referential processing and interoceptive response. Brain regions involved in bringing awareness to internal and external stimuli (i.e. Insula, Supramarginal gyrus) as well as areas involved in memory retrieval (i.e. Hippocampus) showed significant altered connectivity to areas involved in self-referential processing and emotion regulation (i.e. Medial prefrontal cortex, posterior cingulate cortex) therefore causing behavioural disruptions such as re-

experiencing of symptoms, hypervigilance to external stimuli and in some cases, dissociation from the external environment (Terpou et al., 2018; Clancy et al., 2020; Choi et al., 2022; Machorrinho et al., 2022; Stewart & White., 2008). Additionally, when examining therapeutic correlates in response to sensory processing deficits within the disorder, results overwhelming found that the gold standard of treatment is sensorimotor psychotherapy and other modified mindfulness-based practises. The integration of the trend and patterns from this review have the potential to help inform future research in sensory processing deficits in PTSD

In Chapters 3 and 4, we empirically investigated sensory processing alterations in populations through the lens of both cognitive performance and sensory sensitivity. More specifically, in Chapter 3, we used a retroactive self-report, cross-sectional study design to examine the relationship between raw and affective sensory sensitivity, dissociation and functional impairment. Results from this study provided evidence of a significant correlational relationship between sensory sensitivity, dissociation and functional impairment. Interestingly, as compared to affective sensory sensitivity, raw sensory sensitivity was the only significant predictor of functional impairment even when holding dissociation constant while both measures of sensory sensitivity measures proved to be marginally significant partial mediators of the relationship between dissociation and functional impairment. These results support to the growing body of research pointing towards sensory sensitivity as a marker of impairment in PTSD through a possible increase in PTSD symptomology, such as dissociation, caused by sensory overload (Grinapol et al.,2022; Graumann et al, 2023; Harricharan et al., 2021).

Looking towards Chapter 4, using neutral gamified gold standard cognitive tasks, we demonstrated that cognitive performance that required visuospatial processing and spatial working memory in conjunction with each other explained, in part, the relationship between

dissociation and functional impairment. These results were both interesting and unexpected. Although recent research has found evidence regarding visuospatial processing and spatial working memory in PTSD populations (Mathew et al., 2022; Mirabolfathi et al., 2016), other lines of research have provided evidence of other cognitive dysfunctions such as attention, processing speed and verbal memory (Scott et al., 2015). As previous studies investigating cognition in PTSD did not specifically looking at sensory-based cognition, future research concerning the interplay of sensory-based cognition with other cognitive functions such as those mentioned above is warranted.

Although the three studies presented in this thesis addressed different domains affected by sensory processing, they all work towards the common goal of enhancing our understanding of sensory processing manifests and what effects it may have on overall quality of life of those who have been exposed to trauma/ diagnosed with PTSD.

### 4.1 Future Directions

The current state of the literature has provided a strong base of evidence pointing towards sensory processing deficits as possible an underlying cause of classic PTSD symptomology. Often, current research was focused primarily on visual processing which has created a considerable gap in understanding of how multisensory integration as it relates to PTSD symptomology. Future research may consider investigating alterations in less studied sensory modalities (i.e. proprioception, audition...etc.) to elucidate a better understanding of the extent of sensory processing alterations in PTSD and how these alterations may affect common symptomology experienced within the disorder.

Implementation of neuroimaging in future studies may explain the interaction of sensory processing alterations in relation to cognitive performance. For instance, one line of research may investigate the interaction of brain regions involved in visuospatial processing, spatial working memory and dissociation in individuals with PTSD, it's dissociative subtype (PTSD-DS) as compared to non-trauma exposed controls. A recent study by Marlatte et al (2022) did find that patients with PTSD showed navigation through a known complex spatial environment which seem to be broadly related to reduced hippocampal volume and abnormal white matter tracts implicated in multisensory integration. Due to the observed breakdown of areas necessary for multisensory integration It could be possible that altered visuospatial processing and spatial working memory may be a pre-cursor to dissociative tendencies and overall functional impairment. Future direction may include cognitive neuroimaging paradigms to elucidate this possible relationship.

Finally, the creation of a trauma informed sensory processing scale that integrates both measures of affective and raw sensory sensations is a warranted future step in this line of research. Currently, the Adult/Adolescent Sensory Profile (AASP), created by Brown et al (2001), provides an understanding of an individual's sensory profile on four separate domains: low registration, sensory sensitivity, sensory avoidance and sensation seeking. Although this scale provides clear insight into how one's sensory processing patterns may be altered as compared to the general population, it does not provide a comprehensive understanding as to how this may affect one's ability to function in the aftermath of trauma. With this being said, a measure aimed at capturing the severity of sensory processing alterations based of possible qualitative research of those who have been exposed to trauma/ diagnosed with PTSD may

provide that “missing piece” in the fields understanding of the changes experienced by those in the aftermath of trauma.

In our current study, we found that cognitive performance that required visuospatial processing and spatial working memory in conjunction with each other explained, in part, the relationship between dissociation and functional impairment.

### 4.2 Conclusion

The primary aim of this thesis was to consolidate the current literature on sensory processing deficits in PTSD as well as provide novel research findings on the possible negative alterations caused by alterations in sensory processing to help further evaluate and develop new and effective treatment strategies. The results presented in Chapter 2 demonstrate both from a neural and behavioural perspective that individuals who have been exposed to trauma/ diagnosed with PTSD are experiencing life altering changing in sensory processing capabilities. Additionally, current therapeutics aimed at targeting sensory processing and their corresponding efficacies were uncovered. Taken together, these findings can provide a robust base of evidence of sensory processing deficits in trauma populations to inform future novel research. The empirical research presented in Chapter 3 demonstrated that raw and affective sensory sensitivity show significant relationships to classic PTSD symptomology including dissociation. Chapter 4 demonstrated deficits in sensory-based cognitive performance on a task that requires visuospatial processing and spatial working memory in relation to increased functional impairment and dissociation in PSP. Taken together, the three studies presented in this thesis demonstrate the importance of sensory processing alterations as a determiner of the emergence of classic PTSD symptomology.

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