PERSISTENT SUBJECTIVE MEMORY PROBLEMS AFTER CONCUSSION

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Abstract

Introduction: Subjective memory problems - forgetting names, leaving important objects at home - are a common post concussion symptom. Memory complaints after concussion are largely unrelated to injury severity, objective memory performance, or neuroimaging metrics of the brain's structural integrity and may be a manifestation of a functional cognitive disorder (FCD). Several possible mechanisms for FCD have been proposed, including metacognitive bias or factors that interfere with attention, as well as anxiety-related explanations. This study aims to explore several theories as to why people develop persistent memory problems after concussion, despite having normal neuropsychological test scores.

Methods: A cross-sectional study of 54 participants (n=34 with concussion and n=20 healthy controls). Subgroups were formed to compare participants suspected FCD after concussion (n=28) and healthy controls with no concerns about their memory (n=13). Independent sample t-tests compared these two subgroups on candidate predisposing/perpetuating factors in FCD theorical models. Simple linear regressions tested the relationship between these predisposing/perpetuating factors and FCD symptom severity in the full concussion sample.

Results: Contrary to expectations, there was no evidence of a metacognitive deficit or bias associated with FCD symptoms after concussion. The healthy control group and suspected FCD after concussion subgroup differed on measures of somatization, depression, anxiety, memory perfectionism, and certain coping behaviours (checking to turn off electrical appliances and asking someone for reminders). However, within the full concussion sample, only asking for reminders, increased depression, and memory perfectionism, was significantly associated with FCD symptoms.

Conclusions: The current study highlights some promising (e.g., memory perfectionism) and unlikely candidates (e.g., metacognitive bias towards underconfidence) to guide future research on the etiology of FCD after concussion, and possibly FCD in other clinical settings.

Lay Summary

It is unclear why some people experience persistent memory symptoms after a concussion, especially those who appear to be otherwise functioning normally. Explanations such as difficulties with self-evaluation, psychological distress, and counterproductive attempts at coping with symptoms merit exploration. This study examines the association of such factors with persistent memory symptoms after a concussion. Of the factors explored, depression, memory perfectionism, rumination and relying on others for help with reminders were significantly associated with memory symptom severity after concussion. Other factors also differed significantly between the healthy adults and those with persistent memory symptoms after concussion including anxiety and somatization, although these were not associated with memory symptom severity in people with concussion. This research highlights possible reasons why some people develop persistent memory symptoms after a concussion. More research is needed to confirm these findings and develop new treatments for persistent memory symptoms.

Preface

This thesis is original, unpublished, independent work by the author, Edwina Laure Picon. The leading concept formation and data analyses were done by the author with guidance from the thesis supervisor, Dr. Noah Silverberg. The writing of the thesis was done solely by the author. Data from this thesis were part of a larger project examining memory perception after concussion. Dr. Noah Silverberg is also the supervisor on this larger project, and assisted with designing the study, interpreting data, and editing manuscripts. The project reported in this thesis was approved by the Behavioural Research Ethics Board of the University of British Columbia (approval certificate number: H20-03115) and was conducted by the author and the Coping with Neurological Symptoms lab at the University of British Columbia.

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Chapter 1: Introduction

Post-concussion symptoms usually resolve within weeks or months, requiring little to no treatment (Kamins et al., 2017; McCrea et al., 2009), yet some people experience persistent symptoms such as headache, dizziness, troubled sleep, and cognitive difficulties (Cassidy et al., 2014; Dikmen et al., 2010; Machamer et al., 2022). Memory complaints are among the most common, with between 25-45% of people experiencing persistent forgetfulness after concussion (Dikmen et al., 2010; Machamer et al., 2022; Nelson et al., 2019; Theadom et al., 2016). Persistent symptoms following concussion are associated with life dissatisfaction (Voormolen et al., 2019) as well as difficulties with daily functional activities and community participation (Machamer et al., 2022).

It is not yet clear why some people continue to experience persistent memory and other post-concussion symptoms months to years after the injury. Indicators of concussion severity (such as a loss of consciousness) at the time of injury are weakly correlated with the initial severity of symptoms (Iverson et al., 2013) and have relatively little long-term prognostic value (Silverberg et al., 2015b). Cognitive symptoms correlate only weakly with indicators of injury severity (Stillman et al., 2020) and neuroimaging studies have shown that they are largely unrelated to the brain's structural integrity (Lange et al., 2012; Stulemeijer et al., 2007). In contrast, pre-injury anxiety disorders and post-injury anxiety symptoms have been consistently associated with post-concussion symptom chronicity (Broshek et al., 2015; Silverberg et al., 2015a). Similarly, fear avoidance behaviour, negative expectations, and attributions of symptoms to brain injury have been shown to predict worse concussion (Cassetta et al., 2021; Silverberg et al., 2018; Snell et al., 2016; Wijenberg et al., 2017), in addition to catastrophizing which correlates with post-concussion symptom severity (Chaput et al., 2016). When it comes to predicting concussion outcome, how people think about and cope with their symptoms following injury appear to be more important than the characteristics of the injury itself.

Several studies have demonstrated a discordance in the relationship between subjective and objective cognitive functioning after concussion, that is, people tend to perceive their cognitive functioning as worse than their performance on neuropsychological testing (Anderson, 2021; Drag et al., 2012; French et al., 2014; Hromas et al., 2021; Silverberg et al., 2016). Objectively measurable cognitive impairment months after a concussion appears rare (Iverson et al., 2019) and improvements in subjective cognitive symptoms seem unrelated to improvements in objectively measured cognitive functioning at 3 months post concussion (Stenberg et al., 2020). The few studies (Barker-Collo et al., 2015; Ngwenya et al., 2018) that report an association between subjective and objective cognitive functioning on testing, did not control for overall symptom burden or performance validity. There is some evidence that affective symptoms (e.g., anxiety and depression) are associated with a higher discrepancy between subjective and objective cognitive function after mTBI (Hromas et al., 2021), and that higher distress is associated with subjective but not objective cognitive function (Potter & Brown, 2012). Overall, there is limited evidence that subjective cognitive symptoms reporting after concussion reflects underlying cognitive impairment.

A common sentiment is that people with report persistent symptoms after a concussion is exaggerating (Cooper et al., 2011). There might be several motivations for exaggerating symptoms, including external reasons (e.g., to achieve financial compensation) and/or internal reasons (e.g., health anxiety leading to a desire to be taken more seriously by health professionals). The potential for secondary gain may reinforce and maintain symptoms or provide a disincentive for symptom resolution for some people (as they would no longer qualify for benefits) (Fobian & Elliott, 2019) and there is evidence that people with recent concussion who are litigating report more symptoms than those who are not (Lange et al., 2010). Exaggeration might also take the form of intentional underperformance (i.e., deliberately performing poorly on objective tests of cognitive function) and can be evaluated using

performance validity tests (PVT), which are common components of neuropsychological evaluations (Lange et al., 2010). External incentive to under-perform is the strongest known risk factor for PVT failure (Green & Merten, 2013) with higher incentives associated with increased rates of malingering among people involved in personal injury litigation (Cottingham et al., 2014) as well as in people with brain-injury (Bianchini et al., 2006). It is difficult to establish causal relationship, as people who perceive themselves as having greater deficits might be motivated to pursue or prolong litigation. Countries that provide financial compensation through a no-fault accidental injury scheme (e.g., Accident Compensation Corporation in New Zealand) have similar rates of post-concussion symptoms compared with countries allowing litigation (Barker-Collo et al., 2015; Feigin et al., 2013). A recent cross-sectional study (Picon et al., 2021) examining factors associated with persistent symptoms after concussion found no association between persistent, unexpected concussion symptoms (such as difficulty swallowing) and traditional proxies for exaggeration such as litigation status or PVT failure. Instead, perpetuating factors in FND such as anxiety and avoidance behaviours were more strongly associated with symptom reporting.

Functional Cognitive Disorder

Given the evidence that persistent cognitive symptoms after concussion seem largely unrelated to objective indices of memory or brain injury, they might be a manifestation of Functional Cognitive Disorder (FCD). FCD is seen across a variety of clinical settings (e.g., dementia, movement disorder, and rheumatology clinics) and is characterized by persistent, distressing cognitive symptoms that are not attributable to structural neurological injury or disease (Poole et al., 2019). A key diagnostic feature of FCD is an internal inconsistency between one's subjective judgement of their cognitive performance and the objective evidence of their abilities (Ball et al., 2020; McWhirter et al., 2020). Given the presence of

life stressors surrounding the onset of FCD symptoms, a head-injury might be a particularly potent trigger for the onset of FCD due to lay-beliefs about the connection between concussions and cognition(Ball et al., 2020; McWhirter et al., 2020). The FCD literature could help generate hypotheses about why memory symptoms often persist after concussion in the absence of underlying cognitive impairment.

This thesis conceptualizes persistent post-concussion cognitive symptoms as potential FCD to test whether any of the multiple theoretical models of FCD can help clarify why cognitive symptoms often persist after concussion. I will review research evidence for current theories of FCD.

Metacognition

Metacognition may regulate the expression of the core features of FCD (Ball et al., 2020; Bharambe & Larner, 2018; Bhome, McWilliams, et al., 2019; Larner, 2018; Pennington, Newson, et al., 2015) and it has been suggested that impaired metacognition is a root cause of FCD (Bhome, Huntley, et al., 2019; Larner, 2021; Metternich et al., 2009a). Metacognition is the ability to judge and reflect upon one's cognitive processes and is distinct but related to attention. It can be separated into state and trait like components: local metacognition is conceptualized as moment-to-moment evaluations of performance (i.e., judgment of confidence in a decision, feeling of certainty in knowing a fact) whereas global metacognition involves a broader evaluation of one's cognitive abilities, developed over time (Bhome et al., 2022). Impaired local metacognition might lead to difficulties judging whether one's memory is flawed due to biased (e.g., overly negative) interpretation of memory signals or feelings of uncertainty arising from noisy signals. Someone with unimpaired metacognition would avoid the reinforcing cycle of becoming unduly concerned about memory lapses by having a clearer interpretation of what a feeling of forgetting means in a particular situation. Metacognitive deficits have been reported across functional neurological disorder (FND) subpopulations, including functional seizures and

movement disorders and may represent a common underlying problem or “neurobiological malfunction” (Benbadis et al., 2022; Teodoro et al., 2018). Thus, metacognitive ability should also be examined in people with persistent cognitive symptoms after concussion.

Misdirected Attention

Misdirected attention is a prominent explanation for functional neurological disorders, with functional motor and sensory symptoms being induced and maintained by attention (Edwards et al., 2012). FCD has been proposed as a cognitive subtype of FND (Ball et al., 2020) with similar attentional factors - such as increased interoceptive awareness (e.g., from excessive attention directed towards the body and physical ailments) and repetitive thinking about symptoms (i.e., rumination on the consequences of symptoms) - underlying cognitive difficulties (Teodoro et al., 2018). Under this theory, cognitive symptoms in FCD are perpetuated by an increased susceptibility to distraction as a result of decreased externally directed attention . Instead of paying attention to the outer world, attention is overly directed inwards towards the body (e.g., somatization – a tendency to experience psychological distress as physical pain) or mind (rumination). Under the misdirected attention hypothesis, people with FCD may be distracted by physical symptoms or ruminative thoughts, leaving less attention available for cognitive processing, including memory encoding.

Depression

Subjective cognitive difficulties are a hallmark of depression (Gotlib & Joormann, 2010; McDermott & Ebmeier, 2009). Depression and low mood are frequently found to be comorbid with FCD (Bhome, Huntley, et al., 2019; Elhadd et al., 2019; Pennington, Hayre, et al., 2015) and people with FCD have more depressive symptoms compared to people with other cognitive disorders (McWhirter, Ritchie, et al., 2021). Depression may therefore be a major cause of FCD (Stone et al., 2015b) or a co-existing disorder that leads to intensified FCD symptoms (Bhome, Huntley, et al., 2019).

A study comparing the clinical presentation and neuropsychological profiles of FCD in people with and without co-morbid depression (Bhome, Huntley, et al., 2019) found that FCD and depression are distinct disorders, with features such as memory-perfectionism and memory related avoidance behaviours distinguishing between FCD and cognitive impairment in depression. It seems that subjective memory impairment in FCD cannot be explained solely by the cognitive symptoms of depression (e.g., poor concentration

Memory Perfectionism

Memory perfectionism (i.e., excessive concerns about cognitive performance and high standards for one's own memory) might lead to increased self-monitoring, categorization of 'normal' memory failures as pathological, and associated distress (Metternich et al., 2009a; Stone et al., 2015a). Associated with an overly catastrophic interpretation of cognitive failures (e.g., "I forgot something, I must be developing dementia"), which perpetuates the cycle of excessive concern and self-monitoring (Metternich et al., 2009b), memory perfectionism has been proposed as a central factor in FCD (Teodoro et al., 2018). The established relationship between emotion and memory suggests that negative judgment might make instances of forgetting easier to bring to mind (e.g., remembering the frustration and embarrassment after misplacing one's glasses) (Holland & Kensinger, 2010; McGaugh, 2004). In other words, if someone systematically reacts with self-criticalness and concern to memory lapses, the encoding of these episodes of forgetting could enhanced, and give rise to the perception that they are occurring more frequently. A recent study of persistent memory complaints after concussion found that memory perfectionism was associated with the reporting of more severe complaints of forgetting (Picon et al., 2022). Another study found that participants with greater subjective cognitive symptoms after concussion, experience instances of their past memory lapses as more negative compared to memories that do not involve forgetting (Rioux et al., 2022). Individual differences in trait memory perfectionism

might act as an amplifier for other post-concussion factors, clarifying why some people develop FCD after concussion while others do not.

Anxiety and avoidance behaviours

Extending the anxiety disorder literature suggests a novel candidate theory of persistent subjective memory complaints after concussion. In the cognitive model of panic, the catastrophic misinterpretation of physical symptoms and the avoidance of activities that invoke symptoms can lead to an increased sense of danger (Clark, 1986; Salkovskis & Warwick, 2001). Anxiety has been found to be associated with more severe and frequent cognitive complaints (McWhirter et al., 2020). There are multiple ways in which anxiety can perpetuate undue concerns about memory. First, performance may be optimized under certain levels of stimulation (e.g., stress or monetary reward) after which further increases lead to diminished performance and functioning (i.e., the Yerkes Dodson law) (Broadhurst, 1957). Second, anxiety likely contributes to autonomic arousal, which focuses and drains attentional resources, supporting the misdirected attention hypothesis (Staal, 2004). Finally, anxiety-related coping behaviours such as avoidance, checking, and reassurance seeking might perpetuate FCD. When someone doubts their memory, they might begin avoiding memory-demanding tasks or avoid relying on their memory (e.g., relying on someone else to remind them of important events). Although intuitive, these avoidance strategies might have the maladaptive effect of perpetuating the belief of having a poor memory through negative reinforcement. Avoiding normal memory use could prevents opportunities to develop positive beliefs and memory self-efficacy. Excessive reliance on memory compensation strategies (e.g., making lists) may representative subtle avoidance and function like “safety behaviours” in anxiety disorders. There is evidence from the obsessive-compulsive disorder literature that repeated checking can lead to memory distrust (Radomsky & Alcolado, 2010; van den Hout & Kindt, 2003) and that even in non-clinical samples such as an undergraduate population, repeated checking is associated

with decreased memory confidence (Boschen & Vuksanovic, 2007). Checking behaviours are often performed to increase certainty, yet they actually perpetuate uncertainty (Rachman, 2002). For example, frequently double-checking that stove has been turned off or the front door is locked could reinforce the belief that one's memory is poor as the checking is evidence that one's memory is not to be relied on.

Current Study

In order to better understand why people develop FCD, especially after concussion, this study tests the prominent theories including that metacognition is biased (Bhome et al., 2022; Bhome, McWilliams, et al., 2019), that attention is misdirected towards the body (somatic symptoms) or the mind (rumination) (McWhirter et al., 2020) as well as a new proposed theory: that anxiety-related safety behaviours and maladaptive coping (e.g., avoidance of memory, checking, and reassurance-seeking) perpetuate FCD symptoms. It also examines the relationship between affective and personality factors thought to perpetuate or amplify FCD symptoms (i.e., depression and memory perfectionism) that are common across theories. Since these theories are not mutually exclusive, this study aims to investigate which has the most explanatory power in order to help the field prioritize which intervention strategies to test.

H1a. Participants with suspected FCD after concussion will display greater metacognitive bias, lower metacognitive efficiency, and elevated false positive and false negative rates compared to the healthy control group.

H1b. Among all participants with concussion, higher FCD symptom severity will be associated with greater metacognitive bias, lower metacognitive efficiency, and elevated false positive and false negative rates on the memory task .

H2a. Participants with suspected FCD after concussion will have more somatization and rumination compared to the healthy control group.

H2b. Among all participants with concussion, higher FCD symptom severity will be associated with increased somatization and rumination.

H3a. Participants with suspected FCD after concussion will have higher levels of depression compared to the healthy control group.

H3b. Among all participants with concussion, FCD symptom severity will be associated with increased depression symptoms.

H4a. Participants with suspected FCD after concussion will have higher memory perfectionism scores compared to the healthy control group.

H4b. Among all participants with concussion, FCD symptom severity will be associated with higher memory perfectionism scores.

H5a. Participants with suspected FCD will have more general anxiety symptoms and will endorse the use of more external, compensatory memory strategies and checking behaviours compared to the healthy control group.

H5b. Among all participants with concussion, FCD symptom severity will be associated with greater anxiety and with the use of more memory strategies and checking behaviours.

Chapter 2: Methods

Research Design

This study uses a cross-sectional design to investigate candidate predisposing and perpetuating factors in FCD. I compare adults with suspected FCD after concussion to a control group of healthy adults, as well as examine individual differences in people with varying levels of memory concerns after concussion (i.e., people with and without suspected FCD following concussion).

Participants

Data collection is ongoing. Eligibility criteria for all participants: (1) age 18 to 65 years old, to control for age-related memory decline as a confounding factor (see (Fandakova et al., 2015)), (2) fluent in English, as validated translations are not available for most questionnaires, (3) access to a computer or tablet with internet capability, as this study was done virtually due to COVID-19 restrictions, (4) normal objective memory performance on standardized testing – operationalized as recalling more than 5 words on the Brief Test of Adult Cognition by Telephone Word List Recall test during the eligibility screening phone call (to control for objective memory impairment), (5) no history of neurological conditions (e.g., dementia, multiple sclerosis, epilepsy, stroke, severe TBI) or severe psychopathology (e.g., psychosis, schizophrenia, bipolar disorder), which are major risk factors for genuine memory impairment.

Additional eligibility criteria for concussion group: Participants were eligible if they sustained a concussion according to the World Health Organization Neurotrauma Task Force definition (Carroll et al., 2004) between 6 and 36 months prior to enrollment in the study. I did not exclude participants on the basis of having pre-existing or co-occurring mood, anxiety, or substance use disorders. These conditions are quite common (Bryant et al., 2010) in post-concussion populations, and in practice, difficult to disentangle from persistent post-concussion symptoms. Although some participants may be more concerned about their cognitive abilities than others, no participants were expected to have major cognitive impairment or significant physical disabilities.

Additional eligibility criteria for control group: Participants were eligible if they did not have lingering memory symptoms from a health condition (i.e., any health condition that has led to ongoing memory problems, including recent concussion).

Due to the COVID-19 pandemic, prospective recruitment was difficult. Physical distancing restrictions reduced the incidence of concussions and non-emergency health care services such as

outpatient concussion clinics were mostly curtailed. I recruited participants with a concussion using lists from past studies of people willing to be contacted for future research opportunities. The study coordinator used these lists to contact potential participants via email (if provided) as the initial contact informing them of this study and to expect a call from the study coordinator to determine their eligibility and interest in participating in this study.

Additionally, as COVID-19 restrictions were eased and concussion clinics re-opened, we recruited participants prospectively. Clinicians at two local public health concussion clinics (1.GF Strong Adult Concussion Service, 4255 Laurel St, Vancouver, V5Z 2G9; 2. Fraser Health Concussion Clinic, #201-9440 202 St, Langley, V1M 4A6) asked their patients who were approaching discharge or have been discharged in the past 3 months about their interest in participating in this research study. At GF Strong, the clinician asked for their patients' permission (verbally or by email) to share their contact information (name, telephone number, email address) with the research study so that the research team may contact them to share more information about the study and screen them for eligibility. At Fraser Health, a clinician, specifically an Occupational Therapist employed by Fraser Health who works in the Fraser Health Concussion Clinic, identified their own patients as being potentially eligible to participate in this research study and asked that patient whether their contact information can be provided to the research study coordinator. Additionally, I attended patient education groups hosted over Zoom to briefly describe the study and allow participants to express interest. Participants who were interested in being contacted by researchers shared their contact information via a REDCap webform that was shared by link in the Zoom chat.

Control Group - I chose to recruit friends and family members of people with concussion into the control group rather than a convenience community-based sample because people with a concussion might not represent a typical cross-section of the general population with regard to pre-injury

characteristics (e.g., higher on traits such as risk-taking, alcohol consumption, athleticism) and might more closely resemble their family and friends (i.e., “Birds of a feather flock together”) (Bodien et al., 2018; Kit et al., 2007; Pagulayan et al., 2006). By recruiting friends and relatives of the participants with concussion, we endeavored to loosely control for participant characteristic differences that could potentially influence outcome such as age, socio-economic status, and risk-seeking behaviors.

Potential control group participants were recruited from friends and family members of participants with concussion who have already completed the study were given a study flyer to pass along to their family and friends. Potential participants reached out to us, or we contacted them over email. We also recruited control group participants from the friends and family participants with concussion who have recently completed another study. At the end of their final session, an experimenter informed them of the nature of this study and the recruitment process and asked them if they know anyone who might be interested in participating. We obtained verbal consent to follow-up by sending a recruitment flyer to the participant to share with their friend/family members by email. Because the pace of recruiting control participants in this manner was insufficient, additional control group participants were recruited from REACH BC (https://www.reachbc.ca/), a website that posts research studies for the British Columbia public. REACH BC made initial contact via its automatic system-generated email notifications to volunteers/prospective participants who match the research study criteria. Volunteers’/prospective participants’ contact information is shared to the researchers REACH BC account if they select “I’m interested, contact me”.

All potential participants received an introduction email from the study coordinator. In this email were reminded as to why we have their contact information (e.g., participated previously and consented to be contacted for future research studies, expressed interest via REACH BC), the time it will take to participate in the eligibility screen and details about the study. They were provided details about the

study: the purpose of the study, total time requirements, and what each session involves.

The study coordinator waited for a reply from potential participants, via email, confirming that they are interested in participating in the eligibility screen. The potential participant provided verbal consent (via the phone, to the study coordinator) before beginning the eligibility screen. Eligibility screen responses were captured in REDcap (secure data collection tool, hosted by UBC). Participants were provided an emailed copy of the consent form immediately after the telephone eligibility screening and were encouraged to read and consider the consent form and consult with the Study Coordinator if they have questions, before signing the consent form electronically at the beginning of Session 1 on Qualtrics. Because this study did not involve in-person contact and minimal risks, it was determined that obtaining written consent electronically was acceptable.

Measures

Participants completed a battery of self-report measures in order to measure routine demographic information, functional cognitive symptoms, neuropsychological ability, and general psychopathology symptomatology. The demographics questionnaire developed for the present study gathers information including age, years of education, race/ethnicity, gender/sex, work or school status, and number of prior concussions. Each measure is described in more detail below.

Functional Memory Disorder Inventory – Long Version (FMD; Schmidtke & Metternich, 2009). The FMDI Long Version inquires about the weekly frequency of memory complaints thought to be indicative of functional memory disorder (e.g., failing to recall a name, forgetting an important object at home or the date of an appointment). The response options describe how often the memory symptom occurs: “1 - Never”, “2 - Rarely (about once per month)”, “3 - Occasionally (about once weekly)”, and “4 - Frequently (several times per week or more)”. The sum of ratings comprises a total score ranging from 22 to 88. The FMDI has high internal consistency (α =.93) and test-retest reliability over 3 months

(r = .82) and has been shown to differentiate between FMD patients and control subjects with high accuracy at a cut-off score of 48 (Metternich et al., 2008). Due to experimenter error inputting the FMDI into Qualtrics, the scale was displayed to participants with an additional option of "5 – Always". To remedy this error in data analysis, we collapsed all responses of 5′s into 4′s.

Metamemory in Adulthood Questionnaire – Achievement Scale *(MIA-A)* (Dixon et al., 1988). As in a prior FCD study (Metternich et al., 2009b), I measured memory perfectionism with the Achievement subscale from the MIA (Dixon et al., 1988) that was designed to measure the perceived importance of having a good memory and avoiding memory lapses. This subscale has strong internal validity (α = .80). The Achievement subscale consists of 16 items such as "It's important that I am very accurate when remembering names of people", "I think a good memory is something of which to be proud", and "I'm highly motivated to remember new things I learn", which are rated on a scale of 1 (agree strongly) to 5 (disagree strongly). After reverse scoring certain items, higher total MIA-Achievement scores reflect higher self-perceived memory perfectionism. The MIA-Achievement scale loads on a distinct factor and correlates weakly with other MIA subscales designed to measure perceived memory ability (r=0.12-0.25) (Hertzog et al., 1987, 1989), as well as external self-report measures of perceived memory ability (Hultsch et al., 1988). In healthy people, intraindividual differences on the MIA-Achievement scale are stable through adulthood, supporting memory perfectionism as a personality trait (Dixon & Hultsch, 1983; McDonald-Miszczak et al., 1995).

Multifactorial Memory Questionnaire – Strategies subscale (MMQ-S; Troyer & Rich, 2002a). The Strategies subscale of the MMQ invites participants to rate the frequency with which they used various strategies (e.g., writing appointments on a calendar, using a rhyme to remember a grocery list) to aid or improve their memory functioning in daily life over the past 2 weeks. Participants rate frequency statements on a scale of: "4 – All the time", "3 – Often", "2 – Sometimes",

"1 – Rarely" and "0 – Never". The Strategies subscale demonstrates good test-retest reliability (*r* = .88) and strong internal consistency (*r* = .83). Instead of using the total scale score, I chose to look at specific items assessing external (e.g., using an alarm or asking someone to remind you to do something) rather than internal (e.g., creating a rhyme out of what you want to remember) memory strategies. Compared to internal strategies, external strategies more closely resemble avoidance or safety behaviors as opposed to proactive coping or cognitive rehabilitation. Due to experimenter error uploading the measure to Qualtrics, only the first half of the MMQ-Strategies subscale was administered (9 items) and thus only 4 external memory strategies were analyzed.

Memory for Actions and Events Questionnaire – Obsessive/Responsible subscale (MAEQ; Cougle et al., 2007). The MAEQ was designed to assess general memory capabilities and checking behaviours for actions and events that have occurred during the past month There are four subscales (Obsessive/Responsible, Non-obsessive/Responsible, Obsessive/Non-responsible, Non-Obsessive/Non-Responsible), based on whether the participant is responsible for the action/event and whether the action/event represents an obsessive behavior. Each item is rated on a scale from 0-100 for perception of memory ("How good are you at remembering?"), confidence in memory ("Once you believe you have remembered, how confident do you feel in that memory?"), urge to check ("If you think that you might have forgotten, how likely are you to check?"), and discomfort ("How uncomfortable do you feel if you think you may have forgotten?"). Twenty-four-hour test-retest correlations were found to be high (at least r = .7) for individual item subscales. I chose to only use the Obsessive/Responsible subscale and to focus on the urge-to-check ratings of the four items representing the most potentially negative consequences if forgotten (e.g., locking the door, turning off electrical appliances, house lights, or the stove) and omitting the hand-washing items as it is less relevant behavior outside of OCD.

Generalized Anxiety Disorder (GAD-7; Spitzer et al., 2006). The GAD-7 is a measure of 7 general anxiety symptoms over the past two weeks, rated on a 4-point scale ranging from 0 ("not at all") to 3 ("nearly every day"). The GAD-7 has been found to have good test-retest reliability, in addition to good criterion, construct and factorial validity.

Ruminative Thought Style Questionnaire (RTS; Brinker & Dozois, 2009). The RTS is a psychometrically sound, 20 item, single factor measure of the general tendency to ruminate (i.e., recurrent, intrusive, uncontrollable thinking). Responses are on a 7-point Likert-type scale of self-descriptiveness from 1 ("not at all descriptive of me") to 7 ("describes me very well"). The RTS shows high internal consistency (α =.92), test-retest reliability (r = .80), convergent validity (correlates positively with measures of repetitive thought, depressed mood, and anxiety) and divergent validity (does not correlate significantly with social desirability or verbal ability).

Patient Health Questionnaire 15 (PHQ-15; Kroenke et al., 2002). The PHQ-15 measures the degree to which respondents have been bothered by common symptoms across multiple bodily systems on a 3-point scale ranging from 0 ("not at all") to 2 ("bothered a lot") over the past month. It has excellent internal consistency (α = .80) and good concurrent construct and convergent validity with other measures of somatization (Gierk et al., 2015). The PHQ-15 is used to screen for somatoform disorders but is also thought to measure underlying constructs such as interoceptive awareness and a tendency towards somatization.

Patient Health Questionnaire 9 (PHQ-9; Kroenke et al., 2001). The PHQ-9 measures how often respondents have been bothered by 9 depressive symptoms (the 9 diagnostic criteria for DSM-IV depressive disorders) over the past two weeks on a 4-point scale ranging from 0 ("not at all") to 3 ("every day"). It has strong internal reliability (α = .89) amongst primary care patients and excellent test-retest reliability. It has good construct validity, as assessed by mental health professional

interviews and by functional status (Kocalevent et al., 2013; Kroenke et al., 2010; Manea et al., 2015).

Rivermead Post Concussion Symptoms Questionnaire *(RPQ)* (King, Crawford, Wenden, Moss, & Wade, 1995). The RPQ is a widely used self-report measure of symptom severity in concussion research and is recommended in the National Institute of Neurological Disorders and Stroke Common Data Elements for traumatic brain injury and sport-related concussion. Participants rate a list of 16 symptoms on scale ranging from 0 (not experienced at all) to 4 (severe problem), in comparison to before their concussion. Scores of 1 (no more of a problem) are not included in RPQ total score as this corresponds to resolution of a previous symptom.

Test of Memory Malingering (Tombaugh, 1997). We measured performance validity using Trial 1 of the Test of Memory Malingering (TOMM-1) in accordance with virtual administration guidelines from the test publisher (Multi-Health Systems Inc., 2020). The TOMM-1 has the appearance of a challenging (visual recognition) memory test but was designed as a test of *intention* to perform well, i.e., effort or performance validity. In a recent meta-analysis, a cut-off score of below 42 on the TOMM-1 optimally identifies test-takers with known performance invalidity (sensitivity=0.6-0.7 and specificity>0.9) (Martin et al., 2020).

Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph et al., 1998). I administered 9 out of the 12 RBANS subtests via Zoom: List Learning, Story Memory, Figure Copy, Semantic Fluency, Digit Span, List Recall, List Recognition, Story Recall, and Figure Recall. The validity of videoconference administration for the RBANs has been previously supported (Galusha-Glasscock et al., 2016). We used the Delayed Memory Index as a measure of objective memory ability which combines scores from word list recall, word list recognition, story recall, and figure recall subtests. The Delayed Memory Index score is an age-adjusted standard score, with a normative mean of 100 and SD=15. It has strong test-retest reliability and correlates strongly with

legacy neuropsychological measures of episodic memory (Randolph et al., 1998). Participants who obtained an age-adjusted Delayed Memory Index score of under 85 were excluded from data analyses to rule out genuine memory impairment as an explanation for subjective memory symptoms. As second measure of performance validity, we extracted the Effort Index from the RBANS which combines scores from the Digit Span and List Recognition subtests via a scaling system (Silverberg et al., 2007). Participants with scores of 3 or greater on the Effort Index were excluded from data analysis for possible low effort as that cut-off was recently determined to be optimal for detecting performance invalidity (Shura et al., 2018)

Metacognitive Measures. Metacognition was quantified using two experimental tasks derived from Carpenter et al., 2019 based on a common paradigm in metacognitive research (Fleming & Dolan, 2012; McCurdy et al., 2013) that separates task performance from metacognitive ability – mismatch between trial-by-trial objective (accuracy) and subjective (confidence judgments) performance. To additionally examine for a memory-specific metacognitive bias (vs. domain-general lack of confidence) I chose to include a non-memory (brightness perception) task. Research suggests that distinct brain regions might be involved in different cognitive domains and metacognitive performance might be distinct between memory and perception (Baird et al., 2014, 2015; Fleming & Lau, 2014; McCurdy et al., 2013; Morales et al., 2018). Both are two-alternative forced-choice (2-AFC) judgment tasks, in which participants are either asked to determine which of two words appears brighter (perception) or which of the two words has been presented previously in an encoding period (recognition memory). After selecting their choice, participants rate their confidence in the correctness of their decision on a 4-point scale ("1 -very low confidence, 2 -low confidence", "3-high confidence", "4-very high confidence"). Both the memory and perception task consisted of 150 trials, divided into 3 blocks of 50 trials each. The stimuli were the same words (standard nouns, six to twelve letters long)

used in Carpenter et al. (2019).

Metacognitive variables were extracted using a signal-detection theory framework, that has been used in previous research (Carpenter et al., 2019; Fleming & Lau, 2014; Maniscalco & Lau, 2012b; McCurdy et al., 2013; Samaha & Postle, 2017). According to signal-detection theory, participants always make decisions under some level of uncertainty (e.g., a noisy perceptive brightness, vague memories). The discriminability of a signal depends on the separation and the spread of the signal and noise distributions. The most widely used measure of signal discriminability is *d'* = separation / spread. Measures of metacognitive capacity are constrained by basic task performance: accuracy on the primary discrimination task somewhat determines participants' ratings on the secondary confidence task. To account for this performance bias, *Meta-d'* is a measure of secondary metacognitive sensitivity that is expressed in the same units of signal-to-noise ratio as d' (basic discrimination task performance sensitivity). Metacognitive capacity can be estimated by comparing meta-d' to d': Meta-d'/d' (also called the *M-ratio*) quantifies the degree to which confidence ratings discriminate between correct and incorrect trials while controlling for task performance. If, according to signal-detection theory, a participant is "metacognitively ideal" (i.e., their metacognition has access to all the same information as for the primary discrimination task), their meta-d' = d'. When meta-d' < d', a participant is considered to have lower than expected metacognition. Thus, the M-ratio can be used to calculate *metacognitive efficiency*, which considers the variability of basic task performance (d') across participants.

The M-ratio is considered a response bias-free and performance bias-free method for evaluating metacognitive efficiency. It can be calculated by using maximum likelihood estimation fit to each participant's behavioural data. Prior studies investigating metacognition in FCD (Bhome et al., 2022; Pennington et al., 2021) have used the M ratio to measure metacognitive efficiency. To calculate metacognitive bias (whether participants are generally more or less confident), I averaged total

confidence levels within each task, collapsing across correct and incorrect trials. Additionally, I decided to include directional measures derived from task metrics to specifically assess under-confidence, namely the false positive rate (ratio of low-confidence correct responses to all low-confidence responses) and the false negative rate (ratio of low-confidence correct responses to all correct responses).

Procedure

Eligibility Screen. The study coordinator telephoned and obtained consent from potential participants after discussing what the screen entails and what the study involves. The study coordinator asked the potential participant for their age, the timing and characteristics of their injury, health history, the Word List Recall task from the Brief Test of Adult Cognition by Telephone (BTACT; Tun & Lachman, 2006), and for concussion participants, administer the Rivermead Postconcussion Symptom Questionnaire (RPQ; King, Crawford, Wenden, Moss, Wade, et al., 1995).

Session 1 – Online Questionnaires. Once the Study Coordinator determined that a prospective participant was eligible, they were emailed a consent form to review and invited to contact us if they have any questions. In the same email, they received a unique link to a Qualtrics survey (a secure data collection system) containing the self-report questionnaires. The first survey screen is the study consent form, and only participants who agree to continue by clicking "Yes" to the consent form continued with the survey and were prompted to complete self-report questionnaires described above.

Session 2 – Performance validity and Neuropsychological testing. After the questionnaires have been completed and received, research assistants contacted participant to schedule a virtual session with them. Once scheduled, participants were sent a link to engage in virtual testing using Zoom, a videoconference platform. The session was video recorded using the 'record' function in

Zoom. Trial 1 of the Test of Memory Malingering (TOMM; Tombaugh, T. N., 1996) was administered in accordance with remote administration guidelines from the test publisher (Multi-Health Systems Inc., 2020) and subtests of the Repeatable Battery for the Assessment of Neurological Status (RBANS; Randolph et al., 1998). When necessary, the assessor shared their screen with the participant using the 'share screen' function in Zoom to allow the participant to see relevant testing materials. Participants also completed the PHQ-9 and GAD-7 with the assessor in-between trails of the RBANS.

Session 3 – Metacognitive Tasks. After completion of the virtual session 2, a link to the metacognitive (memory and perception) tasks was sent to the participants via email. Participants were asked complete the tasks within a week of receiving the link. These tasks were programmed using PsychoPy and hosted on the online study platform, Pavlovia (Pavlovia.org). After completing the metacognitive tasks, participants were debriefed as to the purpose of the study over email and compensated for their time and participation.

Data Analysis Plan

Missing data and t-test assumptions

Missing data was identified for questionnaires and metacognitive tasks and values were imputed from the mean. Participants with incomplete metacognitive task data were excluded from analyses (see Chart 1 - Flow diagram). Outliers were determined by using 3× interquartile range (IQR) in SPSS. Within the entire sample (n=54) there was one outlier on the RBANS delayed memory index and one on the PHQ-15 and these were left in the sample as they were not influential outliers and did not affect analyses. Normality assumptions were tested for all scales analyzed. No scales had skewness or kurtosis values greater than 2 or less than -2.

Subgrouping

From the full concussion sample (n=34), those with significant functional memory complaints (FMDI score > 48) were selected to form a subgroup of participants with suspected FCD after concussion (n=28). From the control group (n=20), those without significant functional memory complaints (FMDI score < 48) were selected to form a subgroup of healthy control participants (n=13).

Multiple Testing

Given the small sample size and multiple t-tests, there an elevated risk of making Type 1 errors. However, this risk may be acceptable because the present study: (1) tests several different hypotheses (not the same hypothesis in different ways), (2) tests theories with a priori directional hypotheses rather than taking a bottom-up, data-driven approach, and (3) is preliminary-phase work and the first time that these factors have been examined at in a post-concussion population, making type II errors more problematic because null findings may disincentivize further research. My goal at this phase is to narrow our future research agenda by identifying which precipitating/perpetuating factors are most implicated in FCD after concussion. In situations of multiple testing to evaluate one hypothesis (e.g., which external memory strategies correlate with FCD symptoms), I used Bonferroni corrections.

Analyses

I excluded participants from analyses if they failed performance validity testing (TOMM trial 1 score <42 or RBANS Effort Index >3) or the objective memory tests (RBANS Delayed Memory Index <85, <50% accuracy on metacognitive tasks). I assessed hypotheses using between groups analyses (suspected FCD after concussion group, n =28, vs. healthy control group, n=13) and within group analyses (the full sample of participants who had a concussion and no objective memory impairment

n=34). Although this grouping reduced the sample size for some analyses, it allowed me to compare more homogeneous groups with consistent FCD symptoms.

I conducted t-tests between the suspected FCD after concussion group and the healthy control group in order determine group differences in metacognition, misdirected attention, somatization, rumination, depression, memory perfectionism, anxiety, as well as in specific checking behaviors and external memory strategies. I conducted linear regressions with FMDI score as the dependent variable to understand the how these variables are associated with functional cognitive symptoms after concussion.

Chapter 3: Results

Participant Characteristics

Due to COVID-19 restrictions, we endeavored to recruit as many participants as possible and did not conduct a power analysis to determine sample size. See Figure 1 for the Participant Recruitment Flow Diagram. See Table 1 for descriptive characteristics of the sample. See Table 2 for between group differences (suspected FCD after concussion vs healthy control). See Table 3 for within group differences (all participants with a concussion). See Table 4 for a summary of all results.

Metacognition

The t-tests revealed no differences between the suspected FCD group or control group on average confidence in either the perception or memory task. The t-tests examining differences in the rates of false negatives and false positives between groups in the memory task also yielded no significant differences. The linear regressions also yielded no significant associations between false positive rate or false negative rate, on FMDI score in the full concussion group.

Misdirected Attention

The t-tests examining how attentional variables (both thought-focused and body-focused) differ between groups revealed a statistically significant difference in somatization (PHQ-15) scores between groups, with the suspected FCD after concussion subgroup endorsing more somatic symptoms but similar levels of rumination. The linear regression of FMDI score within the full concussion group revealed a strong association with rumination (RTSQ) but a weaker effect of somatization (PHQ-15).

Depression

The t-test of depression (PHQ-9) in the matched samples revealed a significant between groups difference. Additionally, the linear regression showed a significant association of depression with FMDI score in the general concussion group.

Memory Perfectionism

The t-test of memory perfectionism (MIA-A) scores showed higher rates of memory perfectionism in the suspected FCD group compared to the control group. The linear regression within the full concussion group showed a significant association between memory perfectionism and FMDI scores.

Anxiety and Avoidance Behaviours

Anxiety. I compared the means of the matched subgroups on the measure of anxiety (GAD-7) and performed a linear regression of FMDI score on GAD-7 scores in the general concussion group. The suspected FCD after concussion group had significantly higher anxiety scores compared to the healthy control group. The regression performed on the full concussion sample revealed no statistically significant association of general anxiety with FCD symptom severity.

Memory Strategies. The independent samples t-tests comparing the effect of group on use of four memory strategies on the MMQ-S revealed a statistically significant difference between the suspected FCD group and the control group in the endorsement of "Ask someone to help you remember something or to remind you to do something". The linear regressions of total FMDI score on the MMQ strategies among all the participants with past concussion also revealed a significant association with the endorsement of "Ask someone to help you remember something or to remind you to do something." Endorsement of the other three strategies did not differ between groups nor were they significantly associated with FMDI score in participants with concussion.

Checking Behaviours. I performed independent samples t-tests to compare groups on their use of checking behaviours in five common daily tasks from the MAEQ (turning off house lights, locking the door, washing hands, turning off the stove, turning off electrical appliances). The t-tests revealed

that the suspected FCD group endorsed increased checking of electronic appliances compared to the control group, however this difference was not significant at the Bonferroni-adjusted alpha level. The linear regressions of FMDI score on each of the MAEQ checking behaviours within the group of participants who had sustained a concussion revealed that increased checking of electrical appliances not associated with FCD symptom severity.

Chapter 4: Discussion

This study was the first to apply theoretical model of FCDs to explore predisposing and perpetuating factors that may underlie persistent memory complaints after concussion. It adds evidence to support the role of psychological factors involved in FCD in adults with recent concussion. I also examined the relationship between functional cognitive symptoms, metacognitive ability, body- and thought- directed attention as well as depression and memory perfectionism. Additionally, I examined repeated checking behaviors and use of external memory strategies in order to clarify the role of common perpetuating factors in anxiety disorders may also be implicated in FCD. An improved understanding of how FCD develops and persists can guide development of novel methods for treating FCD, both after concussion and in other clinical contexts.

The suspected FCD after concussion group and the healthy control group had comparable objective memory performance (as measured by the RBANS and accuracy in the metamemory task). This is unlikely to be a consequence of eligibility criteria as only participants with very poor objective memory were excluded. This finding contributes evidence to the lack of cognitive deficits after concussion despite subjective impression of poor memory (Iverson et al., 2019) and aligns with previous research that some people perceive their cognitive functioning as worse than their performance on neuropsychological testing (Anderson, 2021; Drag et al., 2012; French et al., 2014; Hromas et al., 2021; Silverberg et al., 2016).

The healthy control group and suspected FCD after concussion subgroups differed on measures of somatization, depression, anxiety, memory perfectionism, and certain memory compensation behaviours (i.e., asking someone to help you remember or remind you). When examined within the full concussion sample, only depression, memory perfectionism, rumination and memory strategies (i.e., asking someone else to remind or help remember), were significantly associated with higher FCD

symptoms. This may indicate that certain factors such as somatization and anxiety, which are theorized to underlie FCD, are also relevant to understanding general symptom persistence after concussion, consistent with prior research (Garden & Sullivan, 2010; Greenberg et al., 2020; Hsieh et al., 2012; Nelson et al., 2016; Root et al., 2016).

Contrary to expectations, none of the metacognitive measures distinguished between the suspected FCD and control groups. This result is supported by recent work from other groups (published after starting data collection for this thesis) using similar measures of metacognition (memory task with confidence ratings) showing little evidence of metacognitive deficits in people with FCD (Bhome et al., 2022; Pennington et al., 2021). There were no differences in average confidence or metacognitive efficiency (the degree to which the participant can determine whether they answered correctly or not) between groups although the FCD group had significantly lower accuracy in the memory task compared to healthy controls (Pennington et al., 2021). Another recent study (Bhome et al., 2022) found that people with FCD have intact local metacognition (moment-to-moment judgements of performance, using a similar recognition memory and perception task) but impaired global metacognition (longer term self-evaluations of performance based on questionnaires) compared to healthy control participants. This evidence might support another possible theory of FCD - a Bayesian model wherein a mis-calibrated prior (global metacognition) overrides correct sensory input (local metacognition) to produce the sensation of impaired cognitive processing (Bhome et al., 2022). Metacognitive ability, as it has been measured using the confidence-rating, alternative forced choice paradigm (Fleming & Dolan, 2012; Fleming & Lau, 2014; Maniscalco & Lau, 2012a; Seow et al., 2021) does not appear to be associated with FCD (Bhome et al., 2022; Pennington et al., 2021). The present study adds to the evidence against the involvement of certain metacognitive factors such under-confidence in recognition memory task ability in FCD-like presentations after concussion.

Somatization was not very strongly associated with FCD symptoms within the sample of people with concussion, however it was the strongest discriminator variable between the matched FCD and control groups. This may reflect a tendency for some people to be more aware of their physical symptoms after a concussion, which could lead to impaired attention and memory as they focus on symptoms. It is also possible that the observed association between "somatization" (PHQ-15 scores) and FCD symptoms (FMDI scores) may be explained by a general tendency for people with FCD to report more symptoms (of any kind). This would be consistent with evidence that people with persistent concussion symptoms report more somatic symptoms (not typically associated with concussion) compared to people with good recovery or healthy controls (Stubbs et al., 2020).

Rumination was not found to be significantly associated with functional cognitive symptom severity among people with persistent symptoms after concussion, yet it did differ significantly between suspected FCD group and a healthy control group. Rates of rumination might be high in populations with persistent symptoms after concussion and thus does not distinguish between those with and without FCD symptoms. Alternatively, instead of self-focused attention, rumination may be better conceptualized as self-focused achievement motivation (Silvia et al., 2005) involving difficulty disengaging from (negative) emotional expressions (LeMoult et al., 2013) and feelings of inadequacy. Rumination may not require as significant attention and be less distracting, as well as be perceived as more helpful, compared to distressing bodily symptoms.

Consistent with prior research, depression scores differentiated between the suspected FCD group and the healthy control group and were associated with increased FCD symptom severity among participants with concussion. This suggests that although co-morbid, FCD is unlikely to be just a feature of depression. More research is needed to determine whether depressive states might lead to increased negative biases or neuroticism that have the effect of magnifying cognitive impairment in FCD (Bhome,

Huntley, et al., 2019). Alternatively, depression may facilitate certain avoidance behaviours such as relying of others to take on responsibilities, that hinder appropriate recognition of memory healing after a concussion.

Results indicated a positive relationship between FCD symptom severity and memory perfectionism in participants with a concussion as well as a significant difference between those with suspected FCD and healthy controls. As this was a cross-sectional study, directionality cannot be determined. It is possible that a tendency towards memory perfectionism predisposes people to dwell on perceived cognitive difficulties after concussion. Alternatively, the noticing of cognitive lapses over time might lead to an increase in memory perfectionism among people with FCD. There is also the possibility that people misremember the extent of their memory ability before their concussion, an example of the "good-old-days" bias, (Silverberg et al., 2016) leading to them holding unrealistically high standards for their current memory abilities. These high standards for memory, coupled with low tolerance for failure, might perpetuate the cycle of anticipatory anxiety for memory situations and the catastrophizing of memory mistakes.

Endorsement of anxiety symptoms were significantly higher in the suspected FCD compared to the healthy control group, yet general anxiety symptoms were not related to functional cognitive symptom severity in the full concussion group. Similarly, the endorsement of checking electrical appliances to ensure they are off was higher in the suspected FCD group but did not meet Bonferroni-adjusted significance and was not associated with FCD symptoms more generally. Only the memory strategy "asking someone to remind or help you remember" was significant in both analyses. Anxiety-driven, maladaptive coping behaviours merit further investigation in the context of FCD after concussion. Certain behaviours (i.e., frequently relying on others as a memory aid) could seem useful early-on in concussion recovery yet perpetuate the sense of impairment if over-used.

I found that depression and memory perfectionism seem to be the most strongly associated with FCD symptom severity after concussion, with these two variables having the largest effect sizes of all the factors investigated. The theory that FCD symptoms arise and are perpetuated by misdirected attention has moderate support, with some evidence that the severity of FCD symptoms after concussion is associated with increased rumination and a tendency to over-focus on bodily symptoms (i.e., somatization). My results also suggest that anxiety and anxiety-related behaviours have moderate support for their association with FCD symptoms after concussion – especially the use of external memory strategies (such as relying on others) rather than checking behaviours, which were less strongly associated with the severity of FCD symptoms. The idea that FCD is associated with local metacognitive deficits (e.g., under confidence in memory decisions given performance) lacks support, with neither analysis yielding significant relationships between metacognitive variables and FCD symptom severity. Taken together, these results suggest that depression and memory perfectionism could be useful treatment targets for addressing persistent cognitive complaints after concussion in the absence of objective impairment. Factors related to attention (i.e., rumination, somatization) and anxiety (e.g., compensatory memory strategies) merit further investigation. The role of metacognition in functional cognitive disorder after concussion should be reconceptualized and tested using different methods.

Limitations

There are several limitations to the current study. Participant characteristics limiting the generalizability of our findings include the over-representation of well-educated (post-secondary degrees), White women compared to the general population. There was a significant age difference between the suspected FCD after concussion group and the healthy control group. Although subjective cognitive symptoms do not seem to be associated with age (McWhirter, King, et al., 2021; McWhirter, Ritchie, et al., 2021), age might moderate the relationship between FCD symptoms and other

variables. I attempted to control for this by including age in the models and did not observe a significant change in the pattern of results (i.e., rumination, depression, memory perfectionism, and "asking someone to remind" remained significantly associated with functional cognitive symptoms when age was included in the linear regression). However, more detailed research is warranted on the potential moderating effects of age on functional cognitive symptoms after concussion.

The group of participants with concussion is likely not representative of a general concussion population – they were recruited from specialty concussion clinics and thus could be more symptomatic (mean RPQ total score = 27.3) and help-seeking compared to other people after concussion. Our small sample size limited the number of possible comparisons and testing of additional covariates such as prior psychological diagnoses. Additionally, the use of PVTs might have erroneously excluded participants with test anxiety or stereotype/diagnosis threat (e.g., public awareness that a brain injury can lead to poor cognition) that failed due to stress rather than deliberate exaggeration or malingering (Silver, 2012). Including measures of performance anxiety or collecting qualitative, narrative accounts of illness perceptions could help to clarify whether performance validity tests are over-sensitive when assessing an FCD population.

There is lack of consensus across the literature on how to best assess confidence in metacognition paradigms (Fleming & Lau, 2014). Most research to date has employed absolute measures (i.e., rating confidence on a Likert-type scale) rather than relative measures (i.e., which of two trials were you more confident on?). Absolute measures are subject to response bias (i.e., reporting only 1's and 2's on the confidence scale due to low confidence vs. a tendency to avoid the upper parts of scales) and they are difficult to compare between participants (i.e., does a 2 indicate low confidence for one person in the same way it does for another?). Unfortunately, a full investigation and comparison of these two types of

scales has yet to be published. For now, it is necessary to hold this limitation in mind when conducting confidence research, especially using between-subjects designs.

Another limitation arises from the need to collect data remotely due to the Covid-19 pandemic. Data was collected using a videoconferencing platform to administer performance validity and neurocognitive tests and a website for metacognitive tasks. These methods pose some threats to validity as the RBANS and TOMM were adapted for Zoom administration with only preliminary evidence for their robustness. Furthermore, participants were unsupervised when performing the metacognitive tasks, raising the possibility of misinterpretation or misunderstanding instructions, insufficient effort, or distraction.

Conclusions

This thesis highlights some likely (e.g., depression, memory perfectionism) and unlikely candidates (e.g., metacognitive bias towards under-confidence) to guide future research on the etiology of FCD after concussion. It provided preliminary novel evidence that anxiety and certain avoidance behaviours (i.e., asking someone to remind or help remember) might be associated with functional cognitive symptoms after concussion and that metacognitive bias is unlikely to be involved. Results support previously implicated factors in FCD including memory perfectionism, depression, somatization, and rumination. Together, these resultshighlighs the need for further research in order to clarify the strength and directionality of these relationships before investigating intervention strategies aimed at regulating these factors.

Future Directions

Future research should further clarify the relationship between memory perfectionism, depression, rumination, and the use of memory strategies with functional cognitive symptom severity using longitudinal studies in order to determine directionality. Future work should also aim to clarify the

role of local vs. global metacognition in FCD since this study only evaluated local metacognition and there is recent evidence for impaired global metacognition in FCD populations (Bhome, 2022). The field can turn to developing and evaluating psychological interventions tailored to the most important modifiable perpetuating factors of FCD. For example, Cognitive Behavioral Therapy (CBT) aimed at reducing the use of external memory strategies through exposure to memory-related events or the examination of negative beliefs about memory using a thought-diary. Given the psychological factors implicated in FCD, CBT is likely to be a good candidate treatment for reducing functional cognitive symptoms as it focuses on systematically examining and restructuring dysfunctional assumptions (e.g., "My memory should be perfect"), negative automatic thoughts (e.g., "I'm developing Alzheimer's"), and cognitive distortions (e.g., "Other people will think I'm irresponsible if I can't remember everything perfectly"). Additional interventions might include metacognitive training, which has been successful in improving metacognitive efficiency healthy adult populations (Carpenter et al., 2019). However, there is recent evidence (Rouy et al., 2022) that experimental confounds (including the absence of rewards at baseline and inconsistency in instructions) might have led to the observed increase in metacognitive performance rather than training effects, highlighting the need for new paradigms. Given the pattern of results obtained, studies of treatments focusing on anxiety and avoidance behaviors should be prioritized over than metacognitive interventions. The field should also investigate potential biomarkers for diagnosing FCD such as unique brain signals (i.e., increased error-related negativity potentials during a memory task).

Tables

Table 1

Descriptive Characteristics

	Control Group		Suspected FCD Group		Full Concussion Group	
Total Group N	13		28		34	
Demographics	N	%	N	%	N	%
Gender (% women)	9	69.2	22	78.6	24	70.6
Education level						
High school	3	23.1	0	0	1	2.9
Some college/university, no degree	0	0	8	28.6	8	23.5
Two-year college degree	1	7.7	6	21.4	6	17.6
Bachelor's degree	7	53.8	8	28.6	10	29.4
Graduate or professional degree	2	15.4	6	21.4	9	17.6
Ethnicity						
White	9	69.2	20	71.4	25	73.5
East, South, or Southeast Asian	4	30.8	8	28.6	9	26.4
Work or School Status						
Full-time	12	92.3	11	39.3	16	47.1
Part-time	0	0	9	32.1	9	26.5
Not working due to injury	1	7.7	8	28.6	9	26.4
More than 2 previous concussions	2	15.4	6	21.4	7	20.6

Neuropsychological Tests	M	SD	M	SD	M	SD
Performance Validity[1]	48.62	-1.56	48.68	-1.68	48.74	-1.58
Episodic Memory[2]	97.85	-10.29	105.46	-7.43	106.44	-7.81
Self-Report Measures						
Rumination[3]	88.77	-19.11	90.54	-22.98	85.68	-24.60
Somatization[4]	4.08	-2.93	12.00	-5.79	10.62	-6.10
Depression[5]	4.92	-3.88	10.64	-5.28	9.80	-5.61
Anxiety[6]	3.92	-4.03	9.07	-5.18	8.47	-5.28
Memory Perfectionism[7]	58.54	-8.12	66.79	-7.19	65.56	-7.80
FCD Symptoms[8]	37.62	-6.23	66.04	-10.77	62.00	-13.24
Checking Behaviours[9]						
House Lights	7.31	2.56	7.61	2.63	7.79	2.46
Stove	9.38	1.56	9.36	1.25	9.47	1.16
Electrical Appliances	4.46	3.31	6.57	2.57	6.79	2.51
Front Door	7.77	3.00	8.07	2.19	8.26	2.06
Wash Hands	5.89	4.23	7.57	2.99	7.15	3.32
Memory Strategies[10]						
Ask someone to remind	1.31	0.73	2.36	0.99	2.15	1.10
Use a calendar	3.54	0.78	3.46	1.04	3.35	1.12
Have a routine	3.15	1.46	3.14	0.93	3.03	1.06
Set a timer or alarm	3.23	0.73	2.96	1.04	2.82	1.22
Metacognitive Memory Task						
Accuracy	0.78	0.13	0.81	0.07	0.81	-0.07

Confidence	2.91	0.47	2.93	0.45	2.96	-0.44
False Negative Rate	0.15	0.12	0.10	0.07	0.10	-0.06
False Positive Rate	0.36	0.12	0.34	0.22	0.35	-0.22
M Ratio	1.07	0.36	0.99	0.31	0.99	-0.29
Metacognitive Perception Task						
Accuracy	0.75	0.01	0.76	0.01	0.76	-0.01
Confidence	2.52	0.65	2.54	0.62	2.56	-0.62
M Ratio	0.70	0.31	0.65	0.19	0.67	-0.19

Note. M-Mean, SD-Standard Deviation; [1]Test of Memory Malingering – Trial 1, [2]Repeated Battery for the Assessment of Neurological Function – Delayed Memory Index, [3]Ruminative Thought Style Questionnaire, [4]Patient Health Questionnaire-15, [5]Patient Health Questionnaire-9, [6]Generalized Anxiety Disorder -7, [7]Metamemory in Adults – Achievement, [8]Functional Memory Disorders Inventory – Long version, [9]Memory for Actions and Events Questionnaire – Obsessive/Responsible , [10]Multifactorial Memory Questionnaire - Strategies

Table 2

Group differences

				95% Confidence Interval for d		
	t	**df**	**Cohen's d**	**Lower Bound**	**Upper Bound**	**Sig.**
Metacognition						
M ratio	-0.70	39	-0.23	-0.89	0.43	0.49
Memory False Negative Rate	-1.55	39	-0.52	-1.18	0.15	0.13
Memory False Positive Rate	-0.29	39	-0.10	-0.76	0.56	0.77
Average Memory Confidence	0.16	39	0.05	-0.60	0.71	0.87
Average Perception Confidence	0.06	39	0.02	-0.64	0.19	0.68
Misdirected Attention						
Rumination	0.24	39	0.08	-0.58	0.74	0.81
Somatization	4.65	39	1.56	0.81	2.29	0.000***
Additional Factors						
Depression	3.48	39	1.17	0.46	1.87	0.001**
Memory Perfectionism	3.38	39	1.10	0.39	1.76	0.002**
Anxiety and Avoidance						
Anxiety	3.16	39	1.06	0.36	1.75	0.003**
Checking Behaviors						
House Lights	0.34	39	0.12	-0.54	0.77	0.73

Stove	-0.06	39	-0.02	-0.68	0.64	0.95
Electrical Appliances	2.23	39	0.75	0.07	1.42	0.03*
Front Door	0.36	39	0.12	-0.54	0.78	0.72
Wash Hands	1.64	39	0.55	-0.12	1.22	0.11
Memory Strategies						
Ask someone to remind	3.29	39	1.11	0.40	1.80	0.002**[+]
Use a calendar	-0.23	39	-0.08	-0.74	0.58	0.82
Have a routine	-0.03	39	-0.01	-0.67	0.65	0.98
Set a timer or alarm	-0.70	39	-0.28	-0.94	0.38	0.41

Note. * p<.05, **p<.01, ***p<.001, [+]Bonferroni adjusted p<.0125

Table 3

Simple linear regression results

	Unstandardized Coefficients		95% Confidence Interval for B		
	B	**Std. Error**	**Lower Bound**	**Upper Bound**	**Sig.**
Metacognition					
M ratio	8.36	7.80	-7.53	24.25	0.29
False Negative Rate	75.12	66.36	-60.60	210.84	0.27
False Positive Rate	-22.47	23.73	-71.00	26.05	0.35
Average Memory Confidence	3.08	9.71	-16.78	22.94	0.75
Average Perception Confidence	0.74	3.92	-7.27	8.74	0.85
Misdirected Attention					
Rumination	0.23	0.09	0.06	0.41	0.01*
Somatization	0.73	0.36	-0.01	1.46	0.05
Additional Factors					
Depression	0.94	0.38	0.16	1.72	0.02*
Memory Perfectionism	0.94	0.25	0.43	1.45	0.001**
Anxiety and Avoidance					
Anxiety	0.62	0.43	-0.26	1.49	0.16
Checking Behaviors					
House Lights	-0.98	0.94	-2.88	0.93	0.30
Stove	0.14	2.06	-3.97	4.24	0.95

Electrical Appliances	-0.28	0.93	-2.18	1.61	0.76
Lock Door	-0.55	1.13	-2.85	1.75	0.63
Wash Hands	0.71	0.69	-0.70	2.13	0.31
Memory Strategies					
Ask someone to remind	4.45	1.97	0.44	8.45	0.03*
Use a calendar	2.18	2.04	-1.99	6.34	0.29
Have a routine	2.84	2.15	-0.16	7.23	0.20
Set a timer or alarm	3.58	1.82	-0.12	7.27	0.06

Note. * p<.05, **p<.01,

Table 4

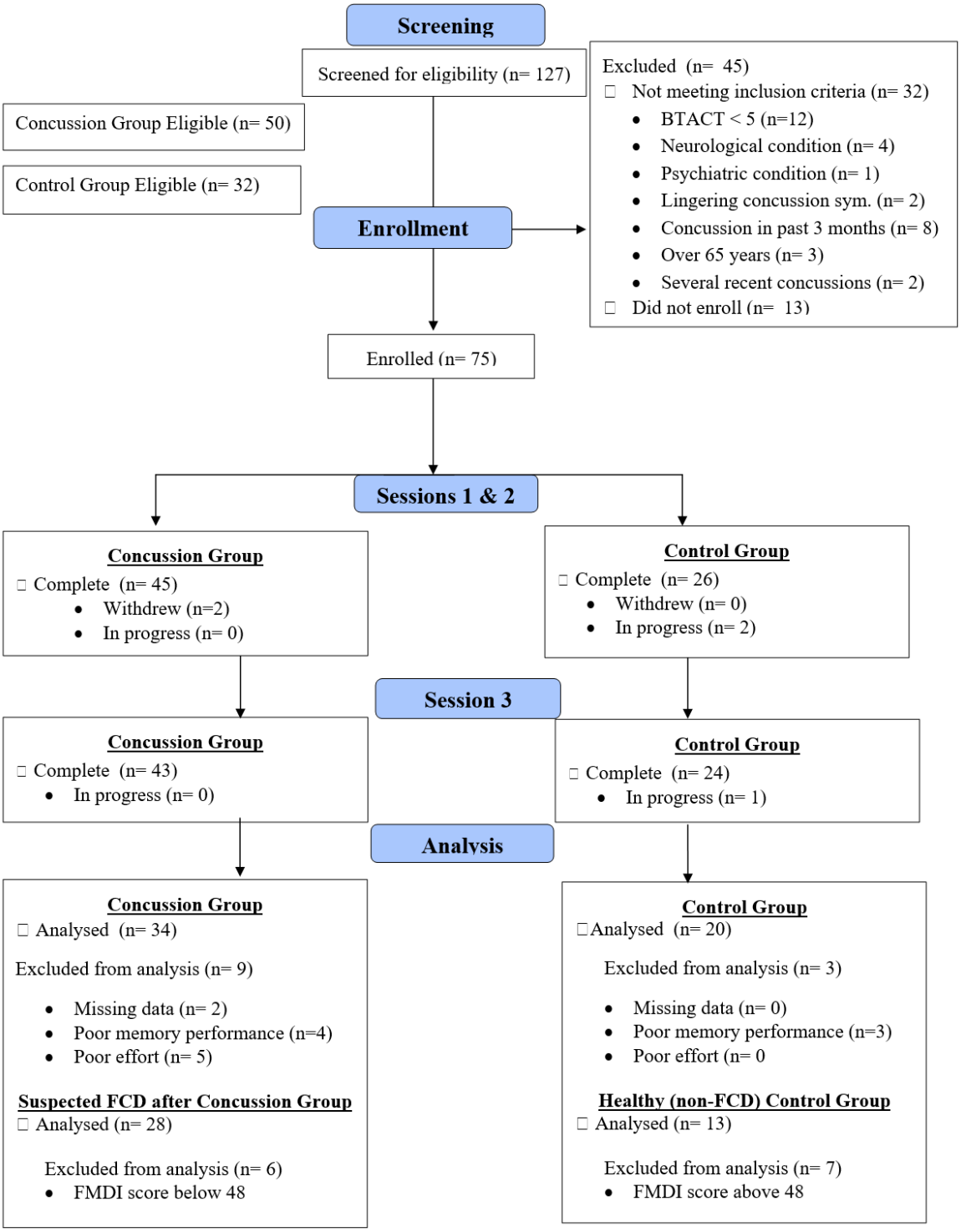
Summary of Results

	Between Group: Suspected FCD vs. Controls	Within Group: Concussion
Metacognition		
M Ratio	not significant	not significant
Memory Task Confidence	not significant	not significant
False Negative Rate	not significant	not significant
False Positive Rate	not significant	not significant
Attentional Misdirection		
Rumination	not significant	higher scores: FCD symptoms
Somatization	FCD > Controls	not significant
Additional Factors		
Depression	FCD > Controls	higher scores: FCD symptoms
Memory Perfectionism	FCD > Controls	higher scores: FCD symptoms
Anxiety and Avoidance		
Anxiety	FCD > Controls	not significant
Checking Behaviours	not significant	not significant
Memory Strategies	FCD > Controls “Ask someone to remind"	"Asking someone to remind": FCD symptoms

Figures

Figure 1

Participant recruitment flow diagram



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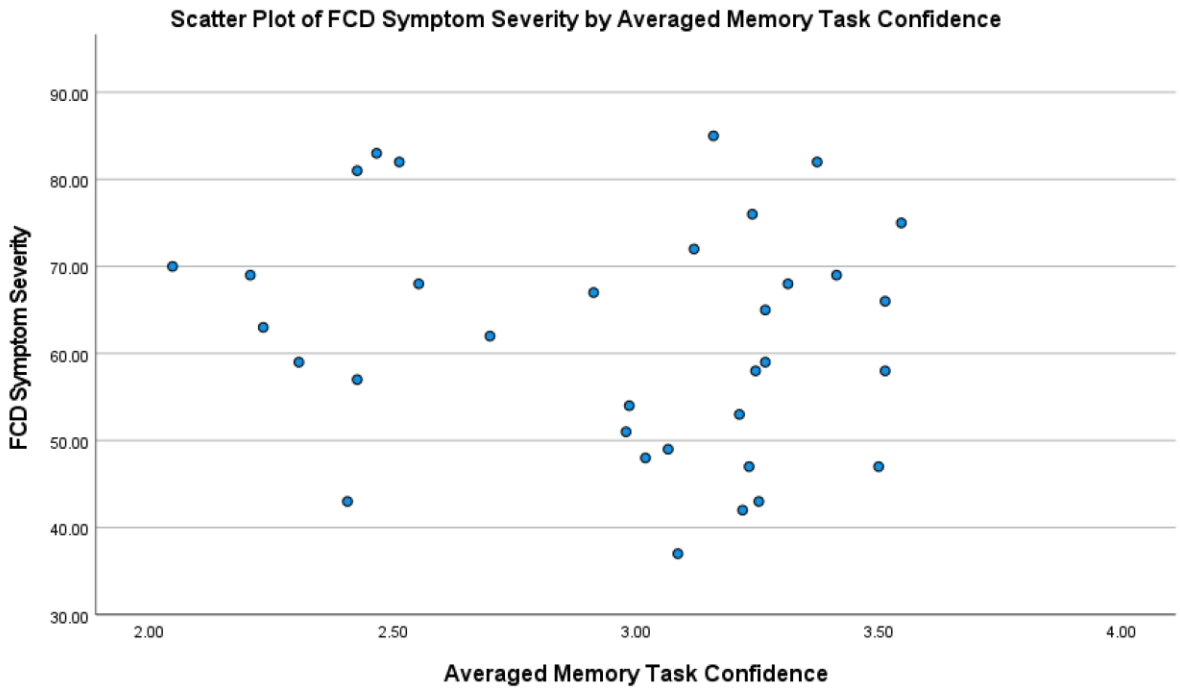
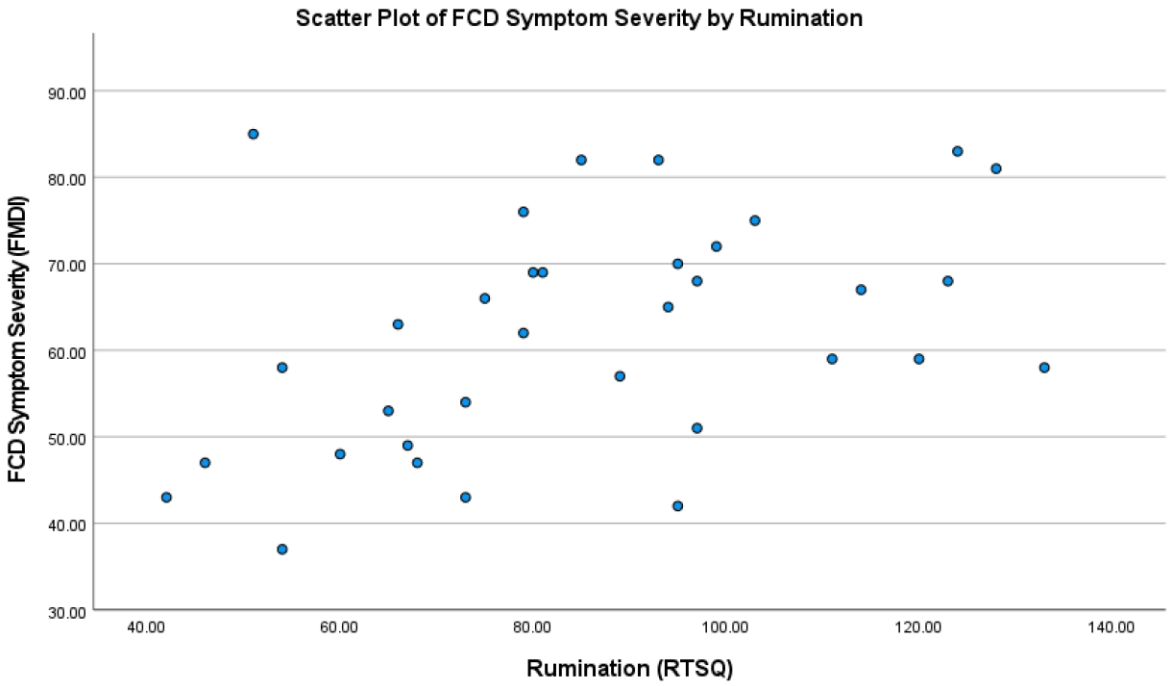
Appendix

Scatter plots of continuous variables used in regression analyses

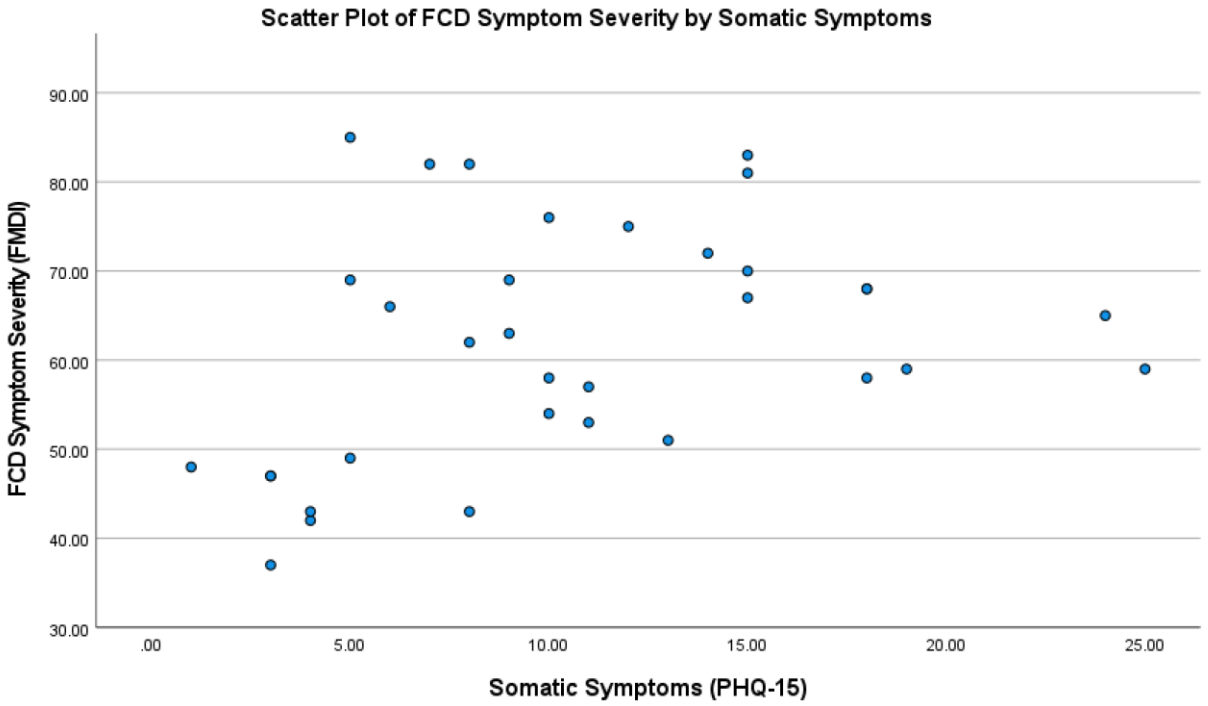
Memory Task Confidence



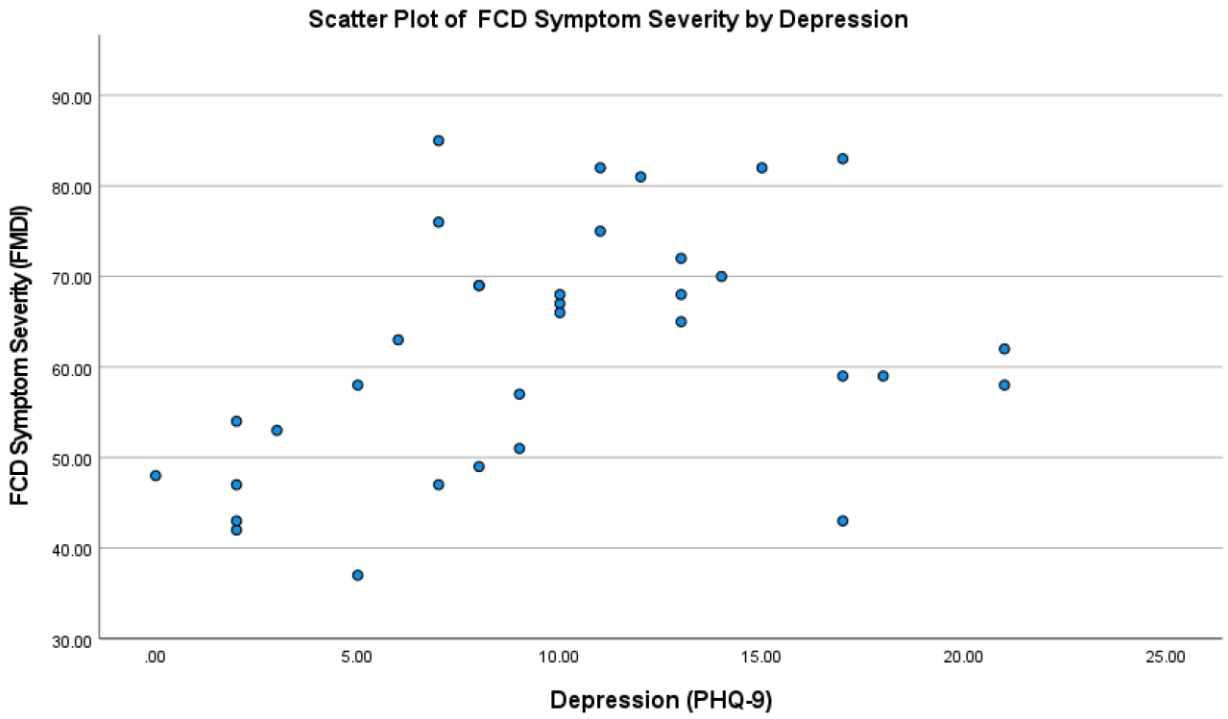
Rumination



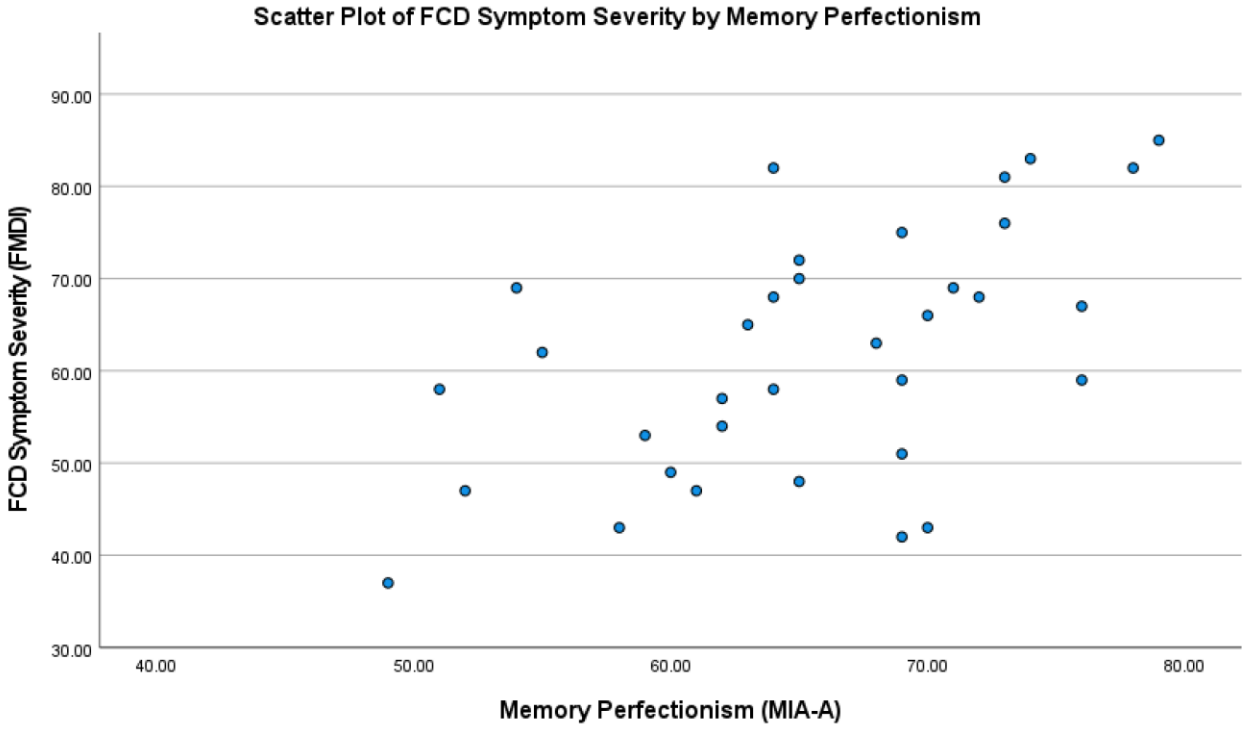
Somatization



Depression



Memory Perfectionism



Anxiety