

When the Past Becomes the “Good Old Days”: Adolescents Underestimate Pre-Injury
Post-Concussion-Like Symptoms by One Month after Mild Traumatic Brain Injury

by

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B.A.H., University of Guelph, 2007

M.Sc., University of Victoria, 2011

A Dissertation Submitted in Partial Fulfillment
of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

in the Department of Psychology

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University of Victoria

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Supervisory Committee

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Abstract

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Objectives: After mild traumatic brain injury (mTBI), psychological factors can contribute to persisting post-concussion symptoms (PCS). Consistent with constructive theories of memory, negative expectations for increased symptoms after mTBI may contribute to misattributing symptoms to the mTBI and underestimating pre-injury symptoms, called the “good old days’ bias” (Gunstad & Suhr, 2001). The good old days’ bias is not thought to be a general retrospective recall bias but studies to date have largely not controlled for normative memory processes including those that lead to a biased, more positive recall of the past. Therefore, the current study examines whether there is a good old days’ bias after mTBI above and beyond normal memory biases. This study also examines how soon after mTBI the good old days’ bias affects recall of pre-injury symptoms in the first month after mTBI in adolescents as well as whether the good old days’ bias causes pre-injury symptom severity to be underestimated or if symptoms are entirely forgotten. Finally, the clinical significance of symptom recall biases is investigated.

Method: The sample is 42 adolescents who sustained an mTBI (ages 13-18 years; 24 males) and 42 uninjured adolescents (ages 13-18 years; 24 males,). The mTBI group rated current and retrospective post-concussion symptom ratings within one week and

again, at one month, post-injury. The control group rated current and retrospective post-concussion symptoms at baseline and one month later. Cross-sectional and longitudinal comparisons using non-parametric statistical tests were used.

Results: Wilcoxon signed-rank tests showed that, by one month post-mTBI, adolescents report fewer total, physical, and emotional pre-injury symptoms than they had reported within one week of their concussion. The control group did not demonstrate this good old days' bias. There were no between-group differences in retrospective PCS ratings at either time point. Chi-square analyses found that the mTBI group was as likely as the control group to recall "no" pre-injury/past symptoms one month post-injury after having initially reported some pre-injury symptoms. Only four more adolescents were classified as "recovered" if their one-month PCS ratings were compared with pre-injury PCS ratings made within 1-week post-concussion rather than pre-injury ratings from 1-month post-injury.

Discussion: There was mixed evidence for a good old days' bias by one month post-concussion. This bias was not demonstrated in healthy adolescents, suggesting that the good old days' bias is found specifically after concussion. During the acute post-injury period, the good old days' bias may only be apparent by studying changes in concussed individuals' own PCS ratings. The good old days' bias leads to underestimating the severity of pre-injury symptoms rather than forgetting them entirely. The good old days' bias does not greatly affect symptom recovery tracking by one month post-concussion. Future studies should directly examine expectations about concussion and their effect on current and retrospective symptom reporting.

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Acknowledgments

Thank you to my supervisors, Dr. Brian Christie and Dr. Mauricio Garcia-Barrera for your support and guidance. It's been wonderful being part of your dynamic, collaborative labs. I am also incredibly grateful to my committee member, Dr. Chand Taneja, for your above-and-beyond support and mentorship in shaping my career. Thanks also to Dr. Clarissa Bush who said the right things at the right times to help get me here.

Thank you to the participants of the CDE study and Neurotracker studies. This work would not have been possible without the entire CDE project team and especially Dr. Isabelle Gagnon and Rosemary Wagner. A huge thanks to my fellow Concussion Lab members, Kristina Kowalski, Hilary Cullen, Kim Oslund, Amy McQuarrie, Erika Shaw, and Allison Rodway.

Thank you to my family for your constant support. To my mum, Andrew, Peter, and Tiffany. Thank you to my friends who have been there since the beginning of this journey. Thank you Esther Direnfeld, Erin Eadie, Jessica Toppazzini, and Alanna Hagar for talking things out with me, and for always encouraging me. Thank you, KV, for quiet, steady encouragement and hikes where things could work themselves out. Thank you to Mario Baldassari and Calum Ramsay for being amazing friends and roommates in putting up with stacks of papers and beautiful mind diagrams. Finally, thank you to Jean-Claude Savard for your support, encouragement, and stickers during the final writing phase.

Dedication

For my mum, Mrs. Sheila Irwin. The strongest person I know. She showed me there's always a way, and it's forward.

And to the memory of my dad, Dr. David Sutherland Irwin. We walk slowly, but we don't walk back.

Introduction

No man ever steps in the same river twice, for it's not the same river and he's not the same man. – Heraclitus (535-475 BC)

Mild traumatic brain injury (mTBI), or concussion, is an acute brain injury that occurs when a direct or indirect force to the head results in disrupted brain function (e.g., post-traumatic amnesia, loss of consciousness, disorientation, and/or other focal signs; World Health Organization, Carroll et al., 2004). About 80% of traumatic brain injuries are mild (Bruns & Hauser, 2003). However, mTBIs are heterogeneous, varying by causal mechanisms, neurometabolic and structural brain changes, neurocognitive deficits, and other signs and symptoms (Iverson & Lange, 2011). The diagnostic criteria for mTBI also vary. This signifies the difficulty in categorizing this injury by severity when manifestation and recovery are influenced, not just by biological and physiological factors, but also by individual psychological, social, and contextual differences (Silverberg & Iverson, 2011; Lishman, 1988).

A number of subjective cognitive, somatic, emotional/neuropsychiatric, and sleep-related symptoms are common after mTBI (see Table 1; Ayr, Yeates, Taylor, & Browne, 2009; Lau, Lovell, Collins, & Pardini, 2009; Pardini et al., 2004; Sady, Vaughan, & Gioia, 2014). Although not specific to post-mTBI sequelae, this cluster of symptoms is referred to as “post-concussion symptoms” (PCS) because they are more common and severe in children and adults after mTBI than after other injuries or in healthy individuals (e.g., Taylor et al., 2010; Yeates et al., 2009; Farmer, Singer, Mellius, Hall, & Charney, 1987; Fay, Jaffe, Polissar, et al., 1993; Mittenberg, Wittner, & Miller, 1997; Ponsford, Willmott, Rothwell, et al., 1999; Yeates, Luria, Bartkowski, et al., 1999). More severe symptoms are associated with greater distress and impairment in academic, leisure, and social functioning (Carroll et al., 2004b). Therefore, there is growing interest in understanding why some individuals experience more severe or long-lasting PCS after mTBI. The current study examines how expectation-based memory biases affect post-concussion symptom reporting before and after an mTBI.

Table 1

Post-concussion symptom clusters on the PCSI-SR13-18 (Gioia et al., 2012)

<u>Symptom Clusters</u>	<u>Component Symptoms</u>	<u>Range of Possible Severity Ratings</u>
Somatic	Headache, dizziness, nausea, balance problems, sensitivity to light, sensitivity to noise, visual problems, slowed down, clumsiness	0-54
Cognitive	Difficulty concentrating, difficulty remembering, feeling mentally foggy, feeling mentally slowed down, slow to answer	0-30
Neuropsychiatric	Irritability, feeling more emotional, sadness, nervousness	0-24
Sleep-related	Fatigue, Drowsiness	0-12

Assessing recovery after mTBI often relies on subjective judgments of whether an individual's functioning and PCS have returned to pre-injury levels. However, evidence is accumulating that judgments about current and past symptoms are fallible. Constructive theories of memory posit that recall and judgment of one's past is guided by beliefs about whether or not one has changed since that time (Conway & Ross, 1984; Wilson & Ross, 2003; Conway & Pleydell-Pearce, 2000; Conway, 2005; Ross, 1989). Even in those who have never had a concussion, there are widespread expectations for negative changes after mTBI, including for increased PCS (e.g., Mittenberg et al., 1992; Ferguson et al., 1999; Gunstad & Suhr, 2002; 2004). Given that expectations can affect judgments about the past, it is important to understand whether beliefs about mTBI can influence recall of the past (i.e., pre-injury), including judgments about whether or not one has changed since the brain injury.

Social and psychological factors can lead to the increased experience and reporting of post-injury/trauma symptoms. There is also evidence that social, psychological, and cognitive factors can lead to the perception of greater change in oneself after trauma or mTBI through the retrospective underestimation of pre-injury symptoms; the difference between one's current and past symptoms is exaggerated. For example, the "good old days' bias" (Gunstad & Suhr, 2001) is the tendency to

retrospectively view oneself as better off before a negative event by underestimating the extent to which one experienced problems and symptoms before the event.

Such social-psychological processes have mostly been studied in the chronic period after mTBI in adults (i.e., 6 months to over 2 years post-injury). However, much less is known about when and how negative expectations about mTBI might bias individuals' judgments of how much they have changed in the very acute period after mTBI. Furthermore, retrospective recall biases after mTBI and other traumas have been couched in terms of detrimental effects of expectations. Less discussed, or controlled for, are normal memory biases that lead to a rosier view of the past even in the absence of trauma. To date, studies have largely not distinguished between social psychological processes that lead to retrospective recall biases specific to post-trauma/injury compared to normative memory and judgment processes that commonly change individuals' judgments of past functioning.

The current study examined the onset and time course of retrospective biases in adolescents' recall of their pre-injury symptoms in the acute period after mTBI (i.e., in the first week and at one month post-injury). Retrospective recall of past/pre-injury PCS was compared with that of healthy individuals over similar time spans to understand whether expectations for negative change after mTBI produce an exaggerated bias in underestimating past problems over and above normal forgetting and the arguably adaptive tendency to recall more positive – and fewer negative – details from the past.

Literature Review

Recovery Versus Persistence of Post-Concussion Symptoms after mTBI

Mild TBIs are common and they affect every-day functioning. The incidence rate estimates of mTBI range from 100 to 300 per 100 000 (Cassidy et al., 2004), with 242 per 100, 000 children presenting to hospitals in British Columbia with concussion in 2009-2010 (Injury Research BC, retrieved 2015). The true population-based rate is estimated to be about 600 per 100 000 because many of these injuries go unreported or unrecognized (Yeates, 2010; Cassidy et al., 2004; Elson & Ward, 1994). However, in the past decade, there has been increased attention to milder traumatic brain injuries, likely related to the focus on sports-related concussion in the media (e.g., Gordon et al., 2006; Lincoln et al., 2011). In turn, there is greater recognition of the impairment caused by increased behavioural, social, emotional, cognitive, physical, and sleep-related problems after concussion (Taylor et al., 2015; Taylor et al., 2010; Bigler, 2010). Impairments can be especially detrimental in children and adolescents because their recovery period is typically longer than in adults (McCrea, 2008). Although the majority recover within three months after mTBI (e.g., McCrea, 2008; Alves, 1992), in the life of a developing child, even three months of recovery can cause significant disruptions in home life, academics, sports/recreation activities, and social-emotional functioning (Mainwaring et al., 2004; Taylor et al., 2015). Furthermore, a minority of children and adults experience persistent cognitive and neuropsychiatric symptoms (e.g., anxiety, irritability, or mood problems), disordered sleep, chronic headaches, and/or neuropsychological deficits, including reduced speed of information processing and executive control, and difficulties with memory and attention (Gioia, Vaughan, & Sady, 2008). Therefore, it is imperative to identify the factors that increase or ameliorate the risk of protracted recovery.

Evaluation and management after mTBI conceptually occur in three phases: acute (first 3 days); post-acute (3 days to 3 months post-injury); and long-term (greater than 3 months post-injury) which describes those with persisting symptoms (Kirkwood et al., 2008). Physiological and biological factors contribute to the likelihood of persisting symptoms after mTBI. Pathophysiological changes after mTBI are associated with the severity of symptoms and deficits in the acute recovery period (i.e., one to three months

post-injury; Dikman et al., 1995). Symptoms are more likely to persist after a “complicated mild TBI,” which is marked by the presence of subtle structural brain abnormalities visible on neuroimaging (e.g., edema, hematoma, contusion, or reduced white matter integrity), possible neurochemical effects (Smits et al., 2011; Roberts, Manshad, Bushnell, & Hines, 1995; Yeates, 1999), and/or a skull fracture (Williams, Levin, & Eisenberg, 1990; Iverson & Lange, 2011). However, injury severity cannot fully account for differences in post-mTBI recovery patterns.

Most individuals appear to recover fully from single, uncomplicated concussions. Importantly, this does not necessarily mean that they no longer experience any symptoms because “post-concussion” symptoms are common in the healthy population (Gouvier et al., 1988; Iverson & Lange, 2003; Sawchyn et al., 2000) and in a variety of psychological and other clinical conditions. For example, PCS are common with depression, chronic pain (Iverson, 2005, 2006), post-traumatic sequelae (Foa et al., 1997), chronic headache (Gunstad & Suhr, 2004), chronic fatigue syndrome (Wearden & Appleby, 1996); Graves’ disease (Stern et al., 1996); gastrointestinal disorders (Hochstrasser & Angst, 1996); functional somatic disorders, whiplash (Stalnacke, 2009), and the common cold. However, individuals may be classified as fully recovered from mTBI when their current symptoms are judged to be no more severe, prevalent, or impairing than they were before the injury (i.e., returned to baseline). Conversely, when individuals judge any current symptoms to be elevated compared to pre-injury symptom severity, they may perceive themselves, or be classified by others, as not fully recovered from the brain injury. The apparent persistence of symptoms can cause distress and prompt seeking of further evaluation and treatment, sometimes leading to a diagnosis of Post-Concussion Syndrome or Disorder.

Most individuals do not receive a comprehensive, specialized assessment after concussion (Kirkwood et al., 2008). However, it is common practice to track the occurrence and resolution of post-concussion symptoms to determine when individuals’ symptoms have returned to “baseline” levels so that they can return to exercise, sports, and academic activities (e.g., guidelines adopted by The Canadian Paediatric Society, Purcell, 2014; Randolph, Millis, Barr, McCrea, Guskiewicz, Hammeke, & Kelly, 2009). More objective measures of post-concussion sequelae include tests of balance and

neuropsychological functions (e.g., Barr et al., 2001; Guskiewicz, 2003). However, self-report symptom checklists are commonly relied on because, at least in athletes, elevated scores on symptom checklists may persist for at least as long as impairments detected by more extensive tests (e.g., neuropsychological testing; Peterson et al., 2003).

Post-concussion symptom rating scales are designed to measure the severity of symptoms and to track recovery from concussion by comparing current symptoms to pre-concussion symptoms. Ideally, post-concussion symptom severity could be compared to baseline symptoms collected prior to the concussion, though pre-injury data are not always available. Therefore, proxy raters and concussed individuals are asked to estimate the degree to which current symptoms are elevated relative to pre-injury levels. Judgments of the extent to which current symptoms differ from pre-injury symptoms may be explicit or implicit. For example, raters may be asked to simply indicate whether a symptom is more of a problem currently than it was before the injury, as on the Rivermead Post-Concussion Symptoms Questionnaire (King, Crawford, Wenden, Moss, & Wade, 1995). More recently, some instruments measure pre-injury symptom estimates separately from ratings of current, post-injury symptoms (e.g., Post-Concussion Symptom Inventory; Gioia, Vaughan, & Sady, 2008; Sady, Vaughan, & Gioia, 2014; Yeates, 2009). This practice allows for the examination of social and cognitive factors that can influence recall of symptoms.

Indeed, psychological, social, motivational, and contextual factors likely influence the severity and maintenance of symptoms, particularly as the time from injury increases (Iverson & Lange, 2011; Lishman, 1986; Silverberg & Iverson, 2011; Hilsabeck, 1998). Therefore, the onset, trajectories, and interactions of physiological, psychological, and contextual factors in determining outcomes after mTBI are under heavy investigation (e.g., Yeates et al., 1999; Yeates et al., 2010; Taylor et al., 2010; Taylor et al., 2015). One area of focus is on how expectations and beliefs about mTBI influence recovery, including individuals' perceptions of how they have been changed by the mTBI (e.g., judging that they have more symptoms now than before the injury).

Social Psychological Factors Affecting Perceptions of Recovery After mTBI

Why examine the role of expectations and beliefs in post-mTBI recovery? Even those who have never experienced a brain injury expect negative outcomes after mTBI. Specifically, a large proportion of non-head injured adults believe an mTBI leads to physical symptoms (e.g., headaches, visual difficulties, sensitivity to light, dizziness), cognitive deficits (e.g., memory difficulties, concentration problems, confusion), fatigue, and emotional problems (e.g., irritability, anxiety, depression; Mittenberg, DiGuilio, Perrin, & Bass, 1992). Moreover, healthy individuals anticipate the frequency and severity of these symptoms as equivalent to, or higher than, what is reported by those who have actually had a head injury (Mittenberg et al., 1992; Ferguson et al., 1999; Gunstad & Suhr, 2001, 2002). Others have demonstrated that individuals also expect an increase in “post-concussion-like symptoms” after the onset of depression, post-traumatic stress disorder, and mTBIs related to motor vehicle accidents and sports (Gunstad & Suhr, 2001, 2002; Ferguson et al., 1999). Such findings demonstrate the non-specificity of post-concussion symptoms in that PCS are both experienced and expected after a number of negative events, not just after concussion. Nevertheless, the cluster of expected symptoms after concussion are thought to form the basis upon which psychological processes act to contribute to the persistence of post-concussion symptoms (Mittenberg et al., 1992; Gunstad & Suhr, 2001, 2002, 2004; Ferguson et al., 1999; Vanderploeg et al., 2012).

Why would negative expectations about the aftermath of an mTBI affect a person’s outcome after actually experiencing an mTBI? On the one hand, expectations and beliefs can increase individuals’ experience of symptoms and deficits currently, if only transiently. For instance, the “nocebo effect” describes when individuals experience aversive symptoms because they believe they are being exposed to a noxious stimulus even in the absence of one (Hahn, 1997). It is most often described in clinical trials of treatments as the counterpart to the placebo effect. However, media messages also influence expectations and can induce nocebo effects. In one experiment, over half of participants who viewed a news story about the negative effect of WiFi on health reported experiencing symptoms during a subsequent sham WiFi exposure compared to none of the group who watched a control film about data transmission security (Witthoft

& Rubin, 2013). These symptoms (i.e., tingling in the fingers, hands, feet, and head; pressure in the head; stomachaches, and trouble concentrating) were attributed to the sham WiFi signal. Two participants had to stop the sham exposure before their time was up because they found their symptoms so aversive. This effect seems particularly worrying given the recent media coverage linking concussions in professional athletes with dementia, depression, suicide, aggression, and “chronic traumatic encephalopathy” (Vanderploeg, Belanger, & Kaufman, 2014). Such messages are often well ahead of what is substantiated in the literature (e.g., Baron, Hein, Lehman, & Gersic, 2012).

Another social-psychological factor that can increase symptom complaints and impact cognitive test performance is “stereotype threat” or, in the case of mTBI, “diagnosis threat” (Gunstad & Suhr, 2002, p.450). Stereotype threat has been studied in a variety of groups (e.g., ethnicity, gender, socioeconomic, age, etc.). The stereotype threat effect occurs when individuals of a stigmatized group perform more poorly on tasks where the stereotype is relevant and salient (e.g., an older adult taking a memory test) compared to when it is not salient (e.g., Hess, Auman, Colcombe, & Rahhal, 2003; Aronson et al., 1999). When attention is called to a personal history of concussion and its potential detrimental impact on cognition, the resulting decreases in cognitive test performance and increased cognitive complaints is termed “diagnostic threat” (Gunstad & Suhr, 2004; Pavawalla et al., 2013; Oren & Fernandes, 2011). The mechanisms proposed to account for nocebo effects and stereotype threat effects vary depending on the population in which they are studied. However, a commonly proposed mechanism for impaired test performance is increased anxiety created by stereotype threat (e.g., Cadinu et al., 2003) and/or personal risk factors for experiencing nocebo effects (e.g., hypochondriasis, neuroticism; Witthoft & Rubin, 2013).

On the other hand, negative beliefs and expectations can produce, not an increase in symptoms today, but underestimations in the recall of symptoms from the past. The subsequent gap that this bias produces between current and past problems creates the appearance that one is different now than they were “before.” Constructive theories of memory offer explanations for how expectations can guide retrospective recall and judgments about the self across time. General principles of these theories and relevant

findings will be outlined below to provide context for the studies on biases affecting retrospective recall of PCS after injury, trauma, and normatively.

Constructive Memory, the Self, and Expectations for Change versus Consistency

When measuring change in people, we often study what happens after a big event. These are the earthquakes that come every couple of decades or the really big ones that happen once a century. They are the assaults, near-death experiences, windfalls, spiritual awakenings, and life-altering injuries and illnesses. It seems easiest to point to what has changed after these events; we can see where the land has shifted and which houses remain standing. However, for most people, much of life is composed of small quakes, imperceptible shifts, and regular tidal waves that, when added up, undeniably change the landscape. Whether people see changes or not may depend on whether they expect them. Even then, people are not always able to judge whether they have changed or not. In the absence of an expectation for change, the default seems to be to see stability in oneself, at least over the short term. It is why parents mark their children's heights against the wall, while rarely-seen grandparents quickly exclaim about how much their grandchildren have grown. The reasons why people do or do not see change in themselves are predicted by theories that emphasize the constructive nature of memory and its reciprocal relationship with the self.

The self is deeply and reciprocally connected with memory, particularly autobiographical memory (Conway & Pleydell-Pearce, 2000; Conway, 2005; Wilson & Ross, 2010). More than that, they construct and reconstruct each other (Woike et al., 1999; Woike, 2008, Conway, 2005). Broadly, autobiographical memory encompasses knowledge about oneself and “constitutes a major crossroads in human cognition where considerations relating to the self, emotion, goals, and personal meanings all intersect” (Conway & Rubin, 1993, p.103). Autobiographical memory includes episodic memory for the events of one's life (e.g., the day one's child was born) and for personal semantic information, or facts about the self (e.g., one's birthplace; Brewer, 1996; Conway & Pleydell-Pearce, 2000; Tulving, 1972, 1983). As part of semantic memory, recalling personal “facts” does not depend on retrieving particular experiences (Wheeler, Stuss, & Tulving, 1997). In contrast, retrieving personal episodic information requires recalling

and re-experiencing specific events, which involves the integration of many sources of information (e.g., sensory-perceptual, linguistic, emotional, narrative, etc.; Wheeler, Stuss, & Tulving, 1997, Wheeler, 2000; Rubin, 2006; Conway & Pleydell-Pearce, 2000). The qualitative experience that defines personal episodic remembering comes from the auto-noetic conscious; remembering one's past involves imagery, a sense of the self in the past, and mentally reliving the experience (Wheeler et al., 1997; Wheeler, 2000). However, despite the sometimes vivid quality of personal episodic memories, memory does not capture literal representations of reality. Instead, memories are open to distortions because they are constructed and reconstructed depending on one's current beliefs, feelings, and goals at the time of remembering.

Recent theoretical work incorporates social-cognitive theories of the self in order to acknowledge the social and cultural contexts in which the self and memories form and change. The conceptual self is a set of non-temporally specific abstracted knowledge structures that define the self, other people, and the world (Conway, Meares et al., 2004; Conway, 2005). These knowledge structures are independent of, yet connected with, autobiographical knowledge and episodic memory such that the underlying themes of these concepts are instantiated by specific instances. Examples of conceptual self-structures include personal scripts, possible selves, self-with-other-units, internal working models, relational schema, self-guides, attitudes, values, and beliefs (see Conway, 2005 for further details). As socially-constructed schemas and categories, these representations of the conceptual self are formed through the influences of socialization with family and peers, schooling, religion, and cultural constituents such as stories, myths, and media influences (Conway, 2005). This characterization of the conceptual self is relevant because these structures are thought to influence, and be a source of, the goals and beliefs that guide memory construction and reconstruction. It is plausible that commonly-held negative expectations for post-trauma and post-mTBI sequelae could influence conceptual self-structures after incurring an mTBI.

Memory reconstruction seems to preferentially support the goal of maintaining a stable sense of self (Ross, 1989; Greenwald, 1980; Conway, 2005). However, in constructing memory and the self, a balance must be struck between coherence and correspondence. Coherence is the adaptive drive to maintain a stable sense of self while

correspondence is the need to somewhat accurately represent reality (Conway, 2005; Conway & Pleydell-Pearce, 2000). However, these two goals are not always compatible as is the case when an individual's experiences are vastly incongruent with beliefs held about the self, others, and the world. When coherence clashes with correspondence, the discrepancy must be resolved. In a sense, either one's beliefs must change to accommodate a new reality, or one's reality must be reconstructed to keep one's beliefs. Failure to reconcile one's experiences with one's beliefs can result in psychopathology (e.g., trauma spectrum disorders, including Post-Traumatic Stress Disorder and adjustment disorders; Holland & Kensinger, 2010; Conway, 2005; Conway & Pleydell-Pearce, 2000). Organic brain damage can also reveal the importance of maintaining a coherent sense of self while still holding beliefs that align with reality (see Conway, 2005). Less dramatic changes in autobiographical memory and self-identity are apparent in even subtle changes in beliefs. In such cases, memory retrieval may be biased in order to minimize the differences between the past and present self or may exaggerate the differences between how one was versus how one is now. That is, memory retrieval and reconstruction can be influenced to conform to expectations of consistency or change (improvement or decrement) in oneself.

Constructive models of memory posit that current expectations about change versus consistency guide judgments and recall of facets from the personal past (e.g., Conway & Ross, 1984; Wilson & Ross, 2003; Conway & Pleydell-Pearce, 2000; Conway, 2005; Ross, 1989). Since one's current view of oneself is available and salient, individuals tend to use relevant aspects of their current self as a benchmark against which to judge their past self. Whether or not the current self is viewed as a good representation of past standing on some feature depends on whether one holds expectations of consistency or of change in that feature (Ross & Conway, 1986; Ross, 1989; Wilson & Ross, 2003).

Congruent with the coherence principle, people tend to recall past attributes, attitudes, and behaviours as being consistent with how these attributes are currently. This implicit consistency theory can represent a bias in recall when individuals remember past features of themselves as being the same as they are now in the face of actual change. In contrast, when individuals expect that they have changed in some way (progress or

decline), recall of the past supports this expectation. Again, real change can have occurred, but to the extent that change is over- or under-estimated, a change expectancy produces a bias in guiding personal retrospective recall (Ross, 1989; Wilson & Ross, 2003; Walker, Skowronski, & Thompson, 2003). These biases are not always detrimental, and may in fact be part of healthy psychological functioning. For example, people commonly devalue or criticize their psychologically “distant” past selves as a way to enhance the current self and create the sense that they have improved over time (Wilson & Ross, 2003). Thus, even though there is a pull to view oneself as stable and consistent across time, there is also a normal tendency to see oneself as improving over time, at least in Western cultures.

Conway & Ross (1984) illustrated how a change expectancy can lead to biased recall. They asked students to rate their study skills before and after participating in an objectively ineffective study skills programme. When later asked to recall their pre-programme skill ratings, a wait-list control group showed no systematic bias in retrospective ratings of their skills. In contrast, students who participated in the course remembered their pre-programme ratings as being significantly worse than they had rated them at the time. By denigrating their pre-course skills, the participants could support their belief that the sham programme had improved their skills, even though it had not. Thereby, perceptions of their current skills were aligned with expectations about the positive value of the programme.

Distorted recollections of the past can have a self-enhancing or even self-protective function, as when there are threats to self-regard. McFarland & Alvaro (2000) asked individuals to evaluate what they were like prior to a personally disturbing or traumatic event. Some made these evaluations after being reminded of the traumatic episode while others were not reminded. Those who were reminded made more critical evaluations of their pre-trauma selves compared to those who had not been reminded. Furthermore, the more severe or disturbing the experience had been, the more individuals denigrated their past self. Interestingly, devaluing who they had been before the trauma made positive personal growth after the trauma appear larger, potentially lessening the trauma’s negative psychological impact.

Given that they are so commonplace, such memory distortions may be largely innocuous and even beneficial (Schacter, 2012). However, in some instances, misremembering one's past compared to the present can lead to less benign or even harmful consequences. For example, women who hold more negative expectations about menstruation retrospectively recall having experienced more menstrual symptoms of irritability, depression, pain, and distress than they had actually reported during menses (McFarland, Ross, & DeCourville, 1989). This pattern of recall bias serves to reinforce negative beliefs about menstruation, thereby perpetuating this cycle. Related to findings from the stereotype threat literature, older individuals retrospectively appraise their past (younger selves) memory function as being better than younger adults report currently, in agreement with common expectations of age-related memory declines (McFarland, Ross, & Giltrow, 1992).

People may also expect that they have changed for the worse after experiencing some negative events. Distress about the event and its meaning can lead to more aversive experiences, including increased symptoms, which are "aversively perceived internal states" (Gijbbers van Wijk & Kolk, 1997, p. 235) not necessarily implying underlying psychological or physical pathology. Individuals may perceive themselves as worse off through retrospectively underestimating the degree to which they experienced problems before the event. This can occur even in the absence of objectively elevated symptoms compared to before the event. If one's present state is used as an anchor against which to judge the past, then the past must be judged as better (i.e., fewer past symptoms). Individuals' perception of their present functioning is coloured by the expectation that they have changed for the worse after the negative event. This "good old days" bias is found after many negative events, including mTBI (Gunstad & Suhr, 2001, 2002, 2004; Hilsabeck, 1998; Ferguson et al., 1999; Iverson, Lange, & Rose, 2010; Brooks et al., 2014; Davis, 2002). Expectations for increased symptoms after mTBI can also lead to misattribution of common symptoms to the head injury, a phenomenon called "expectation as etiology" (Mittenberg et al., 1992). For example, an individual might attribute forgetting their keys to the head injury rather than to normal forgetfulness that was probably common before their injury as well (Gunstad & Suhr, 2001). Both

expectation as etiology and the good old days' bias can lead to discrepancies when recalling current symptoms relative to pre-injury symptoms, as outlined below.

Expectations of Change after mTBI: Expectation as Etiology

In a seminal paper, Mittenberg et al. (1992) postulated that misattribution of benign emotional, physical, and cognitive symptoms to one's head injury can lead to increased perceptions of PCS relative to pre-injury symptoms. They hypothesized that this "expectation as etiology" effect could occur because expectations for experiencing more symptoms after concussion would lead to a cycle of distress, arousal, selective attention to symptoms, misattribution of symptoms to the concussion, and subsequent reinforcement of the same negative expectations. To test this, Mittenberg et al. (1992) asked a group of adults with a remote history of mTBI (average of 1.7 years post-injury) to estimate on a symptom checklist "how [they] used to be" (before the head injury) and how they are now ("after the accident"). A healthy control group of adults were asked to indicate the symptoms they would expect after incurring a "mild" traumatic brain injury in a car accident 6 months ago, as described in a vignette. Although the vignette labeled the brain injury as "mild," the accident involved hitting one's head on the windshield, waking up in hospital, and spending "a week or two" recovering in hospital. Such a scenario may not represent the majority of incidents leading to mTBI. However, there was a high degree of overlap between symptoms actually reported by the mTBI group and those expected by the control group after such an accident. This may reflect the fact that the head-injured group were all seeking treatment for head injury complaints through neuropsychology and neurology outpatient clinics. The head injuries were probably at the more severe end of the mild continuum because most injuries were incurred through motor vehicle accidents and the average duration of loss of consciousness after injury was 23 minutes. Litigation status of the head injury group was unknown, but being in litigation is associated with more current symptoms, with a strong to very strong effect size (Lange, Iverson, & Rose, 2010).

In addition, the authors (Mittenberg et al., 1992) used the current ratings of symptoms in a healthy control group as a proxy base rate of PCS. The logic was that pre-injury severity of PCS in head injured groups should be equivalent to current PCS

severity in healthy controls. Patients reported significantly fewer premorbid symptoms overall compared to current PCS in normal controls. A significantly smaller percentage of the head injury group endorsed having experienced 21 out of 30 symptoms before their injury compared to the “base rates” (i.e., percentage of uninjured controls who endorsed having the symptoms currently). In effect, individuals overestimated the degree of change in symptoms from pre- to post-injury. Of course, this assumes that uninjured individuals would not also underestimate the degree to which they experienced these symptoms 1.7 years ago since their current symptoms – not their retrospective ratings of past symptoms – were used as a base rate against which to gauge the retrospective recall accuracy of the mTBI group. This assumption may not be warranted. Furthermore, in light of more recent work on diagnosis threat producing increased cognitive complaints and performance deficits after mTBI (e.g., Oren & Fernandes, 2011), it is also worth noting that 20 of the 30 checklist items were overtly related to memory. Furthermore, the instruction to rate “how you used to be” compared to how they are “after the accident” is similar to manipulations used to induce stereotype and diagnostic threat effects (e.g., Gunstad & Suhr, 2002). Regardless, the authors (Mittenberg et al., 1992) concluded that head-injured individuals retrospectively underestimate pre-injury PCS severity because they reattribute benign emotional and physiological symptoms to their injury due to negative beliefs about head injury.

Pessimistic Expectations, Misattribution, Distress, and Persisting Post-mTBI Symptoms.

Subsequent studies have found that more pessimistic expectations and beliefs about the consequences of mTBI are associated with longer recovery and greater functional impact of the injury in adults (e.g., Whittaker, Kemp, & House, 2007), more negative affect, anxiety, and stronger identification with the injury (Snell, Siegert, Hay-Smith, & Surgenor, 2011; Snell, Hay-Smith, Surgenor, & Siegert, 2013). In addition, distress and negative affectivity are associated with higher levels of PCS in mTBI and in non-head injured individuals (Snell et al., 2011). These factors may contribute to increased attention to symptoms, concern about their significance, and greater misattribution of symptoms to concussion. However, the degree to which people actually misattribute symptoms to the concussion is unclear because this is difficult to measure directly. For

example, Belanger et al. (2013) found that the strongest predictor of increased PCS in veterans after mTBI was the extent to which PCS were attributed to the concussion. However, attribution was measured by asking individuals to indicate (yes/no) if they attributed each symptom to the concussion. The likely dependence of the measurement of the predictor and outcome ($r = 0.92$) precludes strong conclusions about the relationship between attribution and PCS with this method. Regardless of whether misattribution can be directly measured or not, “expectation as etiology” seems most relevant when current symptoms are elevated *and* pre-injury PCS are markedly underestimated; such a pattern might suggest a “shifting” of pre-injury PCS to post-injury status in one’s judgment.

Increased distress and selective attention to symptoms may be a stronger etiological factor in the acute post-injury period, though they could contribute to maintenance of an identity linked with the injury in the chronic post-injury period (e.g., Snell et al., 2013; Kay et al., 1992). Distress, negative affectivity, and selective attention to symptoms also seem more relevant in treatment-seeking individuals (Gunstad & Suhr, 2004; Mittenberg et al., 1992; Lange, Iverson, & Rose 2010), for those in litigation (Lange, Iverson, & Rose, 2010; Vanderploeg et al., 2012), and in those with more severe injuries (i.e., PCS tends to be more severe and longer-lasting which could contribute to the cycle of distress and maintenance of symptoms). Indeed, more post-injury PCS are reported in each of these groups compared to healthy control groups (Gunstad & Suhr, 2004; Mittenberg et al., 1992; Hilsabeck et al., 1998; Lange, Iverson, & Rose, 2010; Lange, Iverson, Rose, & Alderson, 2010). In contrast, non-treatment-seeking athletes with a remote history of concussion do not always report increased post-concussion symptoms relative to controls but they do underreport pre-injury PCS (e.g., Gunstad & Suhr, 2004; Ferguson, Mittenberg, Barone, & Schneider, 1999). This finding has been pointed to as evidence for expectation-guided recall of past symptoms.

Expectations of Change: The Good Old Days’ Bias

Ferguson, Mittenberg, Barone, & Schneider (1999) investigated the role of expectations about sports-related head injuries on PCS ratings in male amateur athletes (high school and young adults). Non-head injured male athletes were asked which symptoms they would expect to experience 6 months after a sports-related mild brain

injury. Confirming that negative expectations are held about sports-related mTBIs, a 102% increase in symptoms was expected by this uninjured group. However, these expected symptoms overestimated the actual symptoms reported by male athletes who had incurred a sports-related concussion in the past year (average of 6 months post-injury). In fact, with the exception of increased headaches, the latter group had no more current symptoms than the non-head injured athletes.

However, if athletes expect an increase in PCS after concussion but do not actually experience this increase, they might underestimate the incidence of premorbid symptoms in order to reconcile their expectation that current symptoms represent an increase from pre-injury levels. Indeed, the head-injured athletes significantly underestimated the incidence of pre-injury PCS by 97% compared to the base rate of PCS incidence in uninjured athletes. Specifically, 13 out of 30 symptoms were endorsed as occurring less before the injury by head-injured athletes compared to the percentage of non-injured athletes who experienced these symptoms currently. These differing symptoms all related to memory (10/30), anxiety, concentration difficulties, and blurred or double vision. In addition, head-injured athletes' current PCS ratings were significantly higher than their own retrospective pre-injury ratings; they perceived significant increases in 16 out of 30 symptoms after concussion. These findings were taken as evidence that athletes subjectively overestimate the change in symptoms after concussion in the absence of objective change. However, since the control group's current symptoms were used as the basis against which to judge the head-injured group's retrospective pre-injury symptom ratings, the study did not adequately control for normative biases that might affect retrospective judgment of past PCS. On the other hand, the significant difference between the seemingly-recovered athletes' current and pre-injury estimates indicates a good old days' bias, a phrase coined by Gunstad & Suhr (2001).

Gunstad & Suhr (2001) explored whether there would be a general retrospective recall bias to see oneself as healthier in the past. They compared a group of athletes who had incurred a head injury (average of 2.1 years prior) to undergraduates with chronic tension headaches and healthy controls. These groups indicated their current symptoms and estimated their symptoms prior to the head-injury, prior to the onset of their

headaches, or “2-3 years ago” (healthy control group), respectively. The instructions given to the concussion and chronic headaches groups involved asking how their concussion [headaches] has or has not affected their ability to do everyday things and to answer the questions as they would have before the accident or onset of chronic headaches (“how you used to be”; Gunstad & Suhr, 2001, p.326). The study used a 97-item questionnaire composed of neuropsychological symptoms and distractor items. Ratings were made on a 5-point Likert scale but scale anchors were not reported. Results were reported for present/absent scoring where “present” meant 3-5 and “absent” meant a score of 1-2 on an item. Significantly fewer past symptoms compared to current symptoms were reported in the headache and head injury groups, but in the control group, only fewer somatic symptoms were reported in the past. The groups reported experiencing equivalent current symptoms and their retrospective symptom ratings did not differ among the three groups but effect sizes were not reported. The pre-injury/pre-headache ratings were not lower than the control groups’ current symptom ratings, so the authors concluded that the expectation as etiology hypothesis is too specific (i.e., head-injured individuals will not rate their past selves as being “supranormal”). Neither was there evidence for a general retrospective response bias to see oneself as healthier in the past. Instead, they postulated that individuals will rate themselves as having better functioning prior to any negative event compared to the present state because of a general expectation of negative outcomes after a negative event (i.e., a good old days’ bias is produced because of a general expectation that “things were better before”; Gunstad & Suhr, 2002, p. 39). They likened this to the retrospective counterpart of the nocebo effect (Hahn, 1997) whereby individuals expect nonspecific, negative consequences following an event.

In a follow-up study, Gunstad & Suhr (2004) used the same method (Gunstad & Suhr, 2001) to compare current PCS ratings with retrospective premorbid ratings across eight groups of adults: healthy controls, healthy athlete controls, head-injured, head-injured athletes, depressed, headache sufferers, and treatment-seeking depressed or headache sufferers. Head injuries in both groups had occurred more than 2 years prior, on average. Five of the eight groups reported more current than past symptoms (head-injured, depressed, treatment-seeking depressed, headache, and treatment-seeking

headache). Healthy controls, athlete controls, and head-injured athletes did not underestimate past symptoms relative to their current symptoms. The authors expanded their idea of a good old days' bias contending that it could lead to lower pre-morbid symptom estimates in clinical groups relative to normal control groups' current symptoms (Gunstad & Suhr, 2004). To test for a "good old days" bias (i.e., underestimation of premorbid symptoms), current PCS symptoms of the control group were used as a baseline against which to compare premorbid estimates of the clinical groups. Head-injured and headache groups, but not head-injured athletes, reported fewer premorbid symptoms than the control group's current symptoms. The authors once again concluded that a general good old days' bias characterizes the tendency to see oneself as having been better off before any negative event. The fact that the head-injured group reported fewer premorbid symptoms relative to control groups' current symptoms was taken as evidence of an expectation as etiology effect whereby individuals reattribute common aches and pains to the concussion. However, this latter conclusion seems somewhat non-parsimonious since no explanation about misattribution or otherwise was offered for the equivalent finding in individuals with chronic headaches.

In a study that incorporated some control of normative retrospective memory processes, Lange, Iverson & Rose (2010) investigated the influence of the good old days' bias on symptom reporting after mTBI in adults presenting for assessment an average of 1.8 months post-injury. They compared retrospective pre-injury ratings (one month before injury) and current ratings of an mTBI group with current ratings of a control group (past 2 weeks) on the British Columbia Post-Concussion Symptom Inventory, thereby accounting for some retrospective recall bias in the control group. A good old days' bias was suggested by significantly lower pre-injury symptom ratings of the mTBI group than the control group's total symptoms and 6 of the 13 individual symptoms. Individuals currently in litigation reported more post-injury symptoms than non-litigating individuals.

However, litigation status was not associated with self-reported pre-injury retrospective symptom ratings, suggesting that the good old days' bias is a general bias after mTBI. Perhaps because most were still in the recovery phase, post-injury symptom ratings in the mTBI group were significantly greater than both their own retrospective

ratings (large to very large effect sizes) and the control group's current ratings (medium to very large effect sizes). Cumulative percentages of each group that endorsed each symptom currently (control group and mTBI group) and before the injury (mTBI group) were also compared. The mTBI group endorsed a smaller percentage of pre-injury symptoms than the control group for the majority of symptoms. Patients with mTBI appear to misperceive their pre-injury functioning as better than the average person, which is consistent with a good old days' bias. This conclusion illustrates the moving concept of the "good old days'" bias. Rather than just referring to a significant difference between one's own perceived past symptoms compared to current symptoms, it can also encompass perceiving "supranormal" past functioning. Thus, misattribution of symptoms to concussion is not assumed to be necessary to produce exaggerated underestimates of past PCS compared to healthy individuals' current symptoms.

Overall, these studies led to the same general conclusion that adults retrospectively underestimate pre-mTBI symptoms relative to their current symptoms, whether or not their current symptoms are elevated (i.e., compared to uninjured control groups). Some found that the degree to which pre-injury symptoms are underestimated is large enough that it is significantly less than control groups' current symptoms. This was more commonly found in those with non-sports-related mTBI, in those with more severe injuries, those who presented for treatment or assessment, and those in litigation related to their injury. However, except for Lange, Iverson, & Rose (2010), these studies precluded examination of normal memory biases in the recall of PCS, which could artificially exaggerate the effect of the good old days' bias in mTBI groups. Furthermore, the inference that "supranormal" pre-injury ratings in mTBI groups are indicative of misattribution of symptoms to the concussion (i.e., expectation as etiology) seems problematic using these designs. This is because the current ratings of healthy individuals do not capture any of the variance associated with normative retrospective biases. The argument that individuals misattribute symptoms to concussion would be stronger if head-injured groups' retrospective pre-injury PCS ratings were compared to controls groups' ratings of symptoms retrospectively recalled from an equivalent time in the past.

Before outlining how these issues can be addressed, relevant theory about constructive memory and normative retrospective recall biases in uninjured individuals will be outlined. Following this, the importance of controlling for normative memory biases and processes will be outlined through an examination of other studies of retrospective recall of PCS.

Normative Retrospective Recall Biases Leading to a Positive View of the Past

To review, in the absence of an intervening event (e.g., concussion), constructive theories of memory assume that recall of the past will be influenced by expectations of stability in order to maintain a sense of a coherent self (e.g., Conway & Pleydell-Pearce, 2000; Conway & Ross, 1989). Following this logic, individuals who have not incurred a concussion would be expected to recall past symptoms as being consistent with current PCS levels at the time of retrieval, regardless of actual change or stability.

Evidence that healthy individuals expect consistency in PCS across time comes from studies that have found no difference between current PCS severity ratings and estimates of PCS severity from 6 months ago to 2-3 years ago, when ratings were made *concurrently* (Ferguson et al., 1999; Gunstad & Suhr, 2001, 2002, 2004). These findings do not indicate whether this normative expectation for consistency represents a *bias* in recall. It would be a bias if one rated current PCS as being the same as past PCS when there was actual change in PCS. Nor do these findings rule out the possibility that there is a normative tendency to retrospectively recall fewer past PCS. The determination of whether or not there is a general good old days' bias in the retrospective PCS ratings of uninjured individuals can only be made by using a longitudinal design. To date, this design has not been used. Therefore, any conclusions about whether or not a general good old days' bias is unique to retrospective ratings made after a negative event (i.e., concussion) should be tempered until the phenomenon has been examined with a number of normative memory and judgment factors controlled for.

In order to examine whether there is a general good old days' bias in healthy individuals, several variables must be disentangled. Firstly, do healthy individuals actually expect that the degree to which they experience PCS will remain consistent across time? As described above, concurrently-measured ratings of current and

retrospective PCS do not differ markedly in healthy individuals, suggesting that an expectation for consistency generally exists at the time of recall. This makes sense (and is consistent with theories of memory) since it would be surprising for healthy individuals to be able to recollect specific instances in which they experienced particular symptoms (e.g., headaches, fatigue, irritability, mental fogginess, difficulty remembering) to a level of specificity that would elevate their judgments of these symptoms in the non-immediate past relative to the present or, indeed, relative to actual PCS ratings collected in the past.

Furthermore, many theories examining emotion as it relates to memory, biases, and judgment converge on the general expectation that the past will be remembered and evaluated as better or more pleasant than the present (Wilson & Ross, 2003). Several related biases describe this tendency, including the positivity bias, the fading affect bias, and the “rosy retrospection” bias (Mitchell, et al., 1996). The positivity bias is the tendency to recall positive events more readily than negative events or neutral events (Walker, Vogl, & Thompson, 1997). In addition, the intensity of negative emotions fades more quickly than the intensity of positive emotions over time. This fading affect bias is found even when pleasant events are recalled as accurately as negative events (e.g., Cason, 1932; Matlin & Stang, 1978; Thompson et al., 1996). It has been argued that the fading affect bias is an adaptive coping mechanism operating in memory rather than simply a retrospective error in memory. This is because even when the intensities of positive or negative emotions are equivalent at the time of an event, negative affect still fades (becomes less intense) more than positive affect, representing genuine emotional fading (Walker, Vogl, & Thompson, 1997; Walker, Skowronski, & Thompson, 2003). Finally, positive aspects of events are remembered more than the negative aspects, termed the rosy retrospection bias. The net effect is that life’s events are remembered more positively in retrospect compared to the evaluations made while actually living the experience (Mitchell, Thompson, Peterson, & Cronk, 1997). For example, people may look forward to a trip to Disneyland, only to experience much less enjoyment during the trip itself because of screaming children and long wait times for rides. However, recollections of the trip tend to leave out the details of minor inconveniences, leaving feelings of fondness well above what would have been predicted based on what people felt and thought during the actual trip to see Mickey and the gang (Sutton, 1992).

Normative Memory Processes Could Affect Recall of PCS after mTBI and Normatively

The depiction of the good old days' bias as the "retrospective counterpart to the nocebo effect" (Gunstad & Suhr, 2002, p. 39) suggests that it does not apply to healthy individuals. It is surprising that there has been an assumption in the concussion literature that uninjured, healthy individuals would not exhibit any degree of idealization of their past well-being. However, as noted above, this conclusion has been based mainly on study designs that do not control for normative retrospective recall biases and normative forgetting. After all, post-concussion symptoms are all arguably aversive experiences. Do healthy individuals continue to recall with fidelity all of the aches, pains, ups, and downs that those who have incurred a trauma or mTBI forget? On the contrary, an adaptive feature of human memory is the preferential forgetting of negative aspects and events in favour of positive events and affect. Therefore, preferential forgetting of PCS is likely, even if other details of the events during which they were experienced are remembered.

In a well-controlled cross-sectional study, Hilsabeck et al. (1998) compared the current and retrospective pre-injury or pre-trauma PCS ratings of four groups of non-litigating, treatment-seeking adults who had incurred either an injury (moderate to severe closed head injury or back injury) or trauma (low stress change or high stress, sudden change such as the death of a spouse) in the past five years. In agreement with the above studies, they found a greater mean difference between pre- and post-injury PCS ratings in the closed head injury (CHI) group than in the other groups. This good old days' bias was also apparent in the difference between pre-injury and current ratings in the back-injury group but not in the trauma groups. In addition, the pre-injury ratings of the CHI and back-injury groups were lower than the pre-trauma ratings of the low-stress trauma group. This adds strength to the argument that negative expectations about mTBI and physical injuries can lead to a greater good old days' bias.

This argument was further strengthened by comparing the retrospective ratings of the injury groups to the retrospective (not current) ratings of the trauma groups made with respect to a particular (and stressful) event. The use of such an anchor increases the chances that judgments about past functioning are influenced by normal memory

distortions, thus accounting for some of these in comparing the trauma groups' retrospective ratings with those of the CHI and back injury groups. In contrast, previous studies did not prompt control groups to judge their past PCS in reference to specific anchors and, in fact, the use of vague and temporally distant (e.g., 2-3 years ago; Gunstad & Suhr, 2001, 2004) seems to be a manipulation that would encourage control groups to base their estimates of past symptoms on their current symptoms as these would be the most salient anchor. While this is likely the point for the purposes of highlighting the retrospective nocebo effect in the mTBI group, it precludes examination of which cues healthy individuals (or indeed, individuals after mTBI in the absence of a cue to their head injury) might use to guide their recall of PCS from the distant past.

Such an anchoring effect is made more likely because these previous studies asked individuals to rate their current symptoms before rating their past symptoms (e.g., Gunstad & Suhr, 2001, 2004; Ferguson et al., 1999; Mittenberg et al. 1992; Lange et al., 2010). This latter methodological feature is likely not benign. For example, healthy adults retrospectively recall significantly fewer PCS (headaches, increased sensitivity to noise, poor concentration, and poor sleep) from 6 months ago compared to current PCS when these ratings are made in separate sessions, one week apart (Sullivan & Edmed, 2012). The implications of this finding for consistency versus change biases would be clearer if retrospective ratings had been compared to those collected concurrently. At a minimum, this finding suggests the need to ask for retrospective ratings before current ratings for research and practical uses (e.g., clinical, legal). If anything, the argument for the good old days' bias would be strengthened if it is present regardless of the order in which one rates pre-injury and current symptoms.

Hilsabeck et al. (1998) also expected that the difference between pre- and post-injury/trauma ratings would decrease as the time since injury increases because of recovery, decreased distress, and lower expectations of change after the injury/trauma. They examined the mean differences between pre- and post-injury/traumas collapsing across all four groups in three time periods post-injury: 0-12 months, 13-36 months, and 37-60 months. Contrary to their expectations, the mean difference in pre- to post-injury ratings actually increased over these time periods. This suggests the need to study the evolution of retrospective biases over time. Since the increased pre- and post-

injury/trauma ratings were collapsed across trauma type and severity, this finding hints at the action of normative (or at least non-head injury-related) memory processes affecting retrospective recall of PCS over time. Furthermore, it indicates that studies examining retrospective recall biases may not be generalizable to every period after injury (e.g., acute, post-acute, very chronic, etc.).

Examination of normative memory processes may be particularly salient in the acute period after injury/trauma when there is a higher likelihood of recalling specific occurrences of pre-injury symptoms based on episodic memory. Recall over longer periods tends to be based more on inferences about usual behaviour rather than recall of particular episodes of behaviour (e.g., Croyle & Loftus, 1993; Downey, Ryan, Roffman, & Kulich, 1995). In contrast, specific details linked to particular episodes (e.g., moments in a certain day) are highly available for the previous week (Burt, Kemp, Grady, & Conway, 2000; Burt, Watt, Mitchell, & Conway, 1998). These details are rapidly lost unless they are rehearsed. Therefore, in the first week after a mild head injury, details from at least some portion of “pre-injury” life should be available for literal retrospective recall (assuming that retrograde amnesia, if present, was not significant). This raises the question: if one can recall experiencing symptoms before an injury, does this lessen the effect of negative expectations on perceived changes in oneself after injury?

Given their pervasiveness in even healthy individuals, negative expectations for increased symptoms are presumably present immediately after injury. Further, this expectation would be confirmed with the experience of increased symptoms. However, it is unknown when the good old days’ bias or other retrospective recall biases begin to affect recall of pre-injury PCS after injury. Might these biases be present acutely after injury? Davis (2002) compared the pre-injury/pre-trauma PCS estimates and 1-week post-mTBI/non-head-trauma ratings of adults recruited from a medical center to the current PCS ratings of a healthy control group. The mTBI and trauma groups had likely incurred very mild injuries because they did not report more PCS than normal controls, even at 1-week post-injury. While the “other trauma” group reported having significantly fewer PCS before their trauma relative to the control group’s current PCS, there was no significant discrepancy between their own post-trauma and pre-trauma ratings. At one-week post-injury, only the mTBI group recalled experiencing

significantly fewer PCS prior to the injury, a difference that increased even more at 3 months post-injury. Interestingly, the retrospective pre-injury PCS estimates made at 3-months post-mTBI did not further decrease compared to the retrospective pre-injury estimates provided at 1-week. Instead, post-injury symptoms increased from 1-week to 3-months post-injury, which drove the increased difference between pre- and post-injury ratings at the latter time point. This suggests that misattribution of benign symptoms to the concussion may increase post-injury PCS ratings. It may also indicate that a substantial retrospective recall bias is present soon after injury, leading to a precipitous decline in memory for pre-injury problems. While expectancy effects may cause large underestimations of pre-injury symptoms initially, there may not be such appreciable declines in these estimates over time. That is, the “damage” of negative expectations on one’s memory for the past may be done right after injury, but then stabilize.

This is an intriguing and, as yet, unexamined possibility with important implications. For example, brief cognitive-behavioural interventions reduce the likelihood of developing persisting post-concussion symptoms. These interventions provide reassurance about normal symptoms after concussion and teach coping and cognitive restructuring techniques to reduce anxiety, selective attention, and misattribution of benign symptoms to the head injury (e.g., Mittenberg, Tremont, Zielinski, Fichera, & Rayls, 1996; Mittenberg, Zielinski, & Fichera, 1993). Lower rates of post-concussion symptoms have been reported at 6-months post-injury by those who receive this intervention, indicating that the detrimental effects of negative expectations on symptom experience after concussion can be mitigated. However, it is unknown whether attempting to change one’s expectations of concussion would also reduce the good old days’ bias (i.e., retrospective recall biases) because intervention studies have not reported separate pre-injury PCS estimates. Again, this points to the need for longitudinal designs that repeatedly measure both current PCS and retrospective pre-injury PCS estimates in mTBI and control groups. Understanding the onset and evolution of expectancy-related effects requires studying retrospective recall biases from as close in time to the injury or negative event as possible.

The findings from Davis (2002) also point to the importance of accounting for normal retrospective memory processes. Specifically, because the trauma and head injury

groups did not report more PCS than the control group at 1-week post-injury, the difference between their pre-injury PCS and the current ratings of the control group may actually have been due, at least in part, to (normal) reduced recall of symptoms from over a week prior. No such decrement or bias in recall was represented in the current symptom ratings of the control group and so normative memory processes were not controlled for.

The problematic use of a control group's current PCS ratings as a presumptive normative baseline is further demonstrated in a study in Taiwan of adults (Yang, Yuen, Huang, Hsiao, Tsai, & Lin, 2014). Using a longitudinal design, retrospective and current PCS ratings were collected at 1-month and 3-months post-injury in the mTBI group. A healthy control group's current PCS ratings were collected at baseline and two months later for comparison. Unfortunately, retrospective PCS ratings were not collected in the control group to examine the accuracy of retrospective ratings in healthy individuals. Congruent with other studies (and perhaps speaking to the expectations for negative outcomes of mTBI in Taiwan), there was a good old days' bias at one month post-mTBI such that pre-injury ratings were lower than the control group's current PCS ratings. However, this difference between groups disappeared at 3-months post-injury, likely due to the significant increase in PCS reported by the control group at the second time point. Although high rates of attrition in both groups (i.e., over 50%) preclude conclusions about the normative variability in PCS, this study points to the perils of presuming control groups' current symptoms are a proxy for the norm.

Longitudinal mixed designs would help to address some of these issues. Such designs would help to measure the degree of normal variability in symptoms and recall bias across time in both controls and groups of interest. The longer the period over which individuals are asked to recall their past PCS, the more vital it is to use longitudinal designs. It does not seem fair to require individuals with mTBI or trauma to accurately recall pre-injury PCS with fidelity when the test-retest reliability of PCS measures is only $r = 0.24$ across one year in healthy individuals (Iverson & Goetz, 2004). On the other hand, ratings are much more consistent across shorter periods of time. For example, across 45 days, intra-class correlations of 0.88 - 0.93 have been reported in adults (Mailer, Valovich-McLeod, & Bay, 2008). In children, the two-week test-retest

reliability has ranged from $r = 0.66$ (adolescents ages 13 – 18 years) to $r = 0.81$ (children ages 8 -12 years) for total symptom severity (Sady, Vaughan, & Gioia, 2014).

Furthermore, repeated-measures designs allow for dynamic examinations of the evolution of retrospective recall biases specific to mTBI as well as determination of the extent to which these biases affect recall of PCS over and above normal forgetting and other reconstructive memory biases. Unfortunately, this design is highly uncommon in this area.

However, a prospective, 1-year longitudinal study comparing children and adolescents who sustained an mTBI or an orthopedic injury (OI) suggests that understanding the trajectory of factors affecting symptom reports over time is important (Yeates et al., 2009). In this study, parents reported post-concussion symptoms within 3 weeks of their child's injury and at 1-, 3-, and 12-months post-injury. In the first 3 weeks post-injury, 24% of the mTBI group reported 7 to 10 new symptoms (elevated above pre-injury levels) compared to 6% of OI controls. At one year post-injury, 9% of the mTBI group reported an average of four new post-injury PCS symptoms compared to 1% of the OI controls. Although findings were not based on child-reported symptoms, these parent ratings point to the need to further understand non-injury factors (including expectations about mTBI) that influence symptom reports and recovery trajectory (Yeates & Taylor, 2005).

Brooks, Kadoura, Turley, Crawford, Mikrogianakis, & Barlow (2014) used such a design to study retrospective biases affecting symptom ratings of adolescents and their parents. These authors prospectively examined adolescents' retrospective pre-injury PCS ratings at 1-month and 3-months post-injury using the Post-Concussion Symptom Inventory (PCSI; Glass, Natale, Janusz, Gioia, & Anderson, 2005). They also measured parent proxy retrospective pre-injury PCS ratings in the Emergency Department (ED; very acutely after mTBI), at 1-months, and at 3-months post-injury. In the ED, parent proxy ratings suggested a mean premorbid severity score of 7.1 ($SD = 10.1$) with only 34.5% of parents reporting zero premorbid symptoms. By 1-month post-injury, parents' premorbid PCS severity ratings had precipitously decreased ($M=1.4$, $SD = 4.1$), with a substantial proportion (75.6%) reporting zero premorbid PCS symptoms at 1 months. This assumed "good old days" bias remained stable at 3 months post-injury ($M = 0.8$, SD

= 2.5, 83% retrospectively report zero premorbid symptoms). Dramatically more adolescents were classified as experiencing persisting PCS at 1- and 3-months when using concurrent parent reports of premorbid and current PCS rather than using parent premorbid estimates from the ED as a baseline against which to compare current symptoms. That is, as soon as 1-month post-injury, the good old days' bias leads to the appearance of persisting PCS in children when using parent proxy symptom reports. However, it is unknown if this would still be true when using adolescent ratings of their own PCS symptoms.

Parents showed this good old days' bias at 1-month and 3-months post-injury regardless of whether they perceived their child to be "recovered" or "not fully recovered" at 1-month and 3-months post-injury. The determination of "fully recovered" or "not fully recovered" was based on a parent rating of whether or not their child was "different" or the same as before the injury. However, there was a mean difference in parent proxy premorbid estimates in the Emergency Department between groups who were "recovered" and those who were "not recovered." Unfortunately, this point was not further explored in the study.

Differences in initial premorbid ratings between recovered versus non-recovered groups are intriguing in light of the adolescents' own premorbid PCS severity estimates over time in this study. Even at 1-month post-injury, mean premorbid estimates of PCS severity for the entire adolescent group were greater than ratings by their parents at 1-month and, in fact, were equivalent to parent premorbid ratings in the ED ($M = 6.8$, $S.D. = 11.9$; 40.7% rated self as symptom-free before the injury). Again, as a group, there was a significant decline in premorbid symptom ratings from 1-month to 3-months, indicating that underestimation of pre-injury problems increases over time ($M = 5$, $S.D. = 14.6$; 54.8% rated self as being symptom-free before the injury). The pattern of results was similar when the group was split into those who rated themselves as the same versus not the same as before the injury. Specifically, adolescents who reported themselves to be "recovered" and "not recovered" at 1-months post-injury displayed the good old days' bias between 1- and 3-months post-injury, though the analyses in the latter group were likely underpowered. The "recovered" group appeared to have lower premorbid estimates at both time points (1-month: $M = 5.3$, $S.D. = 8.2$; 3-months: $M = 2.6$, $S.D. =$

6.7, Cohen's $d = 0.37$) than the "non-recovered" group (1 month: $M = 9.4$, $S.D. = 15.7$; 3-months: $M = 4.7$, $S.D. = 7.5$, Cohen's $d = 0.41$). These group differences were not examined further.

Also unknown is whether using adolescents' ratings instead of parent ratings would have decreased the percentage that were classified as having persisting post-concussion symptoms. Since adolescent self-ratings of PCS severity were not collected in the Emergency Department (or close to the time of injury), it is also not clear whether their 1-month premorbid estimates were actually an over- or under-estimate of premorbid symptoms. No prior studies have examined whether paediatric self-rated premorbid estimates of PCS are even higher in the ED (or similar to their parents' ratings at the same time). The authors suggested that the good old days' bias may have its most powerful effect on retrospective ratings across the first month post-injury when attention to the injury and its symptoms may be higher. While this study was valuable in showing that pre-injury PCS become progressively underestimated over time, it lacked control group comparisons. Therefore, it is unknown whether this decline represents the effect of a good old days' bias and/or misattribution effects specific to post-mTBI or if normal memory processes (e.g., forgetting, fading affect bias) would account for this progressive underestimation in past symptoms.

What is clear is that, at least in adolescents who perceive themselves to be non-recovered, parents may grossly underestimate pre-existing PCS beginning by at least 1-month post-injury. Parents of all adolescents may also underestimate premorbid PCS even when asked close in time to the injury, though this has not been examined directly to date. However, in a separate sample of uninjured children, a large proportion of parents (62%) reported that their adolescents experienced zero PCS compared to only about 20% of adolescents themselves (Sady, Vaughan, & Gioia, 2014). This suggests that parents are not as aware of symptoms in their child before an mTBI. Furthermore, parents may not be as aware of their children's symptoms after an mTBI, since parents may base judgments of their child's recovery on somatic symptoms (Sandel, Henry, French, & Lovell, 2014) or not recognize symptoms at all (Stevens, Penprase, Kepros, & Dunneback, 2010). Overly optimistic retrospective recall of premorbid functioning over time by parents clearly will affect whether their concussed children are viewed as

recovered or not. Particularly for children who were symptomatic before the injury, symptoms may now be attributed to the concussion by parents. Given that memory for one's own experiences is much better than for that of another's experiences (Symons & Johnson, 1997; Klein & Loftus, 1988), it is perhaps not surprising that adolescents do not show the same degree of pre-injury symptom underestimation as parents. Indeed, since adolescents continue to recall higher premorbid symptoms over time than their parents (especially for those who are not recovered), adolescent ratings may actually be more accurate in determining whether current symptoms represent a return to baseline. However, this question requires examining self-report pre-morbid estimates as close in time to the injury as possible. Furthermore, the factors affecting adolescents' recall and ratings of their symptoms before and after concussion have been largely understudied to date. The current study will address some of these gaps.

Summary and Rationale for the Current Study

There are two ways to think about the good old days' bias. One is as a retrospective nocebo effect affecting one's view of the past compared to the present when an expectation for negative change is cued (e.g., how were you before the injury?). This produces a snapshot of an expectation-guided view of one's past in a particular moment, without necessarily indicating a change in one's view of the past self at other times and in response to other questions. Memory truly is constructed. So, it is likely that people who say they had very few or no aversive symptoms before a head injury six months ago would be able to recall being fatigued, anxious, sad, or having difficulty concentrating when asked about how they felt attending a funeral eight months before.

At what point does the tendency to underestimate pre-injury symptoms begin in response to the question, "how were you before your injury?" If it begins immediately after injury, do underestimates of pre-injury PCS continue to decline until they reach a personal nadir? Or do pre-injury symptoms continue to fade from memory and report over time?

This is the other way to look at the good old days' bias. It involves looking at successive retrospective pre-injury ratings over time. Here, comparisons with controls do not just offer insight into the retrospective nocebo effect, but also into how much people

normally forget these common symptoms as time passes. Maybe underestimates of pre-injury problems are not all due to negative expectations about mTBI but are also due to normal forgetting of the aversive details of daily life. Perhaps healthy individuals do not continue to remember experiencing these symptoms to the degree that is suggested by studies on this topic to date.

To summarize, there is strong evidence that negative expectations for an increase in symptoms after mTBI are widely held. There is also some evidence for a retrospective nocebo effect (i.e., good old days' bias) in adults who are in the chronic stage after mTBI. Although their pre-injury PCS ratings are not always lower than control groups' current PCS ratings, a consistent finding is that of a significant difference between their own current and pre-injury PCS ratings in response to prompts that are similar to manipulations used in diagnostic threat and stereotype threat experiments. At least at the time of giving these ratings, such discrepancies create the appearance of change for the worse (i.e., more relative symptoms) in individuals after mTBI, consistent with expectations of change-guided recall. However, demonstrating this effect in response to a particular prompt several months or years after an mTBI does not indicate that all individuals after mTBI will think of themselves as "changed." The fact that the good old days' bias has been inconsistently demonstrated in individuals who overtly report being recovered supports this point. Nevertheless, the good old days' bias and other social psychological factors can have significant implications in treatment and forensic contexts (Vanderploeg et al., 2014; Iverson & Lange, 2010). In addition, for those who do perceive themselves as changed or "damaged" after a brain injury, it is clearly detrimental if recall biases further exaggerate apparent negative changes in one's post-injury self. Therefore, it is all the more important to understand how and when psychological processes act to construct the view of one's past self after mTBI and in its absence.

Arguably, most studies to date have not controlled for how normal memory processes, including biases, could contribute to underestimation of PCS before a trauma and in the past more generally. Furthermore, the conclusion that there is no general retrospective recall bias of PCS in the absence of a trauma is untested by the design of studies to date. This claim is also at odds with predictions and findings from the literature

on constructive theories of memory. Specifically, because a difference has not been found in concurrent symptom ratings of healthy control groups, some have concluded that the past is not idealized by those who have not experienced a negative event (e.g., Gunstad & Suhr, 2001, 2004; Vanderploeg et al., 2012; Davis, 2002). The lack of difference between current and past PCS ratings in control groups is congruent with consistency-guided recall because, in the absence of being provided with a specific anchor to guide their recall, these healthy individuals likely use their own present PCS severity to judge past PCS. As illustrated by Sullivan & Edmed (2012), this anchoring effect is likely exacerbated by the fact that current ratings have been measured before retrospective ratings in almost all studies to date (except Brooks et al., 2014). Furthermore, it is not a fair comparison to provide a specific cue to guide recall in the mTBI groups (“before your injury”) but to give only a vague and remote time frame to the control groups (e.g., 2-3 years ago; Gunstad & Suhr, 2001, 2004; 6 months ago, Lange, Rose, & Iverson, 2010; Sullivan & Edmed, 2012; Mittenberg et al., 1992; Ferguson et al., 1999).

Perhaps much of the underestimation of problems before an injury is due to reconciliation between perception of current PCS and expectations that these symptoms are worse (changed) than before the injury. However, does this mean that, in the absence of trauma, people normally remember all of the twinges, upsets, and lapses in thinking that run through their days? On the contrary, the broader memory and social psychology literatures suggest that these aversive feelings and events are preferentially forgotten while positive events are differentially recalled so much more than negative ones that the pattern actually constitutes a positivity bias in normal human memory (Walker, Skowronski, & Thompson, 2003). So in cross-section, asking individuals to first provide retrospective PCS ratings before current ones could help to reduce the saliency of current ratings as an anchor for judging the past. In addition, providing a specific anchor to cue recall PCS (e.g., on the day you came to the lab) may further reduce the saliency of current PCS ratings. Both manipulations are expected to reduce the apparent effect of the expectation for consistency.

Additionally, most studies to date have used control groups’ current ratings of PCS instead of retrospective ratings as a normative baseline against which to compare

retrospective pre-injury ratings in trauma and mTBI groups. At the simplest level of interpretation, the difference in the control groups' current report of PCS and the retrospective judgments of those from before a trauma/injury could merely be due to forgetting. However, there is evidence from Hilsabeck et al. (1998)'s study that the underestimation of pre-injury PCS is greater than would be expected from normative memory distortions and fallibilities. Providing control groups with a particular anchor in memory to make retrospective PCS estimates and then using this estimate to compare pre-injury estimates in the mTBI group would address some of the limitations in previous studies. This may not reveal a retrospective recall bias in healthy individuals. However, it is a more stringent control condition to allow for comparisons between control and mTBI groups' retrospective recall to elucidate whether retrospective biases are particular to, or stronger, when made in relation to a trauma or injury.

Relatedly, recall and memory biases in the acute period after mTBI have been vastly understudied, particularly in children and adolescents. Furthermore, since most studies of these biases have been conducted in those who are many months to years post-injury, ratings of pre-injury PCS are very likely based on judgment and inference rather than actual recall of pre-injury functioning (Croyle & Loftus, 1993; Conway, 2005; Conway & Pleydell-Pearce, 2000; Downey, Ryan, Roffman, & Kulich, 1995). This seems like a vital point given that the proposed underlying mechanisms of the recall biases affecting PCS ratings are based on constructive theories of memory. It is important to understand whether negative expectations about mTBI (or any other event) affect retrospective recall immediately after the injury when there is a better chance of basing PCS ratings on actual episodic memories of the days preceding the injury. Different mechanisms may be at work shortly after the injury compared to the retrospective "recall" of PCS at two years versus two days post-injury. If expectations for negative post-mTBI sequelae are ubiquitous and powerful enough to affect the view of oneself 2 years after an mTBI, this raises the question: Does having a concussion today affect the way one remembers how one was yesterday?

Understanding when expectations begin to affect the recall of pre-injury functioning is interesting for several theoretical and practical reasons. Firstly, people are often assessed using PCS measures in the acute period after injury. Therefore, it is

important to examine whether subjective reports are biased even acutely after injury. Such a finding would mean that obtaining an accurate baseline after injury is not possible. Brooks et al. (2014), for example, suggested obtaining a baseline pre-injury estimate as close to the time of injury as possible to overcome biases. However, the validity of even these acute retrospective pre-injury estimates has not been assessed empirically, least of all in children's self-reports. Secondly, examining recall of pre-injury functioning in the acute period after injury increases the chances that actual episodic memories of pre-injury symptom experience will be accessible. For example, details linked to specific events and days are lost by about one week after experiencing them, unless they are rehearsed or are atypical (Burt, Kemp, Grady, & Conway, 2000; Burt, Watt, Mitchell, & Conway, 1998; Croyle & Loftus, 1993). In addition, in the very acute period after concussion, expectation-guided recall of pre-injury functioning may be different because the personal meaning of the concussion may be different while recovery is ongoing (Kay et al., 1992).

Conversely, the roots of negative expectancy effects may be present even in the acute period because holding early negative expectations about the outcome of mTBI predicts actual negative outcomes (e.g., Post-Concussion Syndrome; Whittaker, Kemp, & House, 2007). If individuals retrospectively underestimate their pre-injury PCS immediately after the mTBI or shortly thereafter, this would suggest that the expectation for a negative outcome after concussion is so powerful as to immediately produce the view that one has changed (i.e., pre-injury symptoms are attributed to concussion). This sets up an intriguing test of the power of expectations for negative change on retrospective recall. Are expectations for increased symptoms after concussion so powerful that pre-injury symptoms from recent memory are forgotten or not reported? On the other hand, if pre-injury PCS recall is equivalent to that of normal controls, then is the ability to access exact, episodic memories protective against the biasing effect of the good old days' bias and/or misattribution of symptoms to the concussion?

The results of Davis (2002) suggest that the good old days' bias leads to underestimates of pre-injury PCS at 1-week post-mTBI in adults. The fact that this pre-injury PCS estimate remained just as low (but not lower) at 3-months post-mTBI indicates that the good old days' bias is present early, but may not appreciably lead to

even lower retrospective pre-injury estimates within the first three months after injury. This is further supported by the finding of a significantly lower (but small effect size) pre-injury estimate at 3-months post-injury compared to 1-month post-injury in adolescents (Brooks et al., 2014). This decline in retrospective estimates was significant, but the findings of Davis (2002) suggest that the good old days' bias may produce the biggest underestimation of pre-injury PCS ratings in the first week after mTBI.

The progression, if any, of these biases over time has been understudied, but there is evidence that differences between “before and after” PCS ratings grow significantly over time (e.g., Hilsabeck et al., 1998; Brooks et al., 2014; Wilson & Ross, 2003). By comparing uninjured individuals' judgments and recall of PCS over time with that of individuals who have incurred an mTBI, it can be determined when after injury expectancy effects begin to affect pre-injury ratings and if these are in excess of the action of normative memory processes (e.g., forgetting; fading affect bias, positivity bias, rosy retrospective bias, etc.). Understanding how biases may progress may be most important during the acute period after mTBI when change may be most rapid and symptoms most attended to but so far this too has not been examined in detail.

An open question is whether pre-injury symptoms are completely denied (i.e., “zero” pre-injury PCS) or if the severity or frequency is underestimated to a greater extent than occurs normatively for these non-specific and common symptoms. There is evidence that examining retrospective memory reports of past behaviours in terms of never/ever reduces the appearance of retrospective recall errors (e.g., Downey, Ryan, Roffman, & Kulich, 1995). This is because high frequency behaviours tend to be underestimated while low frequency behaviours are overestimated (e.g., Smith et al., 1991; Croyle & Loftus, 1993). There may be clinical value in determining the severity and frequency of post-concussion symptoms after mTBI, but there is also value in determining if people completely forget that they experienced pre-injury symptoms rather than just underestimating symptom severity. For example, it may not be possible to recall the severity of last week's headache pain, but this is likely dissociable from being able to recall that one had a headache or to infer that one had a headache because they are commonly experienced (i.e., relying on semantic memory; Fienberg, Loftus, & Tanur, 1985; Croyle & Loftus, 1993; Downey et al., 1995).

Finally, most studies to date have examined biases affecting symptom perception in adults. The study in adolescents by Brooks et al. (2014) highlights the need to understand whether biases affect perception of recovery and change by these youths particularly because parents may underestimate their children's pre-injury symptoms. Therefore, characterizing the biases that affect adolescent self-ratings is critical. Significant declines between 1- and 3-months post-injury in adolescents' retrospective self-ratings of pre-injury PCS have been found (Brooks et al., 2014). However, the lack of a control group in that study does not make it clear whether there is a progression in the good old days' bias and/or misattribution particular to mTBI or if these declines over time simply reflect normal memory processes (e.g., forgetting). Furthermore, because adolescents' current PCS ratings were not reported in this study, it is unknown whether there is a good old days' bias such that pre-injury PCS would be significantly lower than current PCS, even in those who perceived themselves to be recovered. It is also unclear if progressively increasing underestimates of pre-injury PCS after mTBI would lead to increased apparent differences between current and past PCS across time. If these biases create such an apparent difference, it may be attributed to a lack of recovery from the concussion without fully appreciating the contribution of social psychological factors (e.g., memory biases) in creating this apparent difference. Since there has only been one study (Brooks et al., 2014) to examine retrospective PCS in adolescents in the acute period after mTBI, there is a clear need to understand the onset and progression of retrospective biases in pre-injury PCS estimates in this group, to what degree they are stronger than would be expected from the action of normal memory processes, and how these biases may lead to a greater apparent difference between current and pre-injury functioning.

Research Questions and Overall Study Design

The main goals of this study were to determine:

1. If a retrospective recall bias (due to expectations of increased post-mTBI symptoms) causes underestimated retrospective pre-injury PCS recall acutely after mTBI (i.e., in the first week post-injury).

2. Whether this retrospective recall bias leads to retrospective pre-injury PCS underestimates 1-month after mTBI.
3. Whether there is an increase in the underestimation of pre-injury symptoms between 1-week and 1-month post-injury, representing a “worsening” of the specific retrospective recall bias of pre-injury PCS after mTBI.

The study examined to what degree retrospective underestimates of pre-injury PCS are due specifically to the effect of negative expectations for increased PCS after mTBI rather than to normal memory processes (e.g., forgetting, positivity biases, etc.).

The current study used a longitudinal survey design to compare the current and retrospective PCS ratings of adolescents (ages 13-18 years) who had incurred an mTBI to the current and retrospective PCS ratings of an uninjured, healthy control group of adolescents. The design and rationale of within-group and between-group comparisons are outlined in Figure 1. Pre-injury and current symptoms were measured within one-week after mTBI and again at one-month post-injury in a group of adolescents. Retrospective symptom estimates corresponding to these time spans (i.e., over 3-4 days and over one month) and current symptoms at each time point were measured in a control group of uninjured adolescents. This design controlled for biases in retrospective recall of symptoms by adolescents over two short periods (i.e., a few days and one month) in the absence of an event to which symptoms might be attributed (i.e., concussion). Specifically, at the initial assessment, a control group of healthy adolescents were asked to estimate the intensity of symptoms they experienced in the three to four days prior to the date of assessment (akin to a pre-injury rating) as well as on the day of assessment (current “baseline” rating). At one month after the initial measurement, healthy adolescents were asked to again rate their current symptom intensity and to retrospectively estimate the intensity of symptoms they had experienced one month prior (i.e., at baseline, on the date of initial measurement) using the cue of “on the day you did Neurotracker baseline testing at the University of Victoria.” The date of initial measurement served as a salient and concrete event against which to anchor memory

recall. Giving a specific anchor in time reduces the likelihood of inaccuracies in reporting (Loftus & Marburger, 1983).

By controlling for normal retrospective memory biases and forgetting, the specific effects of negative expectations for increased symptoms after mTBI on retrospective recall of pre-injury PCS could be isolated above and beyond normal memory effects on these ratings in the very acute (1-week) and acute (1-month) post-injury period. In this way, both the onset and the progression of the good old days' bias in the first month after mTBI were examined.

Secondly, the current study examined whether expectancy effects, including misattribution, cause an "absolute" or relative underestimation of pre-injury symptoms. That is, after an mTBI, are symptoms attributed entirely to the concussion or do individuals tend to overestimate how much the mTBI increases the severity of pre-existing symptoms while still recalling that these symptoms were experienced before the mTBI? Specifically, do negative expectations about mTBI cause one to judge that a symptom was "never" experienced before the injury or does it lead to a decrease in the judgment of its severity or frequency because symptoms are expected to be (or are currently experienced as) more severe and/or frequent after the injury? The importance of examining severity compared to never/ever reports of past symptoms is supported by the finding of a greater number of adolescents reporting that they experienced "zero" pre-injury symptoms at 3- months compared to the number who made such a judgment at 1-month post-injury (Brooks et al., 2014). By completely forgetting that one experienced symptoms before an mTBI, it is more likely that subsequent symptoms will be misattributed to the mTBI.

Thirdly, the current study examined the practical significance of exaggerated differences between current and past functioning caused by retrospective recall biases. Specifically, Brooks et al. (2014) recommended using pre-injury PCS estimates obtained as close to injury as possible as the baseline for assessing recovery in order to reduce the rate at which individuals are classified as "not recovered to baseline." The reasoning was that pre-injury estimates obtained even at 1-month post-injury would be affected by the good old days' bias, thus inflating the difference between pre-injury and current PCS. This conjecture had not previously been tested. Furthermore, Brooks et al. (2014)

examined the classification rate of adolescents “not recovered to baseline” using parent reports only for those adolescents who were rated as being “different” from before the injury. This answers a clinically-relevant question since these are the individuals who will most likely present for follow-up treatment. However, it was unknown whether even individuals who perceive themselves to be “no different” than before the injury might still appear to have elevated symptoms because of the good old days’ bias. The importance of examining whether even those who perceive themselves to be “recovered” still underestimate pre-injury PCS comes from studies showing that the good old days’ bias is still present in non-treatment seeking athletes 2 years after head injury whose current PCS are not elevated. Therefore, the current study assessed whether using adolescents’ (<1 week post-injury) pre-injury PCS estimates as a baseline against which to compare 1-month PCS results in a significantly lower percentage being classified as “not recovered” compared to using concurrently-measured pre-injury PCS estimates at 1-month.

Goals and Hypotheses

Hypothesis #1.

Question 1: In the acute period after mTBI (≤ 1 week post-injury), do adolescents underestimate the degree to which they experienced post-concussion symptoms before the mTBI (because of negative expectations for change) more than is accounted for by normative forgetting and retrospective recall biases?

Since negative expectations about concussion are widespread (e.g., Mittenberg et al., 1992; Ferguson et al., 1999; Gunstad & Suhr, 2001, 2002, 2004; Vanderploeg et al., 2012), expectancy-based recall and misattribution were anticipated to affect judgments of current and pre-injury ratings even acutely after sustaining an mTBI. Further, underestimations of pre-injury symptoms have previously been found at 1-week after mTBI in adults (Davis, 2002). In adolescents, parents’ ratings of pre-injury symptoms drop dramatically from the day of the injury to one-month post-injury (Brooks et al., 2014). Since there is a decline in adolescents’ own pre-injury estimates between one- and three-months post-injury (Brooks et al., 2014) it was anticipated that the degree of underestimation in adolescents’ ratings of pre-injury symptoms would increase

substantially across the first month after mTBI. In particular, it was predicted that adolescents' retrospective pre-injury total PCS severity judgments reported within the first week post-mTBI would be lower than the retrospective ratings ("3-4 days ago") of a control group of uninjured adolescents who were not anticipated to hold expectations of change in symptoms over this period.

Hypothesis #2.

Question 2: At one-month after mTBI, do adolescents underestimate the degree to which they experienced post-concussion symptoms before the mTBI (because of negative expectations for change) more than is accounted for by normative forgetting and retrospective recall biases?

Similar to the reasoning underlying hypothesis #1, it was anticipated that, at one month after mTBI, expectations for increased symptoms after mTBI would lead to a greater underestimation of the severity/frequency of symptoms before the mTBI than would be expected from just the effect of normative memory processes on retrospectively-recalled symptoms from the past (e.g., in the absence of an mTBI). Underestimation of pre-injury symptoms have been found in the first year after mTBI in adults, including the period during which active recovery would be expected to be ongoing (e.g., three weeks to three-months after mTBI; Lange, Iverson, & Rose, 2010; Hilsabeck, 1998; Brooks et al., 2014).

Specifically, significantly less severe pre-injury symptoms were expected to be recalled one month after mTBI than are retrospectively recalled by uninjured individuals across an equivalent one-month interval. The expected difference in severity/frequency of recalled symptoms across one month between these groups reflects the effect of negative expectations for increased symptoms (e.g., misattribution, good old days' bias) after mTBI by the mTBI group over and above normative forgetting and other normative memory biases.

Hypothesis #3.

Question 3: Does the effect of expectancy effects and misattribution on retrospective recall of pre-injury symptoms increase from the first week to the first month after mTBI? It was anticipated that a smaller underestimation of pre-injury symptoms

would be found in the first week after mTBI than by one-month post-mTBI, even after controlling for normative memory processes (e.g., forgetting, fading affect bias, etc.). This is because it is less likely that retrospective pre-injury symptoms can be based on recall of episodic memory at one month post-injury, and so recall is more reliant on judgments guided by expectations (e.g., Conway & Pleydell-Pearce, 2000; Conway, 2005; Croyle & Loftus, 1993; Wilson & Ross, 2003). In the case of those who have incurred an mTBI, these expectations are for increased current symptoms after mTBI (Mittenberg et al., 1992; Ferguson et al., 1999). In addition, the effects of social-psychological and cognitive factors, including negative expectations, account for a greater proportion of symptoms as time since the injury increases (e.g., Silverberg & Iverson, 2005; Whittaker & Kemp, 2007; Hilsabeck et al., 1998). Therefore, the effect of expectation-guided recall of pre-injury symptoms was anticipated to be stronger at one-month post-injury than within the first week after injury.

Two sets of related comparisons were made to test this hypothesis. Firstly, the retrospective symptom estimates between the mTBI and control groups at one-week and one-month post-injury were compared. If the effect of negative expectations on retrospective recall of pre-injury functioning does not increase by one month post-injury, then these mean differences in pre-injury/past symptoms should have been the same or smaller at one month post-injury compared to one-week post-injury/baseline. However, it was expected that the difference would be larger at one month post-injury.

Secondly, the effects of normal memory processes were anticipated to lead to lower recall of symptoms in both groups across the one month interval. The control group was expected to underestimate the severity of symptoms that they reported at baseline, one month prior, though it was unknown if this would be significant. Constructive theories of expectation-guided recall would predict that, over such a short time frame, and in the absence of any intervening event, there should be no appreciable decline in retrospective ratings over time in the control group, in part due to the relative stability of symptoms across short time spans and because a consistency bias should lead to less of a difference between current and estimated past symptoms. That is, the expectation for consistency should lead to fairly accurate estimates of past functioning. Note that the control group's retrospective recall of baseline symptoms were compared to their actual baseline

symptom reports. However, the effect of negative expectations about mTBI were anticipated to lead to even more exaggerated underestimated retrospective recall of pre-injury symptoms in the mTBI group due to expectations for increased symptoms after mTBI. Therefore, significant decreases in reports of past (pre-injury) symptom severity were anticipated in the mTBI group across the first month, though there may not be a significant decrease in the uninjured group's retrospective symptom recall because of the expectation for consistency. Regardless, an interaction between groups and time was anticipated.

Hypothesis #4.

Hypotheses about whether expectancy effects after mTBI work in an “all-or-none” fashion are exploratory since this question has not been explicitly examined before. However, adolescents are more likely to report having “zero” pre-injury symptoms at 3-months post-injury than at 1-month post-injury suggesting that recall of “any” common symptoms in the past decreases over time (Brooks et al., 2014). It is unknown if this increasing tendency to recall “zero” pre-injury symptoms over time is specifically due to expectancy effects (including misattribution of current symptoms to the concussion) or if this tendency is found normatively. It was hypothesized that expectancy effects and misattribution would work in an all-or-nothing way such that pre-injury symptoms would not be recalled rather than being recalled, but as less severe than they are after mTBI.

This was examined in cross-section and dynamically, across time. Specifically, the proportion of each group (mTBI, uninjured control) reporting “zero” pre-injury or retrospective (“3-4 days ago”) symptoms was not expected to differ because specific episodic recall was likely more available across this short time period. Even if severity of symptoms is retrospectively underestimated, it is unlikely that individuals will report “never” having a symptom if they experienced it at all in the previous few days. However, at one-month post-injury, due to expectancy effects and misattribution of symptoms to the concussion, a higher proportion of the mTBI group were anticipated to recall “zero” pre-injury symptoms compared to the uninjured group recalling symptoms from one month ago. In addition, because symptoms are attributed to the mTBI, a greater

proportion of individuals with mTBI were expected to change from reporting “some” pre-injury symptoms within 1-week post-injury to reporting “none” of these symptoms by one-month post-injury compared to the uninjured group across this one-month period.

Hypothesis #5.

It was hypothesized that a smaller proportion of individuals at one month post-mTBI would be classified as “different” from pre-injury baseline when this classification is based on the difference between one-month symptoms and pre-injury symptoms reported in the first week after injury rather than when comparing current one-month symptoms to concurrent retrospective pre-injury symptoms reported at one-month. This is based on the parallel findings in Brooks et al. (2014) using parent-proxy reports that found a substantial reduction in individuals classified as “different” from baseline when using parent ratings from the Emergency Department rather than retrospective ratings from 1-month and 3-months post-injury, respectively. While their findings were based only on adolescents whose parents perceived them as “different” since the concussion (global judgment), the entire group of individuals with mTBI was examined in the current sample. This is because the single question about “how different you feel” may not align with actual symptoms reported, including any differences in current versus pre-injury symptoms. In addition, expectancy effects and attribution are thought to reflect, at least in part, implicit cognitive processes (e.g., Conway & Ross, 1984; Conway, 1989; Conway, 2005). The fact that recovered, non-treatment seeking athletes still demonstrated a good old days’ bias two years after their mTBI supports this notion.

Methods

Overall Study Design

This study used a longitudinal quasi-experimental design with repeated measurement of post-concussion symptom ratings in adolescents with and without a recent mTBI to assess whether there is a good old days' bias within the first week and/or by the first month after mTBI. See Figure 1 for an overview of the procedure.

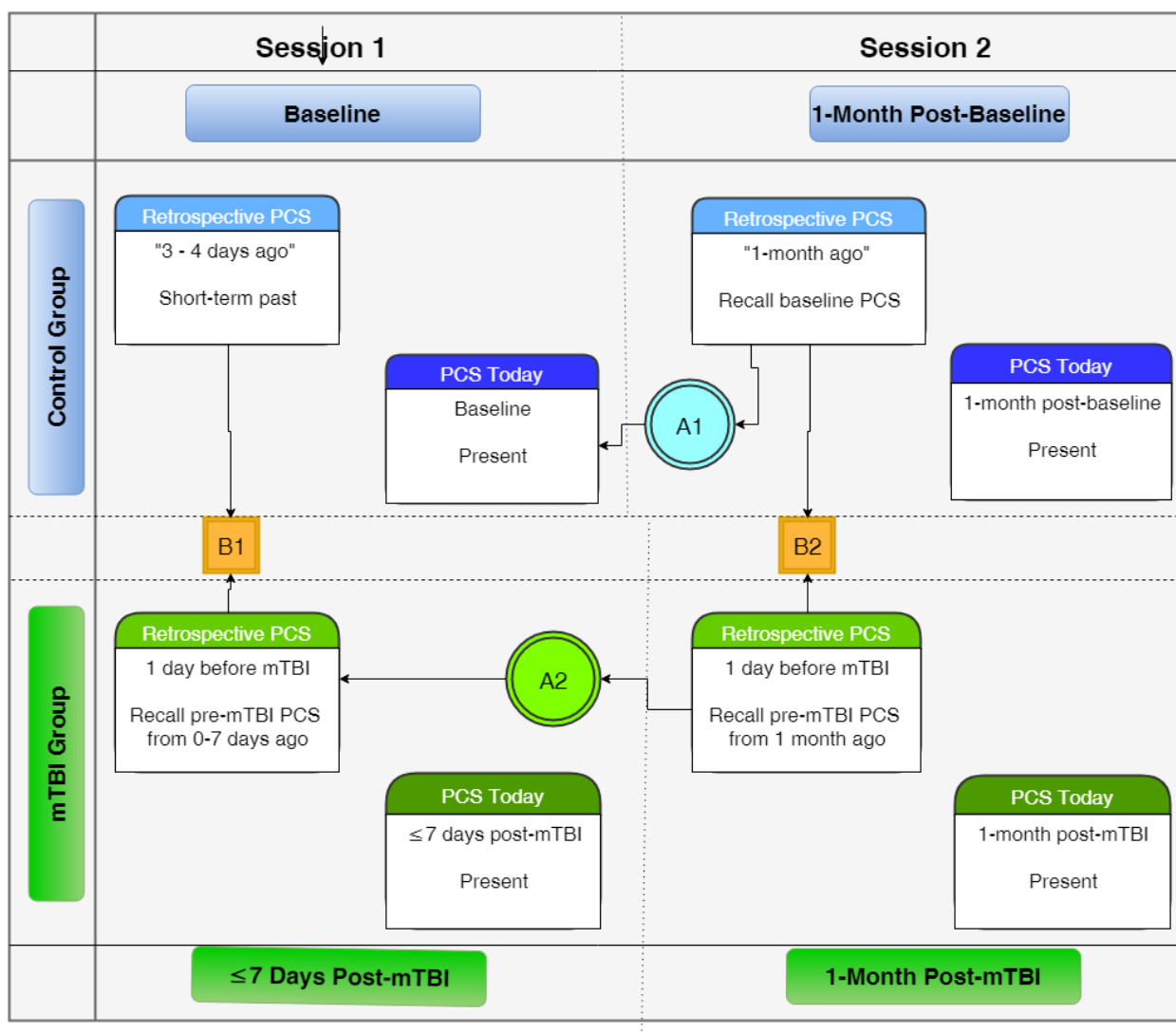


Figure 1. Overall study design and comparisons between and within the mTBI and control groups. Symptom ratings and comparisons used in major statistical analyses are designated by letters in the figure. Circles denote within-group, across-time analyses. Squares denote between-

group comparisons. Contrast A1 and A2 are within-subjects, across-time analyses of whether there is a good old days' bias across time over and above PCS forgotten over time. Contrasts B1 and B2 are within-time, between-subjects analyses of whether there is a good old days' bias within one week and one month of mTBI, respectively.

Participants

The final sample consisted of 84 adolescents, divided in two groups: 42 adolescents who enrolled within 7 days of sustaining a mild TBI (24 males, 18 females; 15 English-speaking, 27 French-speaking) and 42 healthy control adolescents (24 males, 18 females; all English-speaking). Both groups ranged in age from 13 to 18 years. See Table 2 for participant characteristics.

Recruitment

Participants who recently sustained a mild TBI were recruited through two pediatric concussion studies. Almost 10% of the final mTBI sample was recruited from the Neurotracker study with the remainder recruited from the Canada Paediatric mTBI Common Data Elements (CDE) study. Healthy, uninjured control group participants were also recruited through the Neurotracker study. Both studies are briefly explained below (see Figure 2).

Table 2

Demographic characteristics and medical history of mTBI and control groups

	mTBI			Control		
	<u>M</u>	<u>SD</u>	<u>Range</u>	<u>M</u>	<u>SD</u>	<u>Range</u>
Age at enrollment	15.17	1.42	13.01 – 17.97	16.91	1.68	13.19 – 18.93
Days between enrollment and 1-month follow-up	28.81	5.93	14 - 38	32.05	4.59	26 - 50
	<u>n</u>	<u>%</u>		<u>n</u>	<u>%</u>	
Gender						
Male	24	57.1		24	57.1	
Female	18	42.9		18	42.9	
Primary language						
English	15	35.7		42	100	
French	27	64.3		0	0	
Recruitment area						
Montreal	38	90.5		0	0	
Victoria	4	9.5		42	100	
Previous concussions						
0	17	40.5		37	88.1	
1	16	38.1		4	9.5	
2	5	11.9		1	2.4	
3	1	2.4		0	0	
4	1	2.4		0	0	
5	1	2.4		0	0	
Missing	1	2.4		0	0	
Medical/psychiatric history						
Supraventricular tachycardia	0	0		1	2.4	
Migraine headaches	6	14.3		0	0	
Headache treatment	5	11.9		0	0	
Learning disability	3	7.1		0	0	
Attention Deficit Hyperactivity Disorder	3	7.1		1	2.4	
Anxiety disorder	3	7.1		0	0	
Depression	1	2.4		0	0	
Sleep disorder	1	2.4		0	0	
Post-Traumatic Stress Disorder	2	4.8		0	0	

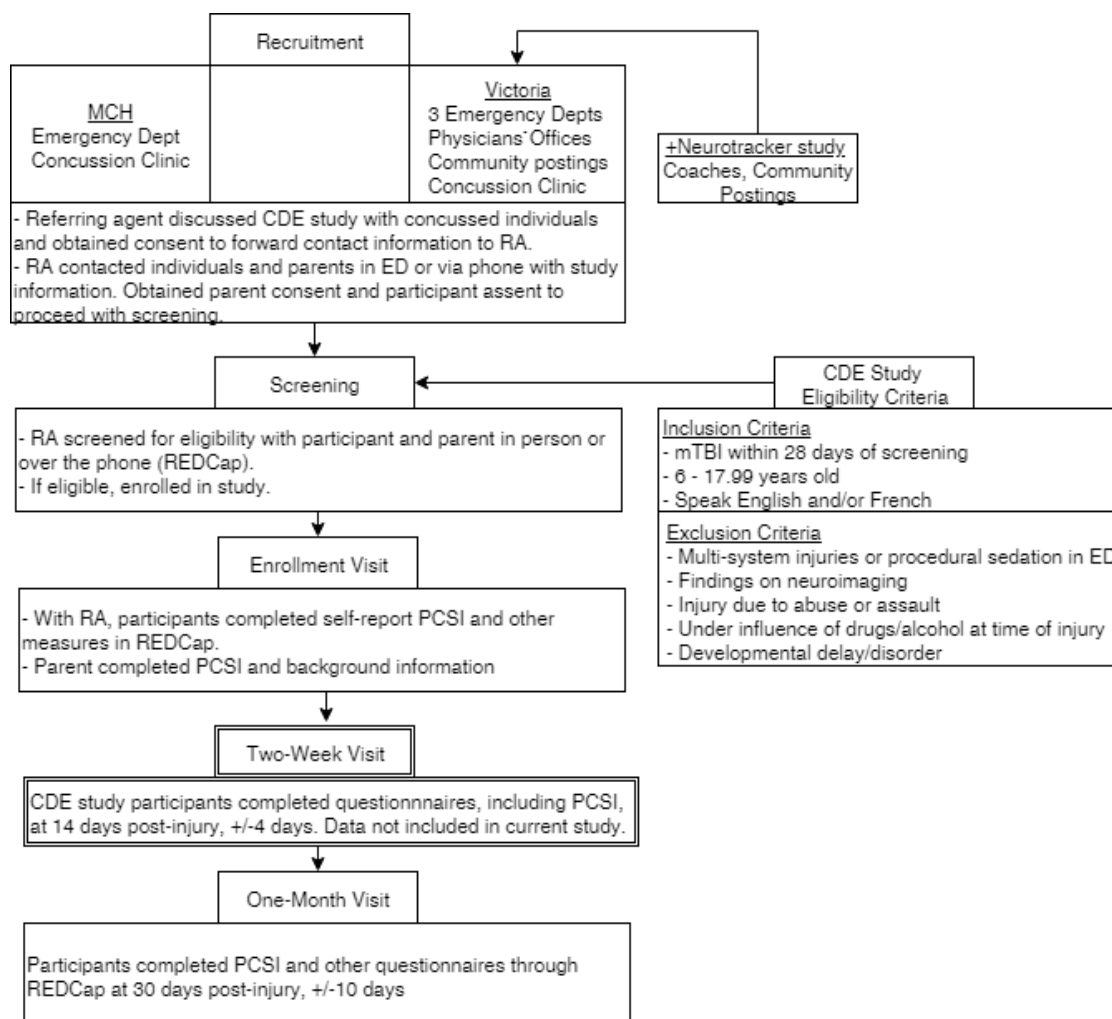


Figure 2. Recruitment, screening, & enrollment of mTBI group in CDE and Neurotracker studies.

Neurotracker study.

Conducted through the University of Victoria's BrainLab, the Neurotracker study examines the validity of using multiple object tracking (MOT; <http://neurotracker.net/neuroc3/4585042506>) and related neurocognitive testing to monitor recovery following concussion and determine readiness to return to usual activities. The larger study collects baseline data of uninjured, typically-developing individuals, ages 6 years to adult, who are at high risk of having an mTBI, mainly

through participating in impact sports. Individuals ages 6 and older who had an mTBI are also included in the Neurotracker study and complete a number of assessments after concussion aimed at tracking recovery and performance on behavioural and neurocognitive measures. Recruitment of mTBI participants was the same for the Neurotracker study and the CDE study's Victoria site (see below). In addition, healthy control participants were recruited through flyers posted throughout the community (recreation centres, sports fields, University of Victoria), emails to local sports organizations, direct contact with team coaches and trainers, and through a local private school's athletic therapist. Control participants were not compensated for participating since the Neurotracker study provides free pre-season baseline concussion testing.

Canada Pediatric mTBI Common Data Elements study.

The Canada Pediatric mTBI Common Data Elements (CDE) study is a national study funded by a Canadian Institutes of Health Research mTBI Team Grant in Children and Youth. Six pediatric mTBI follow-up programs and/or research hospitals across Canada are collaborating: Children's Hospital of Eastern Ontario; Institut de réadaptation en déficiences physiques de Québec; McMaster Children's Hospital; Montreal Children's Hospital; Ste.-Justine Hospital; and University of Victoria with Queen Alexandra Centre for Children's Health. The CDE study's overall aims are to: 1) Establish the feasibility and utility of collecting CDE measures with children and adolescents across Canada; 2) Describe the Canadian pediatric mTBI population seeking health care services in pediatric institutions and follow-up programs; and 3) Explore relations between initial presentation, personal factors, and 6-month post-injury outcome in terms of post-concussion symptoms and functioning in the motor, cognitive, emotional, and social domains. Ideally, initial assessments occur within 48 hours post-injury and follow-up assessments are at 2 weeks, 1 month, 3 months, and 6 months post-injury.

Due to data sharing agreements, data included in the current study were collected during the pilot phase of the CDE study from the Victoria and Montreal Children's Hospital (MCH) sites only.

In Victoria, participants for the Neurotracker and CDE studies were recruited from the community through posters, emails, and newsletters distributed via

community/recreation centres, sports fields, sports' organizations, and team coaches. Health care professionals also made direct referrals including: Emergency Department physicians at Victoria General Hospital, Royal Jubilee Hospital, and Saanich Peninsula Hospital; the concussion clinic at Queen Alexandra Centre for Children's Health; family physicians; pediatricians; walk-in clinics; and clinics offering concussion services such as physiotherapists' offices. At Montreal Children's Hospital (MCH), participants were recruited and screened when they presented to the hospitals' Emergency Departments or to the MCH Concussion Clinic. Participants in the CDE study were compensated with \$25 for participation. Ethics approval was obtained through Island Health and the University of Victoria Joint Ethics Committee for the CDE and Neurotracker studies.

mTBI group. The final mTBI sample consisted of $n = 42$ adolescents, ages 13.01 - 17.99 years at enrollment (M age = 15.17, $SD = 1.42$; 18 females, 24 males; 15 English-speakers, 27 French-speakers). The majority of mTBIs were sports-related, with non-sports-related falls accounting for the remainder. Early signs and ranges of duration of loss of consciousness and post-traumatic amnesia suggest that all mTBI were at the milder end of the injury severity spectrum. See Table 3 for mTBI characteristics.

Table 3

Injury characteristics of the mTBI sample

	<i>M</i>	<i>SD</i>
Days between injury and enrollment	2.98	2.14
	<i>n</i>	<i>% of group</i>
<u>Cause of injury</u>		
Sports	37	88.1
Non-sport-related fall	4	9.5
Missing	1	2.4
	<i>n</i>	<i>% of group</i>
<u>Severity indices*</u>		
Loss of consciousness		
Yes	6	15.0
No	34	85.0

Duration (minutes)	$M (SD) = 1.2 (0.46)$, Range = 0 - 3	
Appeared dazed and confused		
Yes	20	47.6
No	21	50
Confused about recent events		
Yes	11	26.2
No	30	71.4
Answers questions slowly		
Yes	15	35.7
No	26	61.9
Repeats questions		
Yes	5	11.9
No	36	85.7
Forgetful of recent information		
Yes	13	31
No	28	66.7
No early signs	29	69

Note: Data about injury severity were missing for one participant. *As indicated by early signs in the period after the concussion until the enrollment assessment.

Screening. To be eligible for the current study, participants must have had a recent mTBI, as defined by the World Health Organization Task Force on mTBI (2004) and the consensus statement on concussion in sport from the 4th International Conference on Concussion in Sport held in Zurich, November 2012 (McCrory et al., 2013) definitions (see Table 4). Of note, participants also met the updated consensus statement definition of a sports-related concussion from the 5th International Conference on Concussion in Sport held in Berlin, October 2016 (McCrory, Meeuwisse, Dvorak, et al., 2017).

Table 4

Definition of concussion/mTBI

World Health Organization Task Force on mTBI (Carroll et al., 2004)

“MTBI is an acute brain injury resulting from mechanical energy to the head from external physical forces. Operational criteria for clinical identification include:

-
- a. 1 or more of the following: confusion or disorientation, loss of consciousness for 30 minutes or less, post-traumatic amnesia for less than 24 hours, and/or other transient neurological abnormalities such as focal signs, seizure [N.B. Although included in the WHO (2004) definition, participants with intracranial lesions were excluded from this study.]
-
- b. Glasgow Coma Scale score of 13-15 after 30 minutes post-injury or later upon presentation for healthcare.
-
- c. These manifestations of mTBI must not be due to drugs, alcohol, medications, caused by other injuries or treatment for other injuries (e.g., systemic injuries, facial injuries, or intubation), caused by other problems (e.g., psychological trauma, language barrier or coexisting medical conditions) or caused by penetrating craniocerebral injury.” (Carroll et al., 2004, p. 115)

Consensus statement on concussion in sport (McCrory et al., 2013)

“Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces. Several common features that incorporate clinical, pathologic and biomechanical injury constructs that may be utilized in defining the nature of a concussive head injury include:

-
1. Concussion may be caused either by a direct blow to the head, face, neck or elsewhere on the body with an “impulsive” force transmitted to the head.

 2. Concussion typically results in the rapid onset of short-lived impairment of neurological function that resolves spontaneously. However, in some cases, symptoms and signs may evolve over a number of minutes to hours.

 3. Concussion may result in neuro-pathological changes, but the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging studies.

 4. Concussion results in a graded set of clinical symptoms that may or may not involve loss of consciousness. Resolution of the clinical and cognitive symptoms typically follows a sequential course. However, it is important to note that in some cases symptoms may be prolonged.” (McCrory et al., 2013, p. 1)
-

“The suspected diagnosis of concussion can include one or more of the following clinical domains:

1. Symptoms—somatic (e.g., headache), cognitive (e.g., feeling like in a fog) and/or emotional symptoms (e.g., lability);
 2. Physical signs (e.g., loss of consciousness (LOC), amnesia);
 3. Behavioral changes (e.g., irritability);
 4. Cognitive impairment (e.g., slowed reaction times);
 5. Sleep disturbance (e.g. insomnia).” (McCrory et al., 2013, p. 2)
-

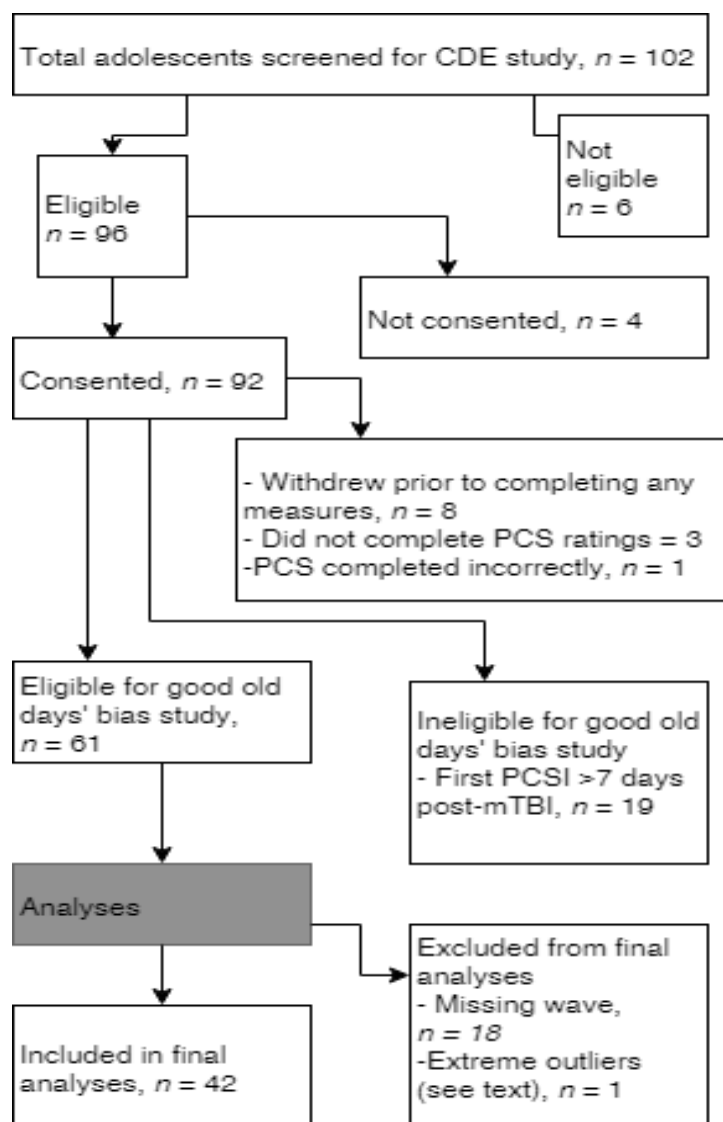
At the time of screening, no neuroimaging was conducted for any participants in the final sample. Additional information about the injury and medical history was acquired through parent questionnaires (see Appendix B). Injury characteristics of the final sample are listed in Table 3.

Additional inclusion criteria for the mTBI group were:

- i) Aged 13 to 17.99 years at the time of injury;
- ii) Completed PCSI-SR13-18 within 7 days of injury;
- iii) Proficient in English or French.

In total, 102 English and/or French-speaking adolescents (M age = 15.24, SD = 1.44 years; 58 males, 44 females; n = 85 from Montreal, n = 17 from Victoria) were screened within 28 days (M = 93.62 hours, SD = 105.48) of incurring an mTBI. See Figure 3 for an overview of screening and eligibility.

Figure 3. Screening and eligibility of mTBI participants for the CDE study.



Four participants declined to participate (M age = 14.27, SD = .54; 3 males, 1 female; all French-speaking). Six participants were excluded from participation in the CDE study, based on the following *a priori* exclusionary criteria:

- i) Incurred multi-system injuries requiring hospitalization for an injury other than mTBI, and/or operations or procedural sedation in the Emergency Department ($n = 1$, female, age 13.81 years, French-speaking);
- ii) Additional diagnoses were made in hospital, including fractures and intracranial lesions (e.g., on standard structural neuroimaging studies) ($n = 0$);

- iii) The injury was due to abuse or assault ($n = 3$, males, 2 English-speaking, 1 French-speaking, average age = 14.39 years);
- iv) The participant was under the influence of drugs or alcohol at the time of injury and/or when seen in the Emergency Department for symptoms ($n = 1$, 17.5 year old English-speaking female);
- v) A history of significant developmental delay/disorder (e.g., intellectual disability, Global Developmental Delay, Cerebral Palsy, Autism Spectrum Disorder, Down's Syndrome, Tourette's Syndrome, Williams Syndrome, seizure disorder, etc.) ($n = 1$, 16.52 years, male, English-speaking). Note: Children were included if they had previous diagnoses of other developmental or psychiatric disorders, including Attention Deficit Hyperactivity Disorder and/or Learning Disabilities.
- vi) Incurred a second brain injury between baseline assessment and the one month post-injury assessment ($n = 0$).

One participant's data (14.11 year old English-speaking female) were excluded because she did not have time to complete the PCSI-SR13-18 at the enrollment visit and so reported mostly zeros resulting in an apparent increase in total PCS severity of 55 at the 1-month follow-up. Eleven participants were excluded because they did not complete the PCSI-SR13-18 at either time point due to lack of time at both visits ($n = 3$) or lack of time during enrollment and withdrawal from the study at the one-month time point ($n = 8$; M age = 16.27, $SD = 1.55$; 5 females). Participants who withdrew from the study after enrollment did not differ from those who did not withdraw in terms of age, $t(88) = -1.92$, $p = .058$, or gender, $\chi^2(1) = 1.02$, $p = .313$.

Data from 19 participants (15 English-speaking, 4 French-speaking; 11 from Victoria, 8 from Montreal) were excluded because they completed their enrollment PCSI SR13-18 more than 7 days post-mTBI (i.e., average days post-injury = 15 days, $SD = 6.77$, range 8- 27 days). These participants did not differ from those in the final sample in terms of age (M age = 15.63, $SD = 1.7$, Mean difference = -0.42, $t(62) = -1.03$, $p = .309$), or gender (11 males, 8 females, $\chi^2(1) = 0.002$, $p = .965$). A further 18 participants' data were excluded listwise from the final sample due to missing an entire wave of symptom rating data. Handling of missing data is discussed in the results section.

Control group. The final control group consisted of 42 uninjured adolescents, ages 13.07 – 18.93 years ($M = 16.91$ years, $SD = 1.68$; 18 females, 24 males). Five participants had at least one doctor-diagnosed lifetime concussion ($n = 4$ with 1; $n = 1$ with 2 prior concussions), though none of these were in the year prior to the baseline time point. One participant had a premorbid history of supraventricular tachycardia and one had a history of ADHD.

Screening. See Figure 4 for overview of screening and eligibility. A total of 102 healthy adolescents (ages 13-18 years) were screened for inclusion in the control group. Of these, four reported medical conditions (supraventricular tachycardia, migraines, unilateral deafness, and asthma, respectively) and two reported psychiatric conditions (anxiety disorder, $n=1$; ADHD, $n=1$). Exclusionary criteria included having a mild head injury in the past year ($n = 11$; 5 males, 6 females; 13.67 – 18.41 years; M age = 16.75 years; 1 with migraines, 1 with asthma, 1 with ADHD, 1 with diabetes) or a moderate to severe head injury at any time ($n = 0$), in agreement with previous studies (e.g., Sady, Vaughan, & Gioia, 2014).

Three participants were excluded because they incurred a concussion between baseline and the 1-month follow-up assessment (2 males, ages 13.8 and 16.56 years; 1 female, aged 18.72 years). One female participant (aged 17.5 years) was excluded due to a significant stressor during baseline testing (i.e., expelled from school). One female participant (age 17.97 years) was excluded because she completed follow-up PCS ratings too late (68 days post-baseline rating).

Male control participants were over-sampled because more male than female athletes completed baseline testing. Rather than discontinuing data collection of male control participants earlier than female participants, data of both genders were collected across the complete seven-month period. This ensured inclusion of athletes of both genders from different sports and accounted for the effect of any seasonal variations on symptom report equally across genders. To create approximately equal sample sizes, a group of 24 male control group participants were randomly selected for inclusion. Selected participants did not differ from the non-selected participants in terms of any dependent variables, age, or number of previous concussions.

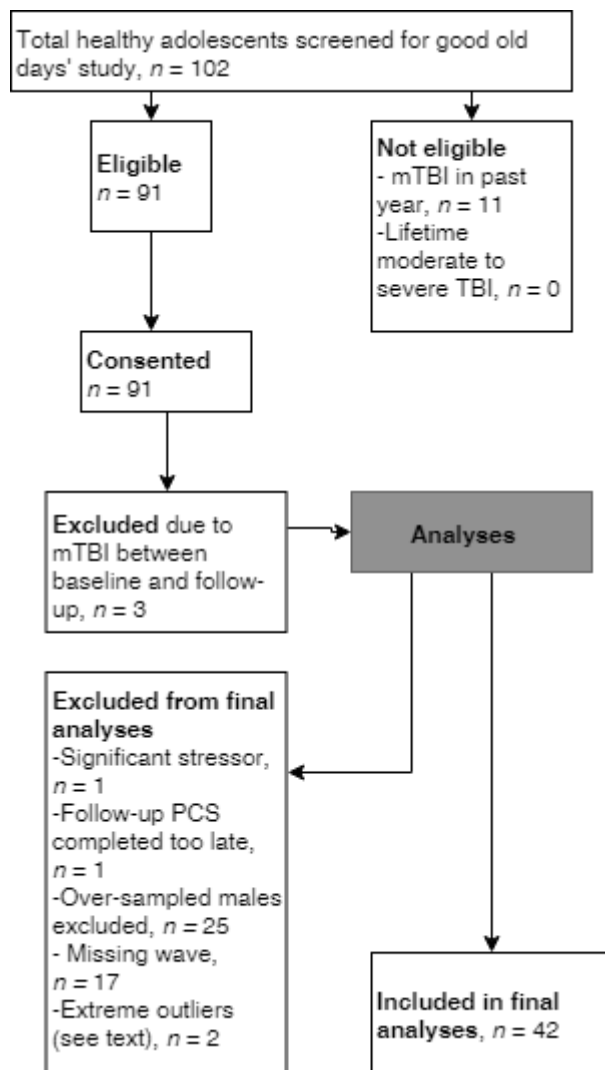


Figure 4. Screening and eligibility of the control group.

Control group check. At the one-month follow-up, seven control group participants reported experiencing a “major life event” (positive or negative) since the baseline assessment. Data of these participants were retained because they did not report a significant increase in total symptoms from baseline to the 1-month assessment using a Wilcoxon signed rank test, $Z = -1.21$ $p = 0.23$. As well, these participants did not report more symptoms (total and per symptom cluster) than participants who did not report a significant intervening event at both the baseline or at the 1-month follow-up, Mann-Whitney test U-values between 139 and 216, all $p > 0.07$. This check ensured that individuals in the control group did not experience a negative event that might have

induced expectations for change and/or significant changes in reported PCS related to this event.

Measures

Background History Questionnaires.

CDE study. Demographic information, including age and sex, and injury-related characteristics were collected for screening and descriptive purposes. Self-reported history of previous head injuries, and other psychiatric or medical conditions was also collected. Questionnaires were administered by a trained research assistant, with data entered into REDCap surveys.

Neurotracker study. Demographic information, including age, sex, and injury-related characteristics was collected using an online or paper questionnaire for screening and descriptive purposes. Participants reported any history of previous head injuries and other psychiatric or medical conditions (see Appendix A).

Injury Severity.

Severity of the current head injury was assessed using the Glasgow Coma Scale (GCS) based on information given by parents and/or adolescents if they were assessed within 48 hours of the injury in the Emergency Department. The Glasgow Coma Scale is a standardized method of grading the severity of neurologic deficits based on a 13-point scale (range = 3-15) that assesses neurological responsiveness in eye opening, verbal response, and motor responses. A score between 13-15 on the GCS is considered mild and is used as one of the screening criteria for inclusion in the CDE study. Fourteen participants had a GCS of 15, 1 had a GCS = 14, and a GCS score was not available for 27 participants because they completed enrollment measures more than 48 hours post-injury.

Post-Concussion Symptom Inventory Self-Report 13-18 years (PCSI-SR13).

Participants completed the 21-item self-report PCSI for adolescents ages 13-18 years (PCSI-SR13). The PCSI-SR13 (Gioia, Schneider, Vaughan, & Isquith, 2009; Sady, Vaughan, & Gioia, 2014) is a measure of self-reported somatic, cognitive, emotional, and sleep-related post-concussion symptom severity that uses developmentally-appropriate

language (see Appendix C). It asks for ratings of retrospective pre-injury baseline symptoms and post-injury symptoms (“current”) observed over the past day. Adolescents rate how much of a problem each symptom was before the injury (24 hours before the injury) and how much of a problem each symptom is currently (yesterday and today). Ratings are made for 20 symptoms on a 7-point Likert scale with the anchors provided of “0 = Not a problem; 3 = Moderate problem; 6 = Severe problem,” producing a total symptom severity score range of 0 – 120. A final question asks to what degree the adolescent feels “differently” than before the injury (not feeling like yourself) on a scale from 0 (“No difference”) to 4 (“Major difference”). This item is not included in the total symptom severity score. The reference to pre-injury and current symptoms in the instructions is not meant to induce a “diagnostic threat,” but is similar to instructions in previous studies that have found such an effect using other measures (e.g., Gunstad & Suhr, 2001, 2004; Ferguson et al., 1999; Mittenberg et al., 1992).

The PCSI-SR13 has strong internal consistency reliability in adolescents with mTBI with symptom cluster subscale α -values range from 0.79 to 0.93, and $\alpha = 0.94$ for the total symptom score (Sady, Vaughan, & Gioia, 2014). Internal consistency reliability in uninjured samples is lower for the symptom cluster subscales but adequate to strong for the total symptom scores in adolescents with subscale α -values ranging from 0.53 to 0.82, with $\alpha = 0.90$ for the total symptom score (Gioia et al., 2014). Test-retest reliability over 3 to 14 days in uninjured adolescents is adequate with intraclass coefficients (ICC) ranging from 0.64 – 0.76 for subscales and 0.79 for total symptom scores on the PCSI-SR13 (Sady, Vaughan, & Gioia, 2014). In that study, the most frequently endorsed symptoms were headaches and fatigue in uninjured and post-mTBI groups of children (ages 5-18 years). The items fit a four-factor model of symptom clusters (see Table 1). The current study examined subscale scores corresponding to these symptom clusters (i.e., somatic, cognitive, emotional, and sleep-related) in addition to total symptom severity scores. For example, male adolescent athletes have been found to base their judgment of their post-concussion recovery predominantly on somatic symptoms (Sandel, Lovell, Kegel, Collins, & Kontos, 2014). This indicates a need to examine whether a good old days’ bias differentially affects recall of certain types of symptoms.

Versions of the PCSI were adapted for use in the Neurotracker study for administration to typically-developing adolescents to correspond to the study questions (see Appendix D).

Procedure

Data collection.

All data were collected through a combination of in-person assessments, telephone administration, and online questionnaires. Data from the CDE study were collected and managed through the REDCap Electronic Data Capture tools (Harris, Taylor, Thielke, Payne, Gonzalez, & Conde, 2009). Limesurvey, a secure online survey program, was used to administer questionnaires to control group participants at the one-month follow-up visit. Measures specific to the University of Victoria site are stored securely in the Vancouver Island Concussion Project (VICP) lab.

Administration of measures and screening of mTBI participants. After referral to either study, an initial screening process determined eligibility to participate in the CDE study, including participant assent. Enrollment questionnaires, including the PCSI, were administered shortly after screening. Participant data were included if the initial (enrollment visit) PCSI was completed within 7 days (168 hours) of the mTBI (range = 0 – 7 days, $M = 2.93$, $SD = 2.14$ days). Parents and adolescents completed some measures online or through phone administration at the screening, enrollment, and the 1-month post-injury follow-up. Participants in the mTBI group completed their one-month post-injury appointment PCSI between 19-39 days post-injury ($M = 31.64$ days, $SD = 4.6$). Participants with mTBI enrolled in the Neurotracker study attended several sessions during the first 28 days after injury, beginning within 24 to 72 hours post-injury. These participants could choose to complete the follow-up questionnaires at 1-month post-injury in person, by telephone, or online.

Control group. Participants completed a modified PCSI during Neurotracker baseline testing. Participants were contacted by email or telephone approximately 1-month after this baseline (range = 26-68 days, $M = 32.59$ days, $SD = 6.3$). Follow-up testing at 1-month involved completion of the PCSI by participants either online, using Limesurvey, or by telephone.

At the baseline assessment, adolescents rated the severity of symptoms they experienced that day (current “baseline” rating), as well as in the three to four days prior, akin to a pre-injury rating. One month after baseline, adolescents were asked to again rate their current symptoms and to retrospectively estimate the symptoms they experienced one month prior, using the cue of, “on the day you did Neurotracker baseline testing at the University of Victoria”.

In addition, the control group indicated whether they expected these symptoms to change or not over the next month as a gross check that uninjured individuals do not expect change in PCS in the absence of an intervening event. See Appendix D for these questions about expectations.

PCSI-SR13-18 ratings were repeated at one month after baseline in the typically-developing healthy control group because: a) Many individuals report a significant decline in PCS across the first month post-concussion and so this period is seen as critical for examining biases and actual change in PCS; and b) A shorter period reduces the chances that an intervening event will unduly affect emotional, cognitive, sleep-related, and somatic symptoms in the control group, including the possibility of incurring a concussion given that the control group will be drawn from a group at high risk of incurring a sports-related head injury.

Checks.

Time points when symptom ratings were made. The mTBI group initially rated their post-concussion symptoms an average of 2.93 days post-injury ($SD = 2.14$ days, range = 0.5 hours – 7 days). They were asked to retrospectively rate their pre-injury PCS in the 24 hours before their concussion such that they recalled symptoms from an average of 3.93 days before the enrollment visit ($SD = 2.14$ days, range = 1-7 days). This time frame corresponded with the control condition instructions to recall symptoms from “3-4 days ago.”

The time between the baseline/enrollment and 1-month visits was an average of 3.4 days longer in the control group than in the mTBI group, $t(79.453) = 3.3$, $p < .001$. The average time between visits in the mTBI group was 28.7 days ($SD = 5.8$, range = 14-38 days post-enrollment visit) while the time between control group visits was 32.1 days ($SD = 4.67$, range = 26-50 days post-baseline). However, at the 1-month visit, the

retrospective total PCS ratings did not differ among those in the control group and mTBI groups with the five longest and shortest durations between PCS ratings, $F(3) = 1.423$, $p = .275$, partial $\eta^2 = .222$.

Statistical Analyses

Prior to undertaking main analyses, preliminary analyses included substantial data cleaning, including handling of missing data, outliers, and zero-inflated non-normal distributions of main variables of interest.

To test hypotheses 1, 2, and 3, the total score (severity of symptoms) and symptom cluster scores (physical, cognitive, emotional, sleep-related) on the PCSI-SR13-18 were the primary dependent variables for analyses. As outlined in the results section, the distributions of both groups' pre-injury symptom ratings were characterized by significant positive skewness, leptokurtosis, heteroscedasticity, zero-inflation, restricted range, and multiple influential "outliers." This is consistent with the distributional properties found in large-scale normative studies of the PCSI-SR13-18 (Sady et al., 2014) and similar PCS ratings scales (e.g., Lovell et al., 2006). Lovell et al. (2006) provided evidence that post-concussion symptoms are not normally-distributed in healthy, uninjured populations. Therefore, the current study used nonparametric tests to investigate the good old days' bias since the assumptions of classical parametric tests were likely to be violated, even with transformation of variables (Wilcox & Keselman, 2003; Wilcox, Carlson, Azen, & Clark, 2013). Rather than testing for mean differences, rank-based tests examine differences in patterns of retrospective recall of past symptoms. They are less influenced by outliers. However, nonparametric equivalents of mixed model ANOVAs are not accessible.

Between group comparisons were made at each time point (baseline, 1-month) using Mann-Whitney U -tests to examine whether the mTBI group's retrospective symptom ratings were lower than the control group's retrospective symptom ratings within 1-week of injury and at 1-month post-injury. Kruskal-Wallis tests with Dunn's pairwise post-hoc tests were used to examine gender and group differences in retrospective emotional symptom ratings at each time point. Separate related-samples Wilcoxon signed-rank tests were used to examine differences in retrospective symptom reporting over time within each group (mTBI, control) to determine whether the good old

days' bias increases over time. Of note, the control group's 1-month retrospective symptoms were compared with their "current" symptoms at baseline since these were the symptoms they were asked to recall.

To examine whether the good old days' bias works in an "all or nothing" way, total symptoms and each symptom cluster were changed to binary variables according to whether at least one symptom from that cluster was endorsed ("some") or not ("none"). Based on whether they reported zero (none) or at least one (some) pre-injury/past symptoms at baseline and one-month, participants were reclassified into one of four categories to indicate their pattern of symptom reporting across time: None to none; none to some; some to none; and some to some. Note that the retrospective estimate of symptoms by the control group at 1-month post-baseline was of the baseline session. These categories, repeated for total and each symptom cluster, were used for descriptive purposes and served to stratify the two groups to examine whether, of those who reported some symptoms, the good old days' bias led to absolute or relative underestimation of these symptoms later.

Between-group comparisons (mTBI versus control) of response patterns were made using Pearson exact chi-square tests, as well as within-group comparisons of response patterns. Separate Pearson chi-square tests were used to determine whether a larger proportion of the mTBI group reported "never" having pre-injury PCS than the control group (i.e., zero versus at least one symptom reported) at baseline and at one-month follow-up. Pearson's exact chi-square tests were used to determine whether, compared to the control group, a greater proportion of the mTBI group changed from reporting "some" pre-injury/retrospective PCS to reporting "zero" pre-injury PCS by one-month post-mTBI. Also to examine whether the good old days' bias works in an "all or nothing" way, McNemar's exact tests determined whether a greater proportion of adolescents in each group (mTBI or control) changed from reporting some symptoms to zero retrospective symptoms over time (some to none) rather than changing from reporting zero to some symptoms (none to some).

To determine whether individuals would be differently classified as "returned to pre-injury baseline" if different pre-injury estimates were used, comparisons of current symptoms at 1-month post-injury to pre-injury symptoms (reported in the first week post-

injury or at 1-month post-injury) were made (Hypothesis 5). First, paired-samples Wilcoxon signed rank tests were used to compare the “current” total symptoms at one-month post-injury with pre-injury total symptom ratings made concurrently or within one week of injury, respectively. Second, the mTBI group was dichotomized into “recovered” or “not recovered” at one-month post-injury. “Recovered” was defined as having equal or fewer current total symptoms at 1-month post-injury as pre-injury symptoms rated, respectively, at one-month post-injury, or within one week of injury. McNemar’s exact tests were used to determine whether a greater proportion of the mTBI group was classified as “recovered” at one-month post-mTBI by using pre-injury PCS ratings from within one week of mTBI rather than using pre-injury PCS ratings made concurrently with post-mTBI ratings at one-month post-injury.

Alpha level was set *a priori* at $p < .05$ for all analyses. All statistical tests were two-tailed and were performed using IBM SPSS Statistics for Windows, Version 24.0.0 (2016).

A Priori Power Analyses.

Only one study has investigated the good old days’ bias prospectively in adolescents after concussion. That study found small to medium effect sizes in the change between retrospective pre-injury ratings in “recovered” and “non-recovered” adolescents from one-month to three-months post-injury ($d = 0.37$ and $d = 0.41$, respectively; Brooks et al., 2014). However, since pre-injury PCS ratings measured shortly after concussion are likely to be higher than retrospective ratings at one month post-injury, the decline in pre-injury PCS ratings from the acute post-injury period to one month post-injury is likely to be even larger (i.e., larger effect sizes than those above). Indeed, when considering parents’ proxy ratings of retrospective pre-injury PCS in their adolescents, large effect sizes were found for the decline in pre-injury ratings from the Emergency Department to one-month post-injury in “recovered” and “non-recovered” adolescents (Cohen’s $d = 0.88$ and $d = 0.79$, respectively; Brooks et al., 2014). However, assuming a conservative effect size of $d = 0.41$, to ensure a minimum power of 0.80 with an alpha level of .05, a sample size of 49 adolescents with concussion was estimated to be needed. On the other hand, that study used parametric tests when pre-injury symptoms likely were non-normally distributed. Using non-parametric tests, up to 15% more

participants could be needed to ensure adequate power (Lehmann, 1998). However, parametric tests would likely be underpowered compared to nonparametric tests given the zero-inflated, highly skewed, long-tailed symptom distributions in the current study.

Sullivan & Edmed (2012) found a small-to-medium effect size ($d = 0.39$) when examining the effects of the good old days' bias and consistency biases on post-concussion symptoms (ratings separated by one week). This was based on a retrospective rating of 6 months ago, so it is unknown if this effect size applies to judgments/recall of symptoms over a few days. Assuming a small effect size (Cohen's $d = 0.39$) and alpha level of 0.05, to ensure a minimum acceptable power level of 0.80, a sample size of $n = 54$ uninjured adolescents was calculated to be needed to test the hypotheses of across-time ratings of pre-injury PCS.

The effect size is large (Cohen's $d = 0.78$) for the difference between the control group's PCS and the 1-week retrospectively estimated PCS of an mTBI group (Davis, 2002). To ensure a minimum power of 0.80 with an alpha level of 0.05, a sample size of 54 ($n = 27$ mTBI; $n = 27$ control) would be needed.

Since effect sizes for all remaining comparisons are at least small, the total sample size of $n = 103$ ($n = 54$ uninjured controls and $n = 49$ mTBI) was calculated *a priori* to ensure minimum power of 0.8 for testing of all hypotheses. The final sample sizes ($n = 42$ each of control and mTBI groups) was slightly under these sample sizes, but it is unclear if the current study was underpowered because it is unknown whether the distributions of symptom ratings in other studies were similar to those in the current study (i.e., zero-inflated, very highly positively skewed, etc.).

Results

Data Preparation

Missing data. No symptom rating data were missing in either group for participants who completed the PCSI-SR13-18 within a wave. Whole wave PCSI data were missing for participants in both groups as described below.

mTBI group. Whole wave PCSI data were missing for 10 mTBI participants at the enrollment visit (9.8% of original mTBI group, 7 males, ages 13.56-16.52, mean age = 14.72, $SD = 1.0$, 6 English-speakers) and for 8 participants at the 1-month follow-up (7.8% of mTBI group, 4 males, ages 13.39-17.48, mean age = 15.07, $SD = 1.33$, 6 English-speakers). Reasons for not completing the PCSI-SR13-18 included lack of time ($n = 5$), lost to follow-up ($n = 11$), incurred a second concussion ($n = 1$), and late exclusion due to a language barrier ($n = 1$). Participants with and without missing data did not differ in terms of age (M age = 14.87, $SD = 1.14$, Mean difference = .34, $t(39.29) = .98$, $p = .33$), gender (11 males, 7 females, $X^2(1) = .315$, $p = .575$), or language (12 English-speakers, 6 French-speakers, $X^2(1) = 3.67$, $p = .06$). Examining missing data patterns among enrollment and one-month pre-injury and post-injury symptoms, gender, and age at enrollment revealed evidence that data were missing completely at random, Little's MCAR test, $X^2(19) = 14.7$, $p = .74$.

Control group. Of the 88 control group participants remaining after applying exclusionary criteria, 17 (19%) did not complete the 1-month PCSI ratings via online survey and they could not be reached by telephone (15 males, 2 females; M age = 16.72, $SD = 1.78$; mean total symptoms at baseline = 5.35, $SD = 10.6$). Participants who completed the 1-month follow-up (M age = 16.72, $SD = 1.75$, 49 males; mean baseline total symptoms = 3.97, $SD = 6.39$) did not differ from those who missed the 1-month follow up by age, $t(86) = -0.003$, ns , gender, $X^2(1) = 2.56$, $p = .11$, or total symptoms at the baseline assessment, $t(86) = -.694$, ns . Examining missing data patterns among baseline and one-month follow-up retrospective symptoms (all clusters), current symptoms, gender, history of concussions, and age at enrollment suggested that data were missing completely at random, Little's MCAR test, $X^2(9) = 13.57$, $p = .14$.

Data for the 18 mTBI participants and 17 control participants who were missing whole wave data were excluded listwise from analyses for several reasons. First, to include data of participants with symptom ratings at only one time point would effectively create six different samples of participants (i.e., for each of the control and mTBI groups, those with complete data versus those with enrollment data only versus those with 1-month data only). This would greatly complicate comparison and interpretation across the two post-injury time points, including evaluating changes in symptom ratings across time.

Second, missing data replacement methods, such as imputation, were not employed because: a) sample sizes are fairly small; b) evidence for using missing data replacement techniques for panel data is not well-established (e.g., Kleinke, Stemmler, Reinecke, & Lösel, 2011); and c) with no previous studies examining change in pre-injury symptom ratings in the first month post-injury, there is no basis against which to evaluate whether imputed values are realistic.

Finally, missing and non-missing data are likely to be observed at random (Tabachnick & Fidell, 2012) since Kolmogorov-Smirnov tests revealed equivalent means and variances between those with complete versus missing waves on the following variables: pre-injury total symptoms, post-injury total symptoms, and mean differences between pre-injury and post-injury total symptoms at both time points. The equivalence between those with and without missing data on these observed parameters suggests that complete data are representative of the larger data set that would also include the missing data. Although being observed at random is a necessary but not sufficient condition for data being missing completely at random (MCAR), it increases the likelihood of ignorable missingness by providing evidence against data being not missing at random (NMAR; Tabachnick & Fidell, 2007). Furthermore, the pattern of missingness is not related to observed parameters relevant to the current study, also providing evidence of ignorable missingness. Since data are likely MCAR, non-complete cases were deleted listwise as the complete cases are likely to be a random subset of the whole sample (Little & Rubin, 1987; Schafer & Graham, 2002; McKnight, McKnight, Sidani, & Figueredo, 2007).

Outliers. Identification of univariate outliers was made in the context of highly positively skewed variables and a proportion of all groups reporting “zero” post-concussion symptoms, including the mTBI group’s pre-injury symptom ratings. This is consistent with previous findings with large normative samples (e.g., Sady et al., 2014; Lovell et al., 2006) with some arguing that PCS are actually non-normally distributed in healthy young individuals (Lovell et al., 2006). Therefore, decisions about handling outliers were made based on: a) The relative spread among non-zero scores in the tails; b) Consideration of factors possibly affecting control groups’ symptom ratings at both time points (e.g., health, psychological health, major life changes, etc.); c) Consideration of pre-injury factors in mTBI participants; and d) Whether including a potential outlier would change the results of main analyses. In addition, bivariate and multivariate outliers were considered in deciding whether to retain an outlier. When potential outliers were retained, analyses were repeated without each potential outlier (Aguinas, Gottredson & Joo, 2013). Changes in findings caused by exclusion of outliers are reported where applicable.

Univariate outliers. To identify possible univariate outliers, frequency tables, box-plots, and histograms were examined for each symptom cluster separately within each group (mTBI, control) as well as between males and females within each group. Tukey’s hinges and modified z -scores based on the median were calculated to account for non-normality and the high proportion of zeroes in symptom ratings. Tukey’s hinges only identified potential outliers above the 75th percentile because of the distributions’ heavy positive skew. Based on Tukey’s hinges, “mild” outliers were identified as being 1.5 to 3 times the interquartile range above the 75th percentile. Extreme outliers were identified as being >3 times the interquartile range above the 75th percentile. Modified z -scores were calculated based on each score’s absolute deviation from the median, divided by a measure of dispersion around the median, either the mean absolute deviation (MeanAD) or median absolute deviation (MAD). When multiplied by a constant, the MeanAD and MAD approximate the standard deviation but are less susceptible to the influence of outliers than the standard deviation. When the MAD equaled zero, the modified z -score was calculated as: $(X_i - MED)/(1.253314 * \text{MeanAD})$ where X_i is an individual symptom index rating, MED is the median of the group symptom index rating, and MeanAD is the

mean absolute deviation from the median. When the MAD did not equal zero, the modified z -score was calculated as $(X_i - \text{MED}) / (0.6745 * \text{MAD})$. Potential outliers were defined as those with modified z -scores > 3.5 (Iglewicz & Hoaglin, 1993). These methods were congruent with each other in identifying univariate outliers.

mTBI group. Five participants in the mTBI group accounted for the most extreme pre-injury symptom cluster ratings at both time points. Data of four of these outliers were retained because their inclusion or exclusion did not substantively alter any results. On the other hand, excluding these outliers may reduce generalizability of the results since these participants are likely part of the population of interest. Data of one participant (15.77 year old, English-speaking female) were excluded because including her data created significant differences in the mTBI group between males and females for several symptom cluster rating means, medians, and distributions (see Appendix E).

Control group. Two female participants (ages 18.49 and 14.62 years, respectively) each reported unusually elevated symptoms. Inclusion of these participants' data accounted entirely for significant gender differences in the control group on 13 symptom cluster totals. Their data were excluded because they may introduce heterogeneity into the control group not representative of a healthy population and their inclusion had a profound effect on analyses.

Bivariate outliers. Potential bivariate outliers were flagged by visually inspecting scatterplots of total and cluster symptom ratings within and between groups at each time point and across time points for the following ratings: Enrollment and 1-month retrospective ratings (mTBI group); Enrollment current and 1-month retrospective ratings (control group); Enrollment and 1-month current ratings; Enrollment retrospective and current ratings; 1-month retrospective and current ratings. A number of bivariate outliers in each group were identified but since all bivariate outliers were redundant with univariate outliers, they are not described.

Multivariate outliers. Multivariate outliers were identified using an SPSS macro (DeCarlo, 1997; available at <http://www.columbia.edu/~ld208/>) with a conservative Mahalanobis $d^2 \geq 28$ ($p < .001$). To identify multivariate outliers across time, the four pre-injury/retrospective symptom cluster ratings at both time points were examined in each group.

mTBI group. In the mTBI group, the female participant identified as a univariate outlier was also identified as a multivariate outlier, with a Mahalanobis d^2 value of 28.69. When this participant was excluded, the next largest Mahalanobis d^2 value was 26.93. No multivariate outliers were identified in the mTBI group when pre-injury symptom cluster ratings were examined separately within each time point.

Control group. In the control group, the same two female participants identified above with the most discrepant symptom ratings had Mahalanobis d^2 values of 34.18 and 30.51, respectively. When examining multivariate outliers amongst the four symptom cluster ratings within time, both participants had significant Mahalanobis d^2 values at the 1-month follow-up (34.61 and 32.04, respectively). One also had a significant d^2 value at the enrollment visit (29.33) for retrospective symptom ratings. These two control participants were excluded from further analyses. When these two participants were excluded, an 18.2 year old female participant's Mahalanobis d^2 value became 30.51. Inspection of symptom cluster scores across time revealed that this participant reported very few symptoms at enrollment but reported many more symptoms (both retrospective and current) at the 1-month follow-up relative to her own enrollment symptoms. However, her Mahalanobis d^2 value was only 14.49 at the follow-up when examining multivariate normality of only the symptom cluster ratings at the 1-month follow-up. There were no differences in results involving across-time comparisons when this participant was included versus excluded, so her data were retained.

Normality – control group. Histograms, Q-Q probability plots, detrended probability plots, skewness and kurtosis values, and Kilmogorov-Smirnov tests indicated that the distributions of the control group's symptom ratings departed substantially from normal (see Table 5). At both time points, current and retrospective ratings of total symptoms and each symptom cluster were highly positively skewed and leptokurtic. Distributions of PCS ratings appeared zero-inflated and resembled a backwards “J-shape” due to a high number of participants reporting no or few symptoms. Kolmogorov-Smirnov tests also indicated that all symptom clusters and total symptoms deviated significantly from normal, $D(42)$ -values range from 0.23 to 0.47, $p < .001$.

Normality – mTBI group. The mTBI group's current PCS ratings were more normally distributed than their retrospective PCS ratings, especially in the first week

post-injury (see Table 6). Nevertheless, Kolmogorov-Smirnov tests indicated that current and retrospective symptom clusters and total symptoms deviated significantly from normal, $D(42)$ -values range from 0.14 to 0.4, $p < .05$ except for total current physical symptoms at enrollment, $D(42) = .11$, $p = 0.2$. All retrospective PCS cluster and total symptom scores were significantly positively skewed, z -scores between 3.65 – 8.46, p -values $< .05$. Distributions of retrospective symptom ratings were also leptokurtic, z -scores between 4.4 – 13.3, $p < .05$, except at baseline, for emotional symptoms, $z = 1$, and sleep-related symptoms, $z = 1.9$, *ns*. Examination of Q-Q probability plots and detrended probability plots revealed that values in the lower ranges tended to deviate from normality for all symptom cluster and total scores.

Linearity and heteroscedasticity. Linearity and homoscedasticity were assessed by visually inspecting bivariate plots between pairs of corresponding symptom cluster scores from the enrollment and 1-month time points. In both groups, there were obvious issues with homoscedasticity (e.g., “cone-like” distributions) and non-linear relationships (e.g., “J-shaped”), as expected with a high proportion of zeros and a wide range in symptom ratings. The mTBI group’s current symptoms followed a J-shaped distribution from the enrollment to 1-month follow-up. This is expected since there was a range in severity of presenting symptoms followed by resolution of most symptoms by 1-month with a few participants continuing to report more symptoms at the 1-month follow-up than most of the mTBI sample.

Homogeneity of variance. Levene’s tests based on medians indicated heterogeneity of variance between groups on all post-injury/current total and cluster PCS ratings at both time points, with session 1 $W(1, 82)$ ranging from 40.61 - 69.16, all $p < 0.001$ and session 2 $W(1, 82)$ ranging from 4.32 – 9.36, p -values ranging from 0.041 – 0.003. This was expected and unproblematic since all main between-group analyses involved the mTBI group’s retrospective PCS ratings. Levene’s tests based on medians suggested homogeneity of variance for all retrospective PCS ratings at both time points, all $W(1, 82) < 3.29$, *ns*. In addition, variance ratios between groups for each retrospective symptom rating variable indicated no gross violations of homogeneity of variance, with all Hartley’s F_{max} values between 1.04 – 7.34 (Tabachnick & Fidell, 2007). Therefore,

Mann-Whitney U-tests can be interpreted as test of median differences between the mTBI and control groups' retrospective symptom ratings.

Data transformation. Data were not transformed because forced-normalization would distort a construct that is not actually normally distributed in the population (i.e., healthy adolescents' post-concussion-like symptoms; Lovell et al., 2006). Transformation would also hinder the interpretability of results involving meaningful scales (i.e., number and severity of symptoms as well as the directionality of change in symptoms across time). As well, transformations would likely not “restore” normality or homoscedasticity, would not address outliers, reduce power, and could rearrange the order of means (Grissom, 2000; Leech & Onwuegbuzie, 2002; Lix, Keselman, & Keselman, 1996; Erceg & Hurn, 2008).

Preliminary Statistical Analyses

Descriptive Statistics. See Tables 5, 6, and 7 for descriptive statistics of symptom ratings and general difference ratings in the control and mTBI groups. See Figure 5 for mean total symptom ratings at baseline and one-month follow-up in both groups.

Table 5

Descriptive statistics and normality of control group PCS ratings

		<u>Mean (S.E.)</u>	<u>Mdn (IQR)</u>	<u>Min/</u> <u>Max</u>	<u>Skewness</u> <u>(S.E.)</u>	<u>Kurtosis</u> <u>(S.E.)</u>	<u>Kilmogorov-</u> <u>Smirnov</u>
<u>Baseline</u>							
Retro.	Phys.	1.1 (0.3)	0 (1)	0-9	2.6 (0.37)*	7.41 (0.72)*	0.29***
	Cog.	0.45 (0.15)	0 (0)	0-3	1.89 (0.37)*	2.17 (0.72)*	0.47***
	Emot.	1.38 (0.34)	0 (2)	0.7	1.65 (0.37)*	1.58 (0.72)*	0.31***
	Sleep	0.9 (0.21)	0 (2)	0-5	1.33 (0.37)*	0.95 (0.72)	0.37***
	Total	3.83 (0.74)	2 (6)	0-19	1.67 (0.37)*	2.64 (0.72)*	0.26***
<u>Current</u>							
Current	Phys.	0.76 (0.28)	0 (1)	0-10	3.74 (0.37)*	16.57 (0.72)*	0.38***
	Cog.	0.76 (0.23)	0 (1)	0-7	2.5 (0.37)*	6.95 (0.72)*	0.39***
	Emot.	0.64 (0.30)	0 (1)	0-11	4.53 (0.37)*	22.24 (0.72)*	0.37***
	Sleep	0.67 (0.18)	0 (1)	0-4	1.74 (0.37)*	2.18 (0.72)*	0.39***
	Total	2.83 (0.73)	1 (3)	0-22	2.64 (0.37)*	7.42 (0.72)*	0.27***
<u>1-Month</u>							
Retro.	Phys.	0.86 (0.23)	0 (2)	0-7	2.36 (0.37)*	6.55 (0.72)*	0.36***
	Cog.	0.60 (0.19)	0 (1)	0-7	3.66 (0.37)*	16.76 (0.72)*	0.35***
	Emot.	0.81 (0.23)	0 (1)	0-7	2.29 (0.37)*	6.12 (0.72)*	0.40***
	Sleep	0.64 (0.17)	0 (1)	0-4	1.64 (0.37)*	1.75 (0.72)*	0.39***
	Total	2.9 (0.59)	2 (4)	0-16	1.64 (0.37)*	2.65 (0.72)*	0.22***
<u>Current</u>							
Current	Phys.	1.26 (0.31)	0 (2)	0-7	1.64 (0.37)*	1.71 (0.72)*	0.33***
	Cog.	0.95 (0.31)	0 (1)	0-8	2.73 (0.37)*	7.08 (0.72)*	0.33***
	Emot.	1.26 (0.32)	0 (2)	0-9	2.16 (0.37)*	4.79 (0.72)*	0.30***
	Sleep	0.90 (0.20)	0 (1)	0-4	1.33 (0.37)*	0.67 (0.72)	0.31***
	Total	4.38 (0.89)	2 (7)	0-25	1.7 (0.37)*	2.9 (0.72)*	0.23***

Note. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. $n = 42$. Retro = retrospective PCS ratings, phys. = total physical symptoms, cog. = total cognitive symptoms, emot. = total emotional symptoms, sleep = total sleep-related symptoms, total = total symptoms.

Table 6

Descriptive statistics and normality of mTBI group PCS ratings

		<u>Mean (SD)</u>	<u>Mdn</u> <u>(IQR)</u>	<u>Range</u>	<u>Skewness</u> <u>(S.E.)</u>	<u>Kurtosis</u> <u>(S.E.)</u>	<u>Kilmogorov-</u> <u>Smirnov</u>
<u>Baseline</u>							
Retro.	Phys.	2.12 (0.54)	0.5 (3)	0-13	2.15 (0.37)*	3.99 (0.72)*	0.27***
	Cog.	1.21 (0.39)	0 (1)	0-11	2.35 (0.37)*	5.16 (0.72)*	0.40***
	Emot.	1.45 (0.32)	0 (2)	0-7	1.35 (0.37)*	0.72 (0.72)	0.31***
	Sleep	1.02 (0.24)	0 (2)	0-5	1.48 (0.37)*	1.39 (0.72)	0.35***
	Total	5.81 (1.33)	2 (7)	0-32	1.99 (0.37)*	3.17 (0.72)*	0.25***
<u>Current</u>							
Phys.		19.98 (1.99)	18 (22)	0-47	0.41 (0.37)	-0.797 (0.72)	0.11, $p = 0.2$
	Cog.	9.9 (1.19)	7.5 (12)	0-29	0.84 (0.37)*	-0.25 (0.72)	0.17**
	Emot.	6.45 (0.92)	4.5 (9)	0-19	0.76 (0.37)*	-0.48 (0.72)	0.16**
	Sleep	5.67 (0.54)	6 (7)	0-11	0.00 (0.37)	-1.36 (0.72)	0.16**
	Total	42 (4.14)	35 (41)	2-100	0.63 (0.37)	-0.54 (0.72)	0.14*, $p = .48$
<u>1-Month</u>							
Retro.	Phys.	1.48 (0.42)	0 (2)	0-12	2.73 (0.37)*	7.93 (0.72)*	0.29***
	Cog.	0.79 (0.3)	0 (1)	0-9	3.13 (0.37)*	9.56 (0.72)*	0.39***
	Emot.	0.81 (0.24)	0 (1)	0-6	2.29 (0.37)*	5.03 (0.72)*	0.37***
	Sleep	0.69 (0.21)	0 (1)	0-6	2.42 (0.37)*	6.18 (0.72)*	0.39***
	Total	3.76 (1.02)	1.5 (3)	0-30	2.88 (0.37)*	8.36 (0.72)*	0.33***
<u>Current</u>							
Phys.		5.17 (1.19)	1(8)	0-26	1.47 (0.37)*	0.76 (0.72)	0.33***
	Cog.	3.4 (0.79)	1 (4)	0-16	1.58 (0.37)*	1.10 (0.72)	0.27***
	Emot.	2.45 (0.51)	1 (4)	0-15	1.74 (0.37)*	3.78 (0.72)*	0.24***
	Sleep	1.86 (0.43)	1 (2)	0-10	1.81 (0.37)*	2.19 (0.72)*	0.29***
	Total	12.88 (2.72)	4 (18)	0-56	1.78 (0.37)*	0.83 (0.72)	0.30***

Note. * = $p < .05$, ** = $p < .01$, *** = $p < .001$. $n = 42$. Retro = retrospective PCS ratings, phys. = total physical symptoms, cog. = total cognitive symptoms, emot. = total emotional symptoms, sleep = total sleep-related symptoms, total = total symptoms.

Table 7

Perceived "general difference" ratings initially and after one month in the mTBI and control groups

<u>Frequency</u>				
<u>n (%)</u>				
	<u>Control</u>	<u>mTBI</u>		
<u>General difference</u>	<u>Baseline</u>	<u>One-Month Post-Baseline</u>	<u>≤ 1 Week of mTBI</u>	<u>One-Month Post-mTBI</u>
0	37 (88.1%)	33 (78.5%)	8 (19%)	21 (50%)
1	4 (9.5%)	8 (19 %)	9 (21.4%)	14 (33.3%)
2	1 (2.4%)	1 (2.4%)	12 (28.5%)	4 (9.5%)
3	-	-	10 (23.8%)	2 (4.8%)
4	-	-	3 (7.1%)	1 (2.4%)

Note. Perceived “general difference” is based on responses to a single question on the PCSI-SR13-18.

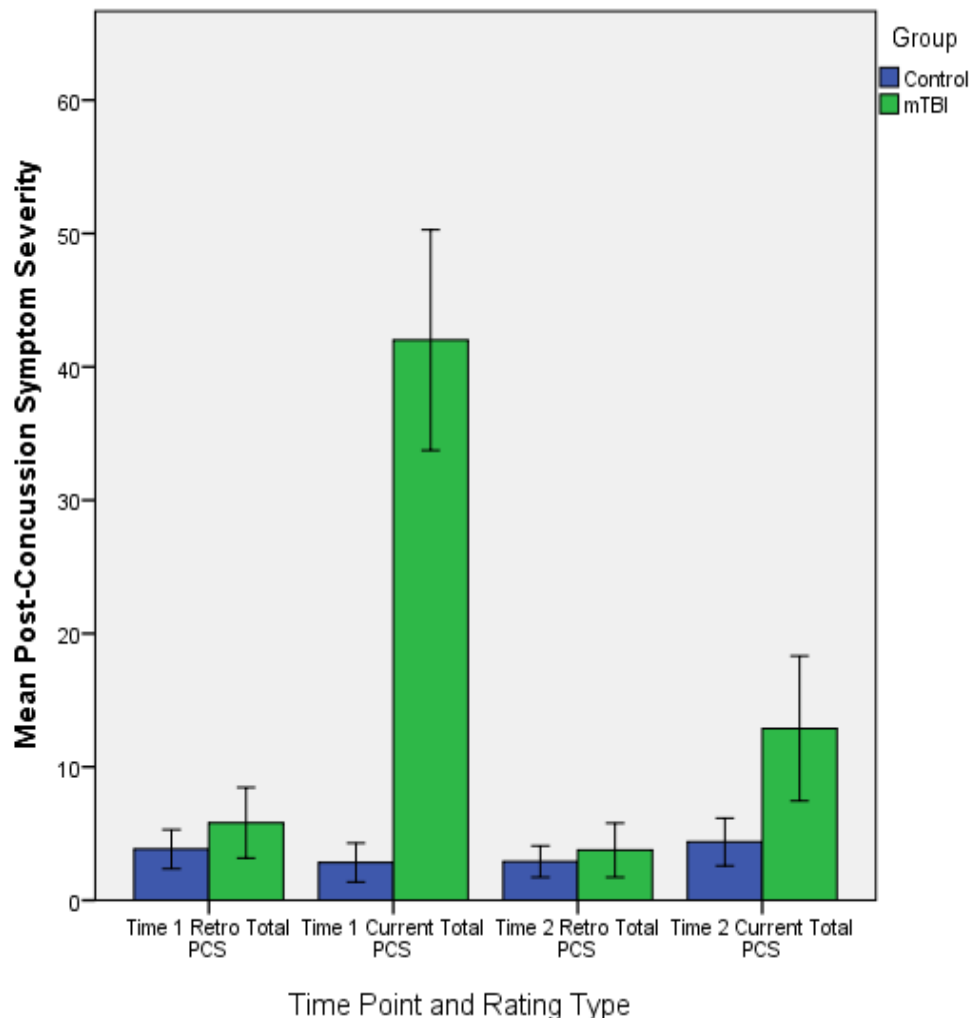


Figure 5. Mean total retrospective and current symptoms at baseline and one-month later in control and mTBI groups. *Note.* Mean ratings shown because medians are close to zero. PCS = Post-concussion symptom severity on the PCSI-SR13-18. Retro = retrospective symptom ratings. Error bars are +/- 2 standard errors.

The range of symptom severity ratings was restricted for individual symptoms and symptom clusters for retrospective and current ratings at both time points in the control group and for pre-injury symptom ratings in the mTBI group (see Tables 5 and 6). In addition, 59.5% of the control group endorsed “zero” symptoms for at least one rating “set” with 19% ($n = 8$; 5 males) endorsing “zero” symptoms for all four rating points. A further 7.1% endorsed zero symptoms at three time points, 11.9% rated zero symptoms at two time points, and 21.5% rated zero symptoms at one time point. Only 40.5% endorsed at least one symptom at all four ratings points.

However, the mTBI and control groups did not differ in the proportions of each group endorsing zero pre-injury/retrospective symptoms at both time points (mTBI = 16.7%, control = 21.4%), $\chi^2(1) = .309$, $p = .782$, or at one time point (mTBI = 31%, control = 26.2%), $\chi^2(1) = .233$, $p = .81$. Equal proportions of both groups endorsed at least one pre-injury/retrospective symptom at both time points (52.4% of both groups, $\chi^2(2) = .417$, $p = .805$). Low symptom reporting is consistent with previous findings in healthy adolescent athletes (Sady et al., 2014; Lovell et al., 2006).

As expected with recovery, the mTBI group reported a significant decrease in current symptoms (total and for all clusters), Z -values between 4.335 to 5.634, $p = .000$ (see Table 8).

Table 8

Change in retrospective ratings of post-concussion-like symptoms from baseline to one-month post-baseline in adolescents with and without mTBI

		<u>Time of Rating</u>				<u>Wilcoxon Signed-Rank Tests (Z) and Effect Sizes (r)</u>		
		<u>Baseline or <1 week post-mTBI†</u>		<u>1-Month Post-Baseline/mTBI</u>		<u>Z</u>	<u>p</u>	<u>Effect Size</u>
	<u>PCSI Symptoms</u>	<u>Median (IQR)</u>	<u>Range</u>	<u>Median (IQR)</u>	<u>Range</u>			
Control	Total	1 (0-3.25)	0-22	2 (0-4.25)	0-16	-.62	.537	.068
	Physical	0 (0-1)	0-10	0 (0-2)	0-7	-.87	.386	.092
	Cognitive	0 (0-1)	0-7	0 (0-1)	0-7	-1.25	.212	.136
	Emotional	0 (0-1)	0-11	0 (0-1.25)	0-7	-1.89	.059	.206
	Sleep-Related	0 (0-1)	0-4	0 (0-1)	0-4	-.18	.858	.020
mTBI	Total	2 (0-7)	0-32	1.5 (0-3)	0-30	-2.31	.020*	.252
	Physical	0.5 (0-3)	0-13	0 (0-2)	0-12	-2.32	.018*	.253
	Cognitive	0 (0-1)	0-11	0 (0-1)	0-9	-1.43	.177	.156
	Emotional	0 (0-2.25)	0-7	0 (0-1)	0-6	-2.46	.012*	.268
	Sleep-Related	0 (0-2)	0-5	0 (0-1)	0-6	-1.18	.253	.129

Note: †Control group's retrospective ratings at 1-month follow-up are compared with their current ratings at baseline. The mTBI group's retrospective ratings at both time points are compared.

In the final control group, there was no significant increase in "current" PCS ratings from baseline to one-month follow-up for total symptoms ($Z = -1.74$, $p = 0.08$) or

for physical ($Z = -1.67, p = 0.10$), cognitive ($Z = -0.24, p = 0.81$), and sleep-related ($Z = -1.34, p = 0.18$) symptom clusters. Wilcoxon signed-rank tests revealed that the control group reported significantly more current total emotional symptoms at the follow-up session than at baseline, $Z = -2.5, p = .01, r = 0.27$. Healthy participants reported a median of zero total emotional symptoms at both time points. However, there was greater variability in emotional symptoms reported at the one month follow-up because, while 43% of the controls reported at least one emotional symptom at the one month follow-up, only 26% did so at baseline, $\chi^2(1) = 5.43, p = 0.03$. It is possible that this reflects the difference in the administration context at baseline versus one-month. However, there was a similar difference in PCSI administration between these two time points in the mTBI group.

Wilcoxon signed-rank tests indicated significant differences between some of the control group's concurrently rated current and retrospective symptoms (see Table 9). The control group retrospectively reported more median emotional symptoms in the few days prior to baseline than on the day of baseline testing, $Z = -2.65, p = .008, r = 0.29$. There was also a trend toward retrospectively reporting more median total symptoms in the past than on the day of baseline testing ($Z = -1.95, p = 0.051, r = 0.21$).

In contrast, relative to the symptoms they reported on the day of the one-month follow-up, controls retrospectively recalled fewer median sleep-related symptoms ($Z = -2.14, p = 0.03, r = 0.23$) and total symptoms ($Z = -2.14, p = 0.03, r = 0.23$) at baseline. This apparent normative good old days' bias could reflect accurate recall of lower symptoms on the day of baseline testing, which is explored further in the discussion.

Given the differences between current and retrospective symptom ratings in the control group at both time points, relevant comparisons with the mTBI group's retrospective ratings were repeated using both the control group's current and retrospective symptom ratings, and any differences in results were reported.

Table 9

Comparison of concurrent ratings of past and current symptoms at baseline and one month later in the control group

PCS Cluster	Descriptive statistics				Wilcoxon Signed-Rank Tests (Z) and Effect					
	Median (IQR)				Sizes (r)					
	Baseline		One month		Concurrent symptom rating comparisons					
	1. Retrospective	2. Current	3. Retro- spective	4. Current	1 vs. 2			3 vs. 4		
				Z	p	r	Z	p	r	
Total	2 (0-6.25)	1 (0-3.25)	2 (0-4.25)	2 (0-7)	-1.95	.051	0.21	-2.1	.034*	0.23
Phys.	0 (0-1.25)	0 (0-1)	0 (0-2)	0 (0-2)	-1.80	.071	0.20	-1.4	.149	0.16
Cog.	0 (0-0)	0 (0-1)	0 (0-1)	0 (0-1)	-1.49	.136	0.16	-1.7	.085	0.19
Emot.	0 (0-2)	0 (0-1)	0 (0-1.25)	0 (0-2)	-2.65	.008**	0.29	-1.9	.064	0.20
Sleep	0 (0-2)	0 (0-1)	0 (0-1)	0 (0-1.25)	-1.35	.176	0.15	-2.1	.033*	0.23

Note: $n = 42$ (18 females, 24 males). Symptom severity ratings on the PCSI-SR13-18. PCS = Post-concussion symptoms; Phys. = physical; Cog. = cognitive; Emot. = emotional; Sleep = sleep-related.

Demographic Variables

The mTBI group was on average 1.74 years younger than the control group ($t(82) = 5.12, p = .011$, Cohen's $d = 1.12$, large effect size) but they did not differ by gender ($\chi^2(1) = 1.71, p = 0.19$). The influence of age on symptom reporting was examined in each group separately using Spearman ρ correlations. At baseline, older control group participants tended to retrospectively report fewer total physical symptoms ($\rho = -.343, p = .026$) but there were no other significant correlations between age and symptom reports (ρ -values range from -2.30 to $.206$, p -values range from 0.143 - 0.955). There were no significant correlations between symptom reporting (i.e., PCSI total scores) and age in the mTBI group (ρ -values range from -0.134 - $0.204, p > 0.22$). Within the control group,

females reported more retrospective total emotional symptoms than males at baseline, $Z = -2.51$, $p = 0.01$ and at 1-month follow-up, $Z = -2.52$, $p = 0.01$. In the mTBI group, there were no gender differences in any retrospective symptom reports, but females reported more current emotional symptoms than males within one week of injury, $Z = -2.92$, $p = 0.003$. Therefore, the effect of the good old days' bias on reporting of emotional symptoms was examined separately by gender and group. Since there were no other gender differences in symptom reporting within groups, all other analyses were conducted between mTBI and control groups with gender collapsed.

Main Analyses

There was no good old days' bias within one week post-mTBI.

Mann-Whitney U -tests were used to examine whether there was a good old days' bias within one week after mTBI by determining whether the mTBI group reported fewer retrospective, pre-injury PCS ratings than the control group's retrospective PCS ratings at baseline. Overall, there was no good old days' bias found within one week of mTBI. The mTBI group did not retrospectively rate fewer median pre-mTBI symptoms than the control group within one week of injury when compared with the control group's retrospective symptom ratings over a similar recall period, U -values between 764.5 - 864, *ns* (see Table 10). Moreover, when the mTBI group's retrospective PCS ratings were compared with the control group's *current* PCS ratings as is done in other studies, the mTBI group reported *more* median pre-injury physical and emotional symptoms than the control group's physical ($U = 658.5$, $p = 0.023$, $r = 0.25$) and emotional symptoms ($U = 667.5$, $p = 0.025$, $r = 0.25$) on the day of baseline testing.

Table 10

Comparison of mTBI group's retrospective post-concussion symptom ratings with control group's retrospective and current symptom ratings at baseline

Symptom Cluster	Descriptive statistics			Mann-Whitney <i>U</i> -Tests (<i>U</i>) and Effect Sizes (<i>r</i>)					
	Median (IQR)			1 vs. 3		2 vs. 3			
	Control		mTBI						
	1. Retro- spective	2. Current	3. Retro- spective	<i>U</i>	<i>p</i>	<i>r</i>	<i>U</i>	<i>p</i>	<i>r</i>
Total	2 (0-6.25)	1 (0-3.25)	2 (0-7)	844.5	.736	.037	706.0	.107	0.18
Physical	0 (0-1.25)	0 (0-1)	0.5 (0-3)	764.5	.254	.127	658.5	.023*	0.25
Cognitive	0 (0-0)	0 (0-1)	0 (0-1)	800	.332	.105	880.0	.985	0.002
Emotional	0 (0-2)	0 (0-1)	0 (0-2)	864	.862	.019	667.5	.025*	0.25
Sleep- Related	0 (0-2)	0 (0-1)	0 (0-2)	861	.835	.023	791.0	.176	0.10

Note: * $p < .05$. mTBI, $n = 42$; Control, $n = 42$. Symptom clusters on the PCSI-SR13-18.

There was no effect of gender on the good old days' bias at one week post-mTBI.

To examine whether there is an effect of gender on the good old days' bias at one-week post-mTBI, Kruskal-Wallis tests were used to compare retrospective PCS ratings of males and females in the control or mTBI group. The independent variable was formed by recoding participants into one of four groups based on gender and group (control, mTBI). No significant differences were found in retrospective ratings of males and females in each group for total symptoms ($\chi^2(3) = 2.14$, $p = 0.54$), physical symptoms ($\chi^2(3) = 1.69$, $p = 0.64$), cognitive symptoms ($\chi^2(3) = 1.82$, $p = 0.61$), or sleep-related symptoms ($\chi^2(3) = 0.89$, $p = 0.82$) at one week post-mTBI. There was a significant difference among groups in retrospective emotional symptoms reported, ($\chi^2(3) = 8.32$, $p = 0.04$). Dunn's pairwise tests indicated that male control participants reported

significantly fewer retrospective emotional symptoms (Mdn = 0, IQR = 1) than female controls (Mdn = 1, IQR = 5, $p = 0.011$) or female mTBI participants (Mdn = 1.5, IQR = 3, $p = 0.046$), though these differences were not significant with the Bonferroni correction for multiple comparisons applied.

There was mixed evidence for a good old days' bias by one month post-mTBI.

Mann-Whitney U -tests were used to examine whether there was a good old days' bias by one month after mTBI by determining whether the mTBI group reported fewer retrospective, pre-injury PCS ratings than either the control group's retrospective or current PCS ratings at the one-month follow-up. Overall, there was no good old days' bias by one month post-mTBI when based on comparing the mTBI and control groups' PCS ratings. The mTBI group did not retrospectively rate fewer median pre-mTBI symptoms at one-month post-injury than either the control group's retrospective or current symptom ratings, U -values between 764.0 – 874.5, ns , all effect sizes small, r -values < 0.13 (see Table 11).

Table 11

Comparison of mTBI group's retrospective post-concussion symptom ratings with control group's retrospective and current symptom ratings at one month follow-up

Symptom Cluster	Descriptive statistics			Mann-Whitney U -Tests (U) and Effect Sizes (r)					
	Control		mTBI	1 vs. 3			2 vs. 3		
	1. Retro-spective	2. Current	3. Retro-spective	U	p	r	U	p	r
Total	2 (4)	2 (7)	1.5 (3)	851.5	.782	.03	828.0	.625	.05
Physical	0 (2)	0 (2)	0 (2)	790.0	.356	.10	854.0	.783	.03
Cognitive	0 (1)	0 (1)	0 (1)	832.5	.593	.06	800.5	.378	.097
Emotional	0 (1)	0 (2)	0 (1)	874.5	.940	.10	780.0	.299	.11
Sleep-Related	0 (1)	0 (1)	0 (1)	866.0	.865	.02	764.0	.228	.13

Note: mTBI, $n = 42$; Control, $n = 42$. Symptom ratings at one-month visit on the PCSI-SR13-18.

There was no effect of gender on the good old days' bias at one-month post-mTBI.

To examine whether there was an effect of gender on the good old days' bias at one-month post-mTBI, Kruskal-Wallis tests were used to compare one-month retrospective PCS ratings of males and females in the control and mTBI groups. The independent variable was formed by recoding participants into one of four groups based on gender and group (control, mTBI). No significant differences were found in retrospective ratings of males and females in each group for total symptoms ($\chi^2(3) = 1.13, p = 0.77$), physical symptoms ($\chi^2(3) = 1.69, p = 0.64$), emotional symptoms ($\chi^2(3) = 5.06, p = 0.17$), cognitive symptoms ($\chi^2(3) = 0.95, p = 0.81$), or sleep-related symptoms ($\chi^2(3) = 1.7, p = 0.63$) at one-month post-mTBI.

There was some evidence that the good old days' bias increases across the first month post-mTBI.

Wilcoxon signed-rank tests were used to examine whether fewer pre-injury PCS were reported at 1-month post-mTBI compared to adolescents' own pre-injury PCS ratings within one week of mTBI. The same analyses were repeated with the control group to determine whether there is a general tendency to retrospectively rate fewer past PCS across one month. In the mTBI group, adolescents did not report fewer cognitive or sleep-related pre-injury PCS at one-month post-injury compared to their own ratings at 1-week post-injury, p -values > 0.15 (see Table 8).

However, fitting with a good old days' bias, by one-month post-mTBI, the mTBI group recalled fewer pre-injury total, physical, and emotional pre-mTBI symptoms than they had reported within 1-week of injury, Z -values between -2.31 to -2.46 , p -values < 0.02 , small effect sizes (see Table 8 for statistics). Specifically, from one-week to one-month post-injury, the median severity of total pre-mTBI symptoms fell from 2 (IQR = 0-7) to 1.5 (IQR = 0-3). The median pre-injury total physical symptom severity fell from 0.5 (IQR = 0-3) to 0 (IQR = 0-2), and the median pre-injury total emotional symptom severity dropped from 0 (IQR = 0-2.25) to 0 (IQR = 0-1). Although the median symptom severity was not dramatically lower across this one-month interval, the smaller interquartile ranges in symptom ratings at one-month post-injury suggest that adolescents were much less likely to report frequent and/or even moderate severity pre-injury

symptoms by one-month post-mTBI. This is evidence of the good old days' bias specific to the mTBI group because the control group did not retrospectively report fewer total, physical, cognitive, emotional, or sleep-related PCS at one-month compared to their baseline ratings, Z -values between -0.18 to -1.89, *ns*, effect sizes very small (r -values from 0.02 - 0.21). Note that the control group's median retrospective ratings at one-month after baseline did not significantly differ from their current or retrospective symptom ratings at baseline, Z -values between -0.39 to -1.56, *ns*, effect sizes very small (r -values from 0.04 - 0.17) .

The good old days' bias does not work in a “never-ever” fashion after mTBI.

Separate Pearson chi-square tests were used to determine whether a larger proportion of the mTBI group reported “never” having pre-injury PCS than the control group (i.e., zero versus at least one symptom reported) at baseline and at one-month follow-up (see Figures 6 and 7). Within one week of mTBI, 33.3% of the mTBI group reported “no” pre-injury symptoms compared with 26.2% of healthy adolescents recalling “no” symptoms from 3-4 days prior. A Pearson chi-square test revealed that adolescents with mTBI were as likely as healthy controls to report having zero or some pre-injury/past symptoms, $\chi^2(1) = .513$, exact $p = .63$ (see Figure 6). By one month post-mTBI, 31% of the mTBI group recalled zero pre-injury symptoms compared with 42.9% of healthy controls that recalled zero symptoms from one month prior. Again, a Pearson exact chi-square test revealed that adolescents at one month post-mTBI were as likely as healthy controls to report having zero or some pre-injury/past symptoms, $\chi^2(1) = 1.28$, exact $p = .37$ (see Figure 7).

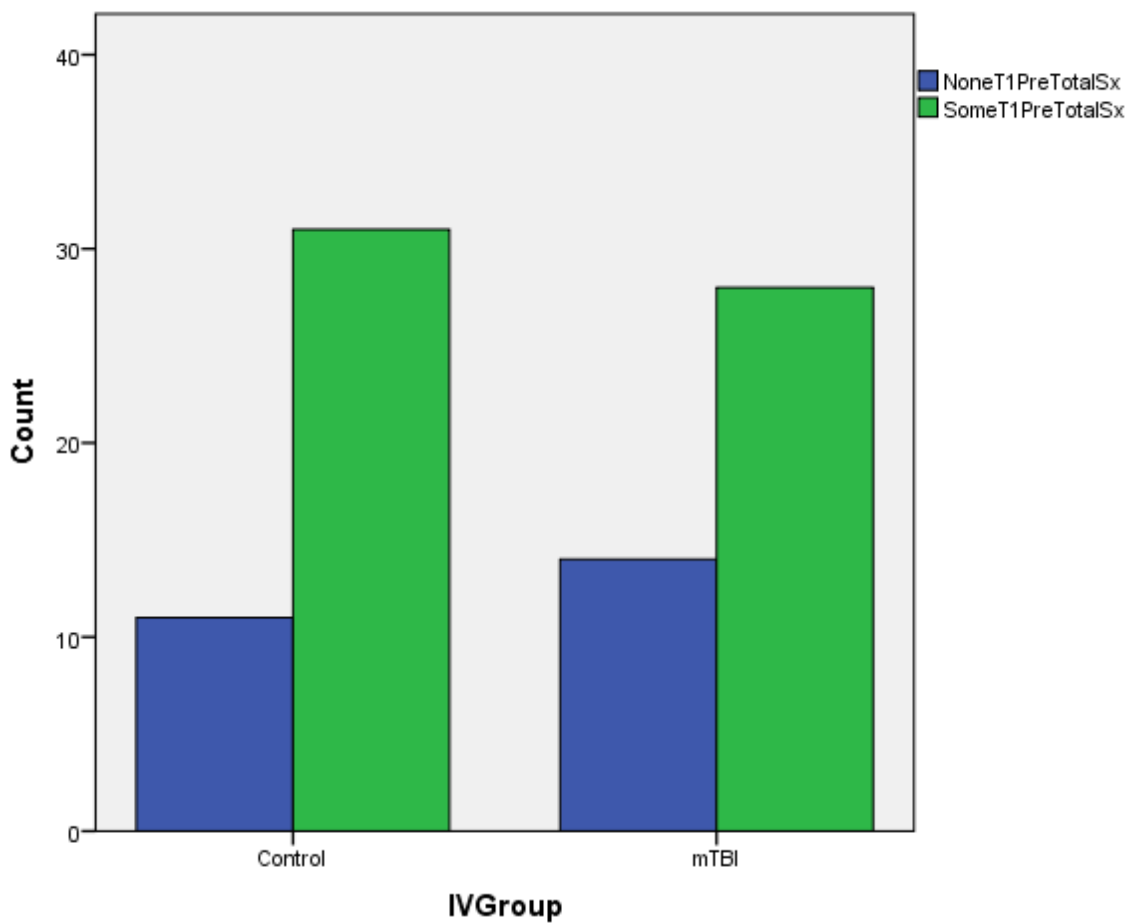


Figure 6. Frequency of control and mTBI group reporting “none” or “some” total retrospective symptoms at baseline/within one week of mTBI.

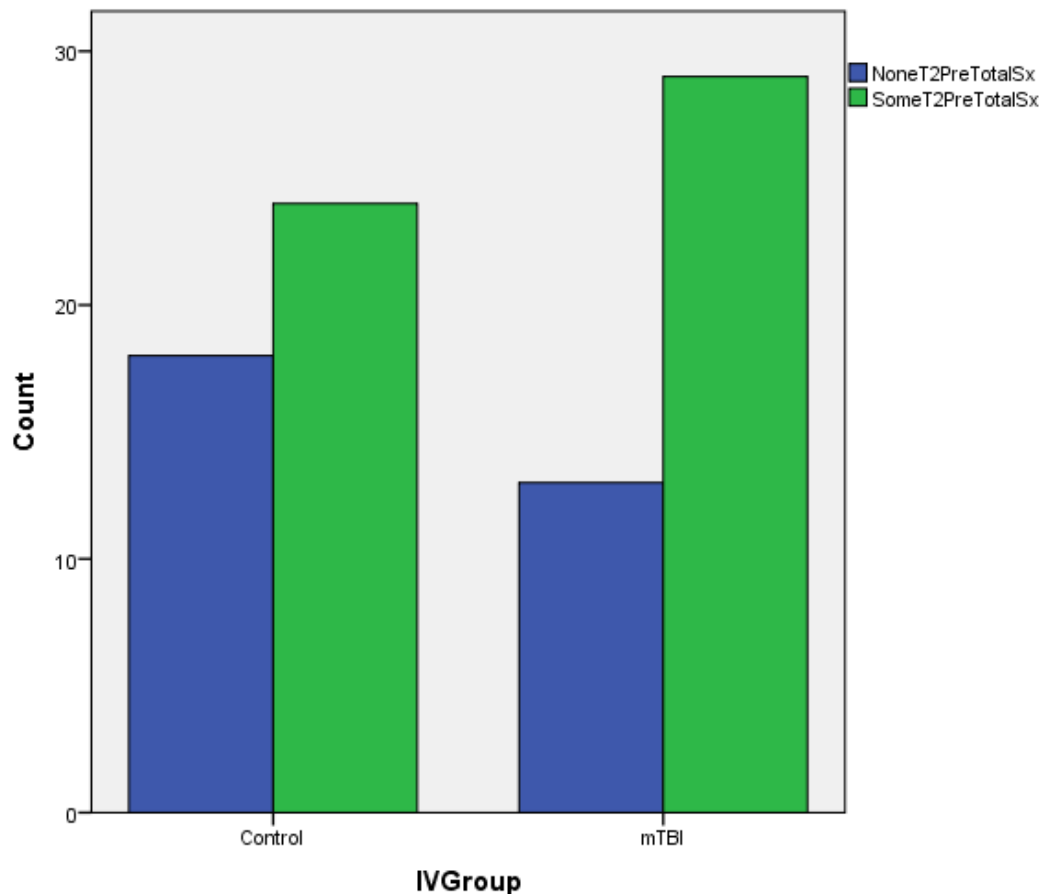


Figure 7. Frequency of control and mTBI group reporting “none” or “some” total retrospective symptoms at one month after baseline or mTBI.

See Figures 8 and 9 for the proportion of each group with each symptom reporting pattern between baseline and one-month later (i.e., none to none; none to some; some to none; some to some). McNemar’s exact tests were used to determine whether the mTBI group was more likely to change from reporting some pre-injury PCS within one week of injury to reporting “no” pre-injury PCS by one month post-injury. Most of the mTBI group ($n = 22$; 52.4%) reported some pre-injury PCS at both time points after injury. McNemar’s exact tests indicated that there was no difference between the proportion of the mTBI group that changed from reporting “some” pre-injury PCS within a week of mTBI to no pre-injury PCS at one-month mTBI ($n = 6$; 14.3%) compared with those who initially reported zero pre-injury PCS and then reported some pre-injury PCS one month later ($n = 7$; 16.7%), $\chi^2(1) = 0$, $p = 1.0$.

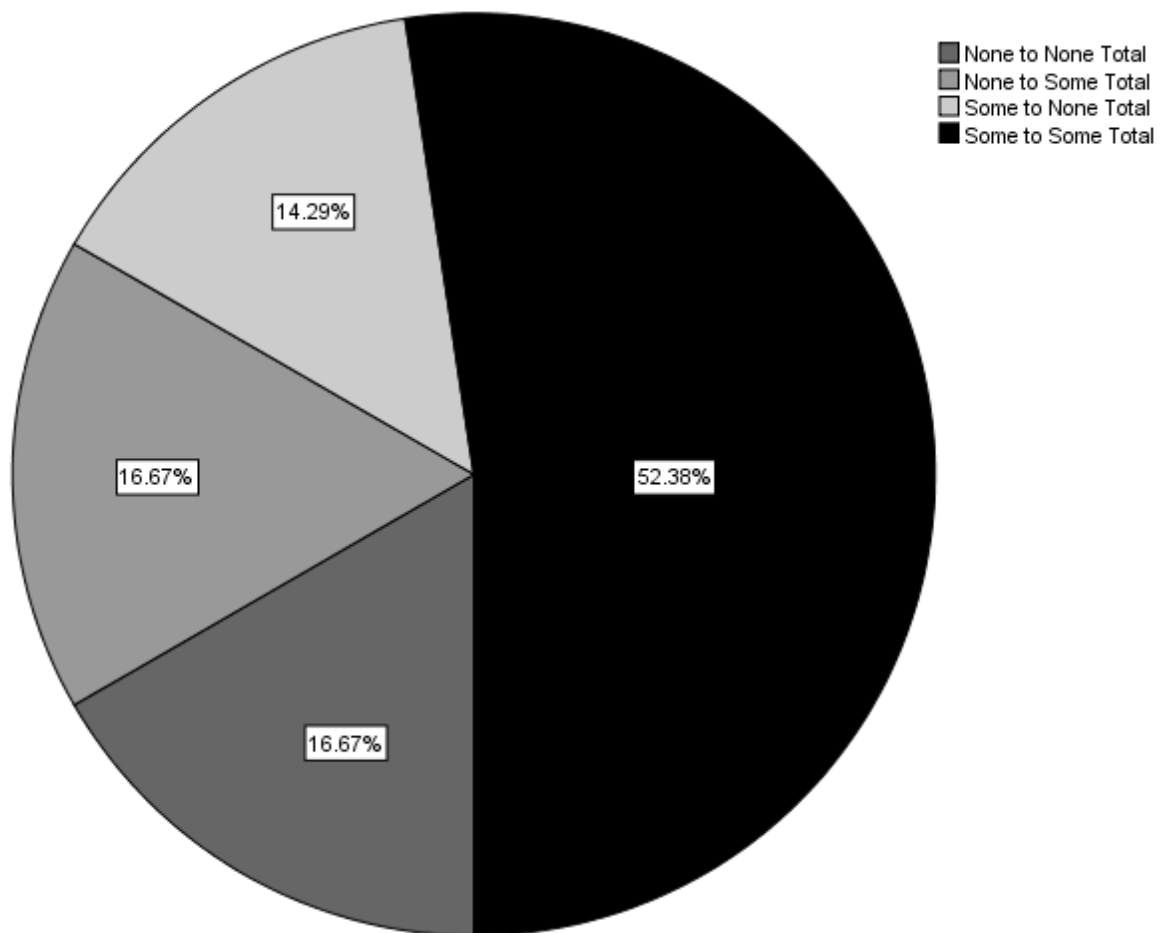


Figure 8. Proportion of mTBI group with each of four total symptom reporting patterns from baseline to one month post-baseline.

Note: Classification into the four symptom reporting patterns is based on whether an individual retrospectively reported either no pre-injury symptoms (none) or at least one pre-injury symptom (some) within 1 week of mTBI and whether they retrospectively recalled some or none of these pre-injury symptoms one-month later.

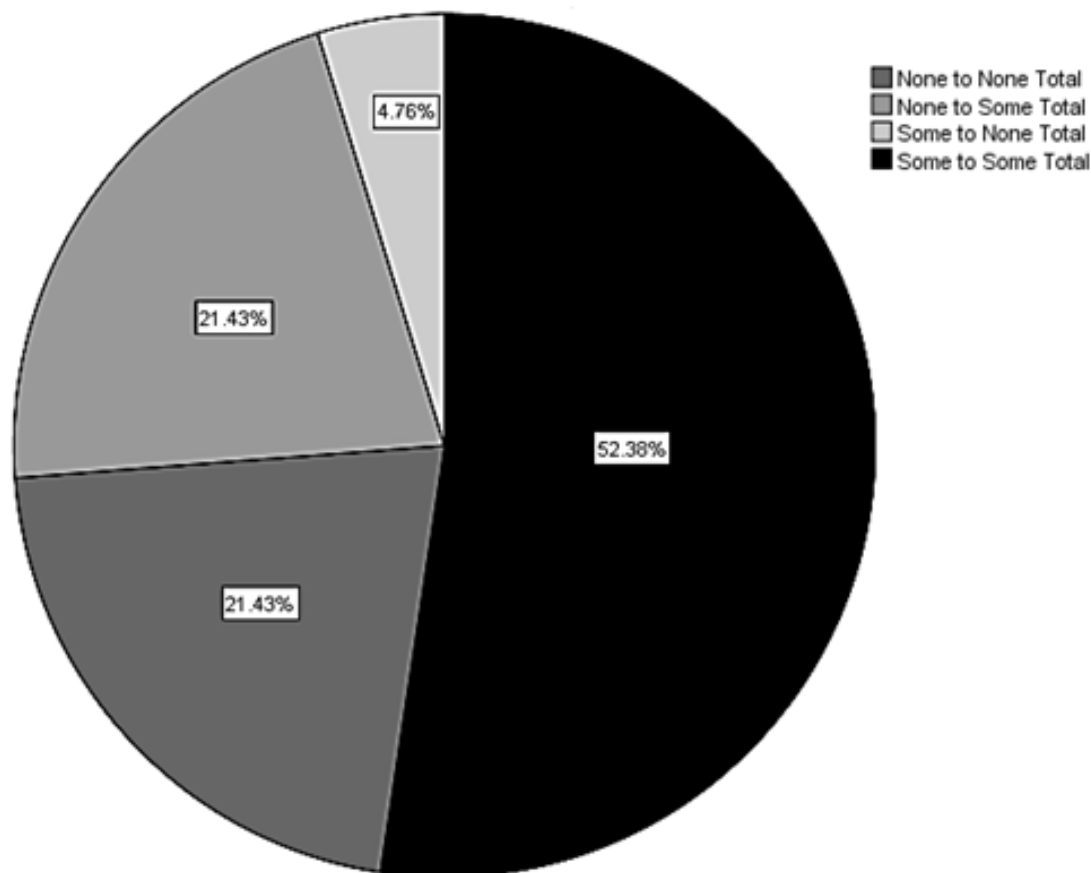


Figure 9. Proportion of control group with each of four total symptom reporting patterns from baseline to one-month post-baseline.

Note: Classification into the four symptom reporting patterns is based on whether an individual reported either no symptoms (none) or at least one symptom (some) at baseline and whether they retrospectively recalled some or none of these symptoms one-month later. In the control group, symptoms reported on the day of baseline testing are used rather than retrospective symptom ratings.

McNemar's exact tests also found no difference between the proportion of healthy controls who changed from reporting "some" to "none" past symptoms at baseline ($n = 2$; 4.8%) compared with those who reported "none" and then "some" symptoms one month later ($n = 9$; 21.4%), $\chi^2(1) = 3.27$, $p = .065$.

Finally, only participants in the mTBI group who reported any pre-injury symptoms at baseline ($n = 28$; 67 % of mTBI group) and in the control group who

reported any baseline symptoms ($n = 21$; 50% of control group) were examined. These groups represent those with symptoms which the good old days' bias could affect (see Figure 10).

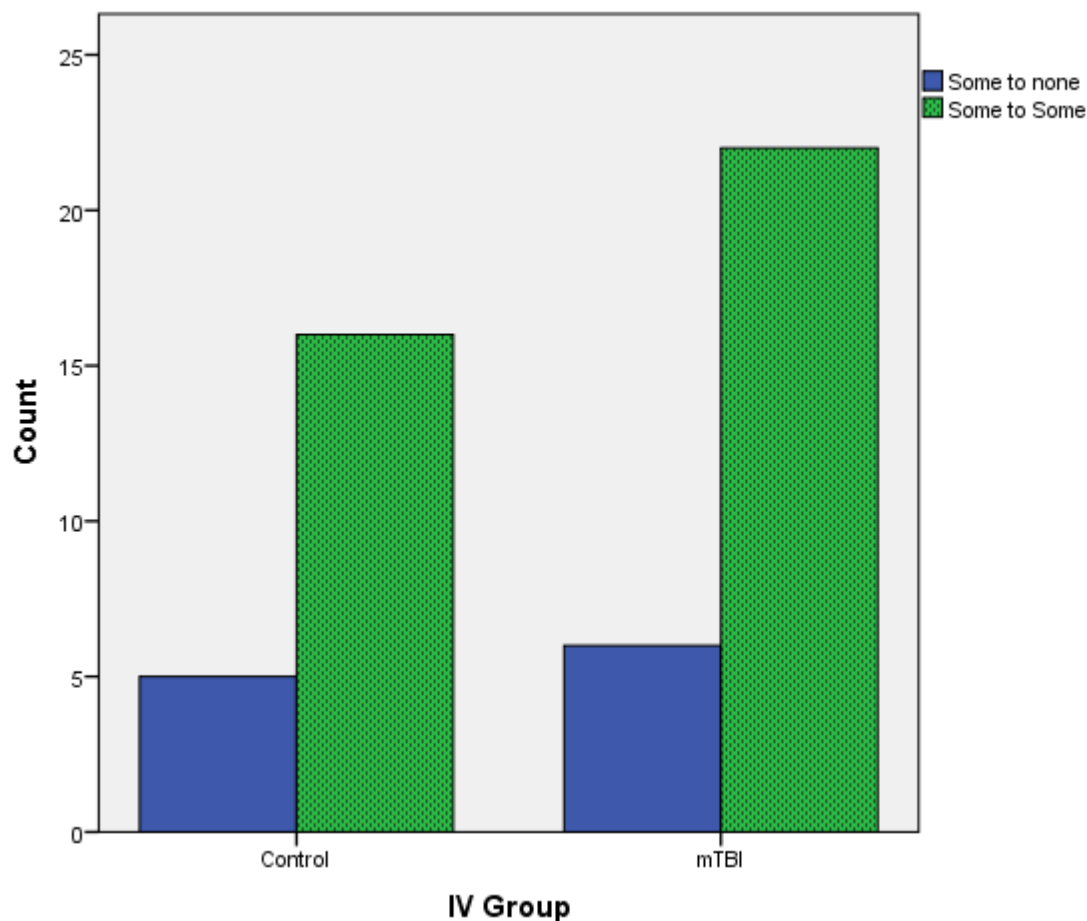


Figure 10. Frequency of changing from reporting “some” pre-mTBI or current symptoms to retrospectively reporting “some” or “none” pre-injury/past symptoms one month later. Note: Control group: $n = 21$; mTBI group: $n = 28$. “Some” symptoms means reporting at least one symptom, with a severity of one or greater, on the PCSI-SR13-18 (Gioia et al., 2012).

A Pearson exact chi-square was used to examine whether, after mTBI, the good old days' bias causes pre-injury symptoms to be completely forgotten or if pre-injury symptom severity is underestimated. A Pearson exact chi-square revealed that, of those initially reporting some pre-injury/past symptoms, the proportion of the mTBI group who later reported “no” pre-injury symptoms ($n = 6$; 21.4%) did not differ significantly from

the proportion of the control group who later reported “no” past symptoms ($n = 5$; 23.8%), $\chi^2(1) = 0.04$, $p = 1.0$. That is, relative to the control group, the mTBI group was not more likely to recall no pre-injury/past symptoms one-month after initially reporting some pre-injury/past symptoms, suggesting that the good old days’ bias does not work in a “never-ever” fashion.

These analyses were repeated separately for each symptom cluster, with results consistent with those examining group differences in response patterns of total symptoms. Fisher’s exact tests determined that, in those initially reporting some pre-injury/past symptoms, there was no difference in the proportion of the mTBI and control groups who reported either none or some past physical symptoms, $\chi^2(1) = 0.08$, $p = 1.0$, cognitive symptoms, $\chi^2(1) = 0.02$, $p = 1.0$, emotional symptoms, $\chi^2(1) = 1.15$, $p = 0.43$, or sleep-related symptoms, $\chi^2(1) = 1.11$, $p = 0.46$.

The good old days’ bias does not affect recovery tracking using symptom ratings by one-month post-mTBI.

Consistent with ongoing recovery in the mTBI group as a whole, Wilcoxon signed rank tests determined that there was a significant difference between the rank-order of the mTBI group’s total symptoms at one month post-injury (Mdn = 12.88, IQR = 2.72) and their pre-injury symptoms rated concurrently (Mdn = 3.76, IQR = 1.02, $Z = -4.374$, $p = .000$, $r = 0.68$) and rated within one week of the injury (Mdn = 5.81, IQR = 1.33), $Z = -2.617$, $p = .009$, $r = 0.40$. The smaller effect size when earlier rather than later pre-injury ratings were used to determine recovery is consistent with a detrimental effect of the good old days’ bias on tracking post-mTBI recovery.

McNemar’s exact tests were used to determine whether a greater proportion of the mTBI group was classified as “recovered” at one-month post-mTBI by using pre-injury PCS ratings from within one week of mTBI rather than using pre-injury PCS ratings made concurrently with post-mTBI ratings at one-month post-injury (see Figure 11).

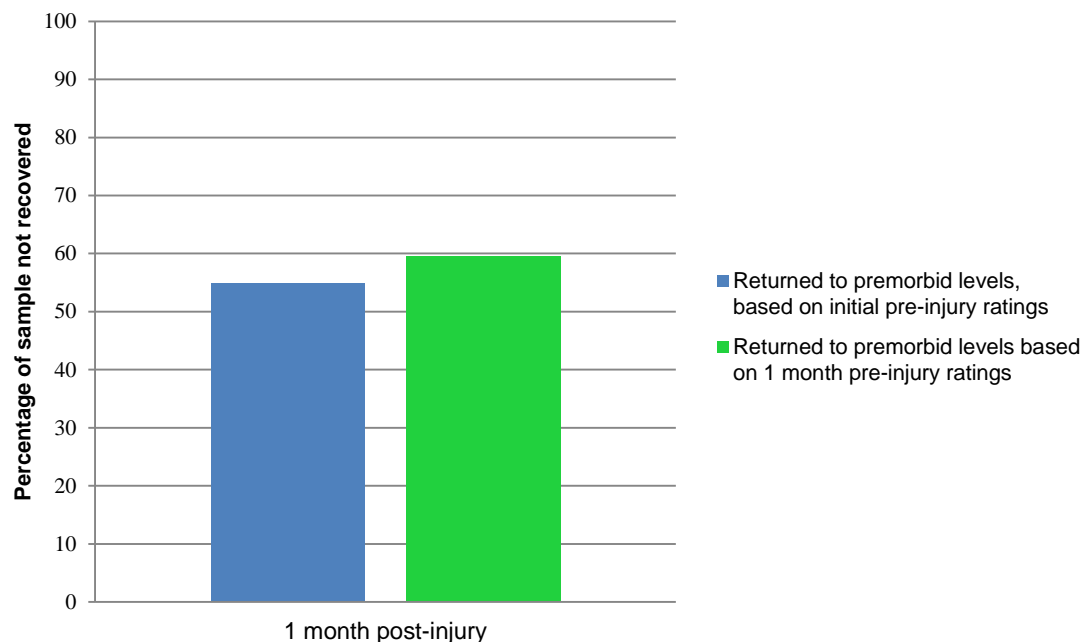


Figure 11. Differences in proportion of mTBI group classified as "recovered" or "not recovered" at one month post-mTBI when comparing total symptoms to pre-injury symptoms rated within one week or at one month post-injury.

“Recovered” was defined as having equal or fewer current total symptoms at 1-month post-injury than retrospective pre-injury symptoms rated, respectively, at one-month post-injury, or within one week of injury. Of the 42 mTBI participants, 21 (57.1%) were classified as recovered and 15 (35.7%) were classified as “not recovered” regardless of which pre-injury total symptom ratings were used. An exact McNemar’s test determined that there was no significant difference in the proportion of the mTBI group classified as “not recovered” at 1-month post-injury whether their current symptoms were compared with pre-injury symptoms rated concurrently ($n = 2$, 4.8%) or within one week of injury ($n = 4$, 9.5%), ($X^2(1) = 0.17$, $p = .69$). The same pattern of results was found when exact McNemar’s tests were repeated for each symptom cluster, including physical ($X^2(1) = 1.25$, $p = .73$), cognitive ($X^2(1) = 0.17$, $p = .68$), emotional ($X^2(1) = 0$, $p = 1.0$), and sleep-related symptoms ($X^2(1) = 0$, $p = 1.0$). This suggests that the good old days’ bias did not reduce the value of pre-injury symptoms retrospectively recalled to track mTBI recovery by one month post-injury.

These analyses were repeated in the control group to determine if there is a general tendency to appear worse when comparing one's current symptoms with past symptoms recalled at the same time. Exact McNemar's test found no difference in the proportion of the control group who appeared worse (~not recovered) at one-month follow-up relative to total retrospective symptoms recalled at the same time ($n = 7$, 16.7%) rather than to symptoms rated at baseline ($n = 4$; 9.5%, $X^2(1) = .36$, $p = .59$). The same pattern held for all cluster symptoms, including physical ($X^2(1) = 2.25$, $p = .125$), cognitive ($X^2(1) = .167$, $p = .69$), emotional ($X^2(1) = .57$, $p = .45$), and sleep-related ($X^2(1) = .57$, $p = .45$).

Discussion

The purpose of this study was to investigate whether adolescents' pre-injury symptom ratings are affected by a good old days' bias in the first month after a concussion. Overall, the study found some evidence that a good old days' bias leads adolescents to underestimate their pre-injury post-concussion-like symptoms by the first month post-injury. However, the findings were mixed. As predicted, and consistent with Brooks et al.'s (2014) findings, the good old days' bias was found when comparing concussed adolescents' own pre-injury PCS ratings over time. Specifically, at one month post-mTBI, the mTBI group retrospectively underestimated their pre-injury total, physical and emotional symptoms compared to their own initial pre-injury PCS ratings made within one week of injury. This bias was only found in the concussed group, in support of the good old days' bias being caused by negative expectations after an aversive event rather than being a general memory bias (Gunstad & Suhr, 2001, 2002; Hilsabeck, Gouvier, & Bolter, 1998). Contrary to predictions and previous studies, the current study did not find a good old days' bias using cross-sectional analyses typically used by many studies (e.g., Mittenberg, DiGiulio, Perrin, & Bass, 1992; Ferguson, Mittenberg, Barone, & Schneider, 1999; Hilsabeck, 1998; Gunstad & Suhr, 2001, 2004; Davis, 2002; Iverson et al., 2010; Lange, Iverson, & Rose, 2010; Yang, Yuen, Huang, Hsiao, Tsai, & Lin, 2014). Within one week and at one month post-concussion, the mTBI group's retrospective pre-injury ratings were not lower than either the current or retrospective symptom ratings of healthy controls over similar time spans. The reasons for these mixed findings will be discussed in terms of the nature of the mTBI population, particularities of the control group, and the post-injury timeframe under study.

The concussion group did not rate their pre-injury selves as "supranormal" compared to the healthy controls, as has previously been found in undergraduate athletes six months after concussion (Ferguson et al., 1999), non-athlete undergraduates with chronic headaches or two years post-mTBI (Gunstad & Suhr, 2004), in adults one week after mTBI or trauma (Davis, 2002), and in litigating adults an average of two months after mTBI (Lange, Iverson, & Rose, 2010). Importantly, most of the current study's mTBI group were young, healthy athletes who had incurred sports-related concussions. Therefore, the study results are consistent with findings that head-injured athletes do not

report lower pre-injury symptoms relative to healthy athletes or non-athlete control groups' current symptoms (Gunstad & Suhr, 2001, 2004). On the other hand, the study contrasts with Ferguson et al. (1999) who found that head-injured athletes recall fewer pre-injury symptoms (largely memory-related) relative to current uninjured athlete controls' symptoms. This difference may reflect many factors. Firstly, most other studies have been conducted during the chronic phase of recovery, typically six months to up to two and a half years post-concussion. Since the current study examined the good old days' bias during the acute and post-acute period, it is difficult to compare the results directly with other studies that examined expectation-based biases during the chronic period after concussion. For example, in many previous studies, even if concussed athletes did not report greater current symptoms than controls, they would underestimate pre-injury symptoms relative to their own current symptoms. In the current study, elevated symptoms during the first month post-concussion is typical of recovery (McCrea, 2008; Alves, 1992), making it much more difficult to parse out the contribution of any expectation-based biases on symptom reporting. Also, by asking participants to recall symptoms over relatively short periods, the current study may have decreased the effect of the good old days' bias because individuals are more likely to recall precise details of their lives over shorter periods of time (Croyle & Loftus, 1993; Burt, Kemp, Grady, & Conway, 2000). In support of this, there was great variability in symptom ratings among the current study's control group, including some significant differences between past and current symptom ratings which is not typically seen in other studies.

Secondly, most other studies of the good old days' bias and "expectation as etiology" measured a much greater number of symptoms, ranging from 30 to 97 symptoms (Ferguson et al., 1999; Gunstad & Suhr, 2001, 2002; Mittenberg et al., 1992). Not all of these symptoms were necessarily typical of concussion and these measures included multiple items about symptoms that are highly common in the general population, such as memory problems (McCaffrey, 2006). In fact, control groups endorsed higher rates of symptoms in the above studies compared with studies like the current one using more narrow post-concussion symptom rating scales. Some studies even used parametric statistical analyses, suggesting that they did not suffer from high rates of zero symptom endorsement (Gunstad & Suhr, 2001, 2002; Ferguson et al., 1999).

It is easier to detect changes and differences between mTBI and control groups' endorsement of symptoms when the control group endorses symptoms. Indeed, the low rate of symptom endorsement in the current study made it difficult to examine normative changes and biases in symptom reporting. This could be related to the healthiness of the athlete control group. There are a great number of physical symptoms on the Post-Concussion Symptom Inventory (Gioia et al., 2012) that are not endorsed as highly by healthy adolescents as some symptoms used in other studies. For example, the base rate of endorsing most of the physical symptoms in healthy adolescents is especially low (Sady et al., 2014).

On the other hand, the current study did find a good old days' bias affecting retrospective symptom reporting after mTBI, consistent with the previous literature in a pediatric sample that also used longitudinal methods. Brooks et al. (2014) found a good old days' bias by three months post-injury compared with the mTBI group's own pre-injury symptom ratings made at one month post-injury. Those authors wondered if a good old days' bias was actually present prior to one month, which the current study suggests is so. Interestingly, the good old days' bias was found for total, physical, and emotional symptoms but not for cognitive or sleep-related symptoms in the current study. Perhaps it is not surprising that recall biases could differentially affect symptom clusters. For example, in children with moderate to severe traumatic brain injuries, different trajectories of change have been found over time for somatic and cognitive versus emotional and behavioural symptom clusters (Yeates et al., 2001). Relative to an orthopedically-injured group, that TBI group showed a decline over time of cognitive/somatic symptoms with an increase in emotional and behavioural symptoms (Yeates et al., 2001). Furthermore, these two supraordinate clusters have differential associations with family functioning and children's pre-injury behaviours (Gasquoin, 1997; Yeates & Taylor, 2005), lending further support to the importance of examining different symptom types separately (Taylor et al., 2010). It could be that retrospective recall biases do not affect each type of symptom equally. For example, emotional symptoms might be recalled with less fidelity than other symptoms given that recalled emotions seem to be recreated at the time of memory retrieval, dependent on one's emotional state and goals at the time of retrieval (Levine & Pizarro, 2004; Holland &

Kensinger, 2010) and may be inaccurate as a result (Christianson & Safer, 1996). In contrast, currently having sleeping troubles does not necessarily mean that one will recall having sleeping problems in the past if these are not chronic issues. Alternatively, since fatigue and sleep-related problems are common even in young, healthy people (e.g., Sady et al., 2014; McCaffrey, 2006), perhaps these symptoms are less susceptible to the good old days' bias, as found in the current study.

Although negative expectations about concussion are widespread, there was no good old days' bias found within one week post-mTBI, as tentatively predicted. It is possible that the concussed group actually underestimated their own pre-injury symptoms even within one week after injury. However, to examine this, the control group would need to be well matched to allow for sensitive detection of retrospectively-underestimated symptoms in an mTBI group that was very healthy prior to their injuries. Alternatively, symptom ratings made prior to injury could be compared with post-injury retrospective PCS ratings. Such a study would be possible given that baseline testing is increasingly common in sports, or at least has been recommended by consensus (McCrary, et al., 2016) or agreement statements (Guskiewicz et al., 2006; Moser et al., 2007).

Ever/ever, not never/ever

If a good old days' bias were found immediately after concussion, the current study suggests that it would worsen across one month. Although there was not a dramatic drop in the median pre-injury symptom severity reported at one-month post-mTBI, the mTBI group was less likely to report frequent or moderate severity pre-injury symptoms by one month post-mTBI. Nevertheless, the current study findings suggest that the good old days' bias does not work in a never/ever way, at least not in a way that is specific to mTBI. The mTBI group was as likely as the control group to report some or no past symptoms after having reported some pre-injury/past symptoms initially. This suggests that, although the severity of pre-injury PCS may be underestimated after an mTBI, symptoms do not seem to be entirely forgotten more than is accounted for by normative memory processes. It may be that healthy individuals are more likely to remember experiencing aversive symptoms if they are infrequent. Although this question has not

been examined in an mTBI sample before, this finding would be suggested by studies of retrospective behaviour recall which have found that adults tend to overreport low frequency occurrences and underreport high frequency events in everyday life (e.g., Thompson & Mingay, 1991) or men differentially recalling sexual behaviours that vary by frequency (Downey, Ryan, Roffman, & Kulich, 1995).

On the other hand, the finding that the good old days' bias does not work in a never/ever way contrasts with Sullivan and Edmed's (2012) finding that healthy adults report a significantly smaller number of symptoms in the past relative to their present ratings. The authors argued that there is a normative good old days' bias and their findings suggest that it does work in a never/ever way. In other words, healthy adults may not endorse past symptoms rather than simply underestimating past symptoms' severity. Interestingly, there were far fewer individuals in the current study who retrospectively *overestimated* the severity or presence of past/pre-injury symptoms in either group. This suggests that normative positive memory biases affect retrospective symptom ratings in healthy adolescents. Otherwise, one would expect as many individuals to overestimate past symptoms as to underestimate them. The current study could not examine this directly given the high proportion of those reporting zero symptoms and the relatively small sample and cell sizes.

Finally, a percentage of both groups initially reported having at least one symptom that they did not report in retrospect one month later. In fact, when examining endorsement rates of pre-injury symptoms using simple counts, the current study's mTBI sample retrospectively endorsed a smaller percentage of 18 out of 20 pre-injury symptoms at one month post-injury compared to pre-injury symptoms that they endorsed within one week of injury. Unfortunately, small cell sizes again did not allow for testing whether these differences were statistically significant. Still, given these equivocal results, there continues to be a need to understand whether pre-injury symptoms are entirely forgotten after mTBI or just underestimated.

Healthy adolescents and retrospective recall biases

When recalling symptoms from a few days prior at baseline, the control group recalled more past emotional symptoms, with a trend for recalling more total past

symptoms. This significant difference – regardless of direction – has not been reported in other studies. However, the current study’s design likely contributed to this different finding. The control group recalled symptoms from just three to four days prior, making it more likely that they could access verbatim memories of actual differences in emotional state and other symptoms (Croyle & Loftus, 1993). Differences in retrospective and current symptom ratings could therefore reflect accurate recall of actual differences in symptom experience over this short period. The fact that PCS are normatively variable, with only moderate test-retest reliability (Sady et al., 2014) suggests that differences in recall of symptoms over short periods can be expected.

Interestingly, there appeared to be a good old days’ bias in the healthy controls at one month post-baseline. Relative to their symptoms reported at the one month follow-up, they retrospectively recalled fewer past total and sleep-related symptoms – an apparent good old days’ bias. However, they did not actually underestimate their past symptoms. Instead, their recall of baseline symptoms was accurate. They had actually reported fewer baseline symptoms and had experienced an actual increase in emotional symptoms over one month. Therefore, in generally healthy individuals who are experiencing greater symptoms without mTBI, a normative good old days’ bias may lead to retrospective recall of “typical” symptoms. However, it does not seem fair to call this a bias, since symptoms were accurately recalled. As well, one month after baseline, the healthy controls did not recall having significantly higher emotional symptoms in the days prior to baseline testing. In this respect, recall of symptoms over a longer delay may reflect judgment of typical symptoms or functioning rather than precise verbatim recall of fluctuations in symptoms in the absence of an intervening event such as a concussion. This has implications for interpreting “underestimated” pre-injury symptom ratings after concussion in individuals who may have variable post-concussion-like symptoms prior to concussion, such as those with comorbid conditions. If they were experiencing symptoms as a result of these other conditions prior to their concussion but then these symptoms improve at some time after the concussion, there is the potential for the apparent “underestimation” of pre-injury symptoms to be interpreted as a good old days’ bias. For example one participant who was excluded from the current study analyses seemed to have experienced a migraine in the day prior to her concussion. Her pre-injury symptoms

at baseline were very high. One month later, these pre-injury symptoms were still elevated compared to other controls, but did show a decrease compared to very high pre-injury PCS ratings at baseline. This suggests that clinicians should attempt to measure typical pre-injury symptoms rather than symptoms from a very specific period to capture an individual's normal symptom variability rather than risking measuring a particularly high- or low-symptom day.

Very few studies have found differences between current and retrospective symptom reports in healthy controls. However, this is likely due to methodological factors since healthy controls' symptom recall is not typically the focus of study. In examining whether there is a normative good old days' bias, Sullivan and Edmed (2012) found that healthy young adults retrospectively recall fewer physical symptoms when their retrospective ratings were made separately from - one week before - current symptom ratings. However, they did not examine how retrospective ratings may change relative to concurrently-experienced symptoms. Given the robust literature on emotion's effect on recall (e.g., Kensinger, 2009), this is an area worth further study. For example, individuals presenting with prolonged concussion recovery may be distressed. It would be important to understand how their mood, anxiety, and distress may influence reporting of their current and pre-injury symptoms.

Constructive memory theories and the good old days' bias

This study adds support for situating the good old days' bias within constructive memory theories (Ross, 1989; Conway & Ross, 1984; Hirt, 1990; Ferguson et al., 1999). That is, expectations for change after concussion guide retrospective recall of a healthier pre-concussion self, while healthy individuals' expectations for consistency lead to recall of past symptoms that resemble current symptoms. On the other hand, the consistency "bias" is not so powerful as to override recall of actual variations in symptoms over relatively brief periods, as healthy adolescents in this study recalled greater emotional symptoms three to four days prior to baseline. This has not been found in previous studies, but could reflect that verbatim recall would be more likely across a few days, increasing the chances of accurate recall of actual symptoms and emotional states. In fact, it may be that the ability to recall precise details in functioning prior to concussion is also

protective against biases caused by expectations for change, including the good old days' bias. This is suggested by the current study's finding of no good old days' bias within the first week after concussion.

Gender

Healthy control males reported fewer retrospective emotional symptoms than females with and without mTBI. Males in the mTBI group also reported fewer post-injury emotional symptoms than females within one week of mTBI. Frommer et al., (2011) also found that female adolescents reported more severe post-concussion symptoms than males, though for physical and cognitive symptoms more than for emotional symptoms. They suggested that gender differences in post-concussion symptoms may be related to females' unique response to concussion. However, in the current study, gender differences in symptom reporting were found in both the mTBI and control groups and were limited to emotional symptoms. Therefore, gender differences in adolescents' retrospective emotional symptom reporting may have been related more to gender differences in reporting of emotions *per se* rather than due to a unique gender-based response to concussion or a gender-specific good old days' bias. There may, however, be gender-based biases affecting recall of past emotional symptoms based on cultural expectations that women are more emotional than men (Feldman Barrett, Robin, Pietromonaco, & Eysell, 1998). More recently, it has been suggested that gender differences in symptom reporting may be explained by normal hormonal changes associated with the menstrual cycle (Brown, Elsass, Miller, Reed, & Reneker, 2015), at least after sports-related concussion.

Nevertheless, if these gender differences represent underreporting of symptoms in males who actually experience symptoms, this has implications for the management of concussion recovery, including return to play/learn decisions. It at least reinforces the need for a clinical evaluation that includes objective tests. This is particularly true because concussed males who report no PCS demonstrate neurocognitive impairment compared to non-concussed athletes (Fazio, Lovell, Pardini, et al., 2007). Those concussed athletes who reported symptoms were even more impaired on neurocognitive tests compared with those who reported no symptoms (Fazio et al., 2007). Therefore,

subjective symptoms (when reported), may index ongoing recovery and are useful in clinical evaluation of post-concussion recovery.

Clinical implications of the good old days' bias

In contrast to Brooks et al.'s (2014) findings, the good old days' bias did not have an appreciable effect on recovery tracking in the current study. Even though the mTBI group retrospectively reported fewer pre-injury symptoms by one month post-injury, only four participants were classified as "recovered" at one month post-injury if early pre-injury symptom ratings were used rather than pre-injury symptom ratings made at one month post-injury. A much larger percentage of the Brooks et al. (2014) sample were classified as "not recovered" due to the good old days' bias. However, that was found at three months post-injury when many more individuals would be expected to be recovered or to report fewer post-injury symptoms. In the current study, many participants were still reporting quite a few post-injury symptoms at one-month post-injury. Being mostly young, healthy athletes, the mTBI sample also reported few pre-injury symptoms at both time points so that for most of the group, even having a few post-injury symptoms resulted in "elevated" symptoms relative to their pre-injury symptoms. As found in Brooks et al. (2014), it may be that the effect of the good old days' bias on tracking recovery is more obvious as time since injury increases. Still, the possibility remains that the good old days' bias leads to underestimation of pre-injury symptoms immediately after a concussion, making any post-injury retrospective symptom reports unreliable for the purpose of tracking symptom resolution. However, the current study offers some evidence that pre-injury symptoms are not underestimated within one week of mTBI, at least in a healthy young sample.

The majority of individuals with mTBI in the current study showed a reduction of symptoms by one month post-injury, with a portion even reporting no symptoms at the one-month follow-up. In some cases, those with mTBI looked "healthier" than healthy controls even within one week of concussion. This shows the difficulty in using symptom ratings to measure concussion severity and recovery when not even one symptom is specific to concussion. It also illustrates that the concussion population is heterogeneous. Indeed, the individuals who reported "zero" symptoms in the control and mTBI groups

may be different in important ways from those who reported some symptoms. A willingness to report symptoms may itself be associated with individual factors, like personality, that could predispose one to prolonged recovery (e.g., Kay, 1992; Silverberg & Iverson, 2011; Lishman, 1988). Perhaps the good old days' bias, expectation as etiology, and other expectation-based biases are much more powerful in those who report symptoms. It is certainly easier to measure these biases when symptoms are reported. Perhaps those who report "zero" symptoms are underreporting or minimizing symptoms, making them a separate subset within the mTBI population. There is a need for future studies to stratify the mTBI population to examine what are the factors that contribute to reporting any, many, or no symptoms in general.

Many factors affect the utility of subjective symptom ratings in tracking recovery after concussion. The current study provided evidence that the good old days' bias decreases the usefulness of self-reported symptom ratings by only one month after injury in adolescents. At the same time, symptom ratings made within one week of injury may be less susceptible to the good old days' bias, as demonstrated in the current study. This suggests that pre-injury symptoms should be estimated as close in time to the injury (e.g., the emergency department) as possible, as previously suggested by Brooks et al (2014). However, the reliability of self-reported pre-injury symptom ratings across even short time periods is open to myriad influences, including normal variation in non-specific "post-concussion"-like symptoms (e.g., Sady et al., 2014; Iverson & Lange, 2003).

The tendency to recall "average" functioning rather than precise details of symptoms prior to concussion is not necessarily a detrimental bias. Arguably, the average number and severity of symptoms before a concussion would serve as a suitable baseline for an individual. In contrast, comparing current PCS severity to ratings of pre-injury PCS that were made on a day when that individual was experiencing atypical symptoms could lead to inaccurate decisions about a recovery or non-recovery from concussion. Clinically, it may be helpful to increase the likelihood that individuals rate their typical level of pre-injury symptoms rather than unusually high or low pre-injury ratings. For example, asking individuals to rate PCS severity over a longer period (e.g., 1-2 weeks) before their concussion rather than the 24 hours before concussion may better

capture average symptom experience (e.g., British Columbia Postconcussion Symptom Inventory, Iverson & Lange, 2003). Probing about particular events that could have accounted for particularly high or low pre-injury symptoms (e.g., illness, end of school year, etc.) could aid in interpreting pre-injury symptom levels. Alternatively, asking individuals to provide pre-injury PCS ratings for multiple time points prior to their concussion using specific anchors could aid in gathering an index of intra-individual variability in PCS. This method has yet to be evaluated. It may be especially useful in the acute period after concussion, since expectation-induced biases do not appear to significantly lower pre-injury PCS ratings in the first week after concussion. Probing for the presence of any pre-injury PCS could also curb misattribution of symptoms to a concussion because it could illustrate the non-specific nature of these symptoms. Finally, for those at high risk of incurring concussions, such as athletes, obtaining multiple baseline symptom ratings could provide an index of intra-individual variability in PCS. By measuring PCS periodically throughout the season, such repeated PCS ratings could also provide clinicians with recent pre-concussion baseline PCS ratings if an athlete does incur a concussion. Several smartphone apps are available to track symptoms, and could be adapted for this use. A corollary of providing multiple PCS ratings over time may be that it illustrates the variability of “post-concussion symptoms” even in healthy athletes. For an individual who is not recovering well after concussion, such information could provide a valuable illustration that not all of their symptoms may be related to their concussion.

In sum, symptom ratings are an imperfect tool when tracking recovery. However, they do have utility and should not be abandoned altogether. Symptom rating tools are inexpensive to measure, widely available, readily understood, require little training to administer and score, and symptoms are related to everyday functioning and distress (e.g., Mainwaring et al., 2004). Given that they are imperfect, symptom ratings should be used as part of a multidisciplinary, comprehensive assessment, particularly when there is prolonged recovery.

Limitations

The findings of this study are most generalizable to young healthy athletes, who likely differ from the general population in important ways. Athletes who participate in organized sports are physically and mentally healthier than the general population (Daniels & Leaper, 2006; Findlay & Coplan, 2008; Steptoe & Butler, 1996; Asken, Snyder, Smith, Zaremski, & Bauer, 2016), including reporting lower rates of concussion-like symptoms (Asken et al., 2016; Dean et al., 2012; Iverson & Lange, 2003; Lees-Haley & Brown, 1993). Both groups in this study were relatively young, healthy athletes. Unsurprisingly, they reported few or zero symptoms at all or prior to injury, respectively. This limited the ability to detect retrospective minimization of pre-injury or past symptoms since individuals could not minimize zero symptoms. It may be that the good old days' bias and other response biases are less likely to occur in healthy individuals who truly had few pre-mTBI symptoms. Those who have nothing have nothing to lose. Individuals who report very few symptoms may also have a general tendency to underreport symptoms, which would be important to examine separately. These points could be tested by stratifying the control group by the degree of symptoms reported at baseline and the mTBI groups by degree of pre-injury symptoms reported. Alternatively, using an orthopedic injuries group without concussion may be a suitable comparison group to determine if the good old days' bias is related to expectations about concussion recovery specifically versus a reaction to injury and sequelae more broadly.

The current study's mTBI group may have been quite healthy compared to adult samples, particularly compared to adult samples seeking specialized treatment for prolonged concussion or who were involved in litigation (e.g., Iverson et al., 2010; Lange, Iverson, & Rose, 2010). As well, most had incurred a single concussion and the current findings may not extend to those who have had multiple concussions. One wonders what the "baseline" of "pre-injury" symptoms should be when measuring recovery in the latter group. Yet to be examined is whether the good old days' bias is even greater in this group because of the expectation for poorer recovery after multiple concussions.

The control group may also have been particularly healthy, as they were largely young athletes. Since the control group was not matched to the mTBI group, it is possible

that there were important differences between the two groups that would make the control groups' symptom ratings an unsuitable proxy norm. For example, the control group was slightly older than the mTBI group, though age was not associated with greater symptom reporting in either group. The context of symptom ratings being made as part of pre-season baseline testing may also have influenced PCS ratings in ways that would obscure examination of both normative memory processes and typical symptom reporting in healthy young athletes. For example, young athletes may “sandbag,” or underperform during baseline testing in an attempt to get around return-to-play protocols (e.g., Iverson & Schatz, 2015). However, if they were sandbagging, one would expect athletes to actually report greater pre-season symptoms so that post-injury symptoms would not appear to be as elevated compared to these baseline symptom ratings.

The fact that baseline testing often took place in a group setting with other teammates for most of the control group may also have led to lower reported PCS ratings. For example, some athletes may underreport concussion symptoms due to perceived norms about concussion reporting or due to pressure from teammates, parents, and fans not to report symptoms (Kroshus, Kubzansky, Goldman, & Austin, 2014; Kroshus, Garnett, Hawrilenko, Baugh, & Calzo, 2015). Interestingly, female athletes rate greater intentions to report concussions despite perceiving similar pressure not to report them as male athletes do (Kroshus et al., 2015). This may contribute to why female athletes in the current study reported greater symptoms than male controls. This may also explain why controls reported greater PCS symptoms one month after baseline as these latter PCS reports were made under more private circumstances. One would expect them to similarly underreport past symptoms at baseline, though, but they actually reported more retrospective symptoms at baseline. They could have been feeling particularly good on the day of baseline testing, or particularly bad in the few days prior to baseline testing. However, 88% of the control group at baseline reported feeling “no different” than they usually do. At one-month follow-up, most (78.6%) continued to report feeling no different than they usually do. Regardless, this methodological issue places some limits on the interpretability of comparisons between the mTBI and control groups in this study.

Future directions

Very few studies have directly investigated perceptions and expectations about concussion in concussed individuals. Instead, negative expectations about concussion and misattribution of symptoms are inferred from symptom rating patterns. Studies that examine the good old days' and other recall biases suggest that symptom ratings should not be relied on in tracking concussion recovery. However, if the real culprit is in how concussions – not symptoms - are perceived, then perceptions about concussion should be directly examined. In fact, Whittaker, Kemp, and House (2007) found that people's beliefs about the severity and extent of a concussion's negative impact on their lives predicted persisting PCS at 3-months post-injury. Beliefs predicted worse outcome whereas even injury severity, psychological distress, initial PCS severity, anxiety, depression, and PTSD symptom severity did not. This suggests that, after concussion, it matters less what people think when looking back, and more what they expect when looking forward. Here, assessing and intervening around patient beliefs about their symptoms and the anticipated effect of those symptoms in their lives would be a vital adjunct to symptom tracking. To this end, further studies are needed to understand concussion perceptions using a formal model of illness perceptions (e.g., Common Sense Model of Illness Representation; Leventhal et al., 1980). It is important to understand which aspects of negative "illness" perceptions relate to greater vulnerability to expectation-based biases. With respect to the good old days' bias, one might expect greater misattribution of symptoms to concussion when someone holds a strong representation of concussion's "identity" in terms of symptoms, believes that concussions cause chronic or cyclical problems, and holds strong negative expectations of a concussion's consequences. By understanding the expectations underlying biased perceptions of post-concussion functioning, it would be possible to identify individuals who are vulnerable to these biases. Designing early interventions that target important expectations could mitigate the risk for poor post-concussion outcomes. In fact, there is already evidence that providing children with reassurance designed to set positive expectations for recovery reduces post-concussion symptoms (Borg et al., 2004; Nygren-de Boussard et al., 2014).

Rather than reflecting negative expectations about concussion, recalling fewer pre-injury symptoms one month after mTBI could reflect a shift in the mTBI participants' internal standards of measurement of symptom severity, or a response-shift effect resulting from experiencing greater symptoms than usual for them. In this way, recalling fewer pre-mTBI symptoms would reflect, not misattribution of symptoms to the mTBI, but a shift in one's internal standards of what "severe" symptoms mean. For example, if an individual rates their headache as a "6 out of 6" on a headache severity scale but experiences the worst migraine of their life a month later, they may, in hindsight, rate their original headache as less severe because their internal benchmark for a severe headache has been set higher. Such response-shift effects in internal standards has been found in some oncology patients rating fatigue before treatment and then recalling pre-treatment fatigue after treatment (Sprangers et al., 1999). Interestingly, those who did not show a response shift in fatigue ratings did not perceive themselves as physically changed. Understanding whether there is a response-shift in internal standards of symptom severity ratings after concussion, and whether this varies by severity of post-concussion symptoms or perceived change in oneself should be investigated. Qualitative interviews could be useful in understanding individuals' perceptions of whether they have changed or even whether their own internal standards for symptom severity have changed, as done with oncology patients (Sprangers et al., 1999). Functionally, underestimating pre-injury symptoms by one month post-injury has the same effect on measuring recovery after concussion if one compares post-concussion symptoms to pre-injury symptom ratings. Perhaps binary ratings of whether one "never" or "ever" had symptoms prior to a concussion are less susceptible to bias or response-shift effects than symptom severity ratings. One could imagine redefining what a "bad" headache is based on experiencing a lifetime-worst headache, but would it be so easy to forget having had previous headaches completely? If distress about the meaning of post-concussion symptoms adds to symptoms, then perhaps just recalling that one has had symptoms prior to a concussion would be useful in reducing this "expectation as etiology" effect. If so, rather than rating the severity of symptoms in a particular period prior to the mTBI, it may be more useful to ask individuals to indicate if they "ever" had post-concussion symptoms prior to their injury.

The good old days` bias, rosy retrospective, positivity bias, and fading affect biases are thought to lead to underestimation of some aspect of the past. These biases can be distinguished from the propensity to *underreport* symptoms, whether retrospectively or in the present. Underreporting of PCS and even of concussions has been documented in healthy adolescent male athletes (e.g., Kroshus, Kubzansky, Golman, & Austin, 2015; Meier, Brummel, Singh, Nerio, Polanski, & Bellgown, 2015). Underreporting problems and symptoms has been attributed to sandbagging in athletes (Iverson & Schatz, 2015) and gender socialization more broadly (Gioia, 2012; Robinson, Johnson, & Shields, 1998; Feldman Barrett, Robin, Pietromonaco & Eyssell, 1998). For example, although males and females report no differences in emotional experiences in the moment, females retrospectively recall feeling more emotions than males (Robinson et al., 1998; Feldman et al., 1998). The impact of symptom underreporting on tracking recovery after concussion is important. However, for the purpose of understanding biases that cause retrospective *underestimation* of PCS in those who do report symptoms, it may be warranted to treat those individuals who report no symptoms as a separate population from those who do in future studies.

Repeated and close monitoring of PCS by parents, coaches, and healthcare professionals is explicitly included in standard guidelines for determining recovery from concussion and graduated return to normal activities (e.g., Canadian Paediatric Society, Healthy Active Living and Sports Medicine Committee; Purcell, 2014). There are no studies yet that have examined the effect of repeated symptom measurement on expectations or attributions of symptoms to the concussion. It may be that the more someone fills out a “post-concussion symptom” inventory, the more they are susceptible to misattributing symptoms to their concussion and underestimating pre-injury symptoms.

Conclusion

In summary, the current study extended the literature by providing support for a good old days` bias by one month post-mTBI in adolescents. Given the fact that most of the mTBI group continued to experience symptoms at one month post-injury, the good old days` bias did not appreciably affect the number who were “misclassified” as not

recovered at one-month post-injury. The fact that the good old days' bias was not found in cross-sectional comparisons between the mTBI and control groups' symptom ratings is likely related to methodological differences between the current study and other studies. Most notably, the current study examined young, healthy athlete samples during the acute phase after mostly sports-related concussions. Findings may not extend to older, less healthy, non-athletic samples who incur more severe concussions or who are involved in litigation. Future studies are needed to examine these populations during the acute phase post-injury. Direct study of concussion-related expectations is needed in the entire mTBI population.

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Appendix A. Neurotracker Intake Form

Group		Participant Number	
DOB (yyyy/mm/dd)		Gender	
Date (yyyy/mm/dd)		Baseline or Post-Injury	

MOT AND RELATED TESTING – INTAKE FORM

CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			
EMERGENCY CONTACT INFORMATION			
First Name		Last Name	
Phone (home)		Phone (cell)	
Email			
Relationship to You			
GENERAL INFORMATION			
Height (ft)		Weight (lbs)	
Age		DOB (yyyy/mm/dd)	
Gender		Highest Education Level	
What hand do you write with?			
What hand do you shoot a hockey puck with?			
What hand do you use to throw a ball?			
EXTRA CURRICULARS			
List any instruments you play		For how many years?	
Do you play video games?		For how many hrs/wk?	
CURRENT SPORT PARTICIPATION			
SPORT	POSITION	LEVEL	YEARS

Appendix B.

CDE Study Parent Questionnaires 1 & 2

Parent Questionnaire Part 1

THE PATIENT DID NOT CONSENT/ASSENT TO THE STUDY - DO NOT COMPLETE THIS QUESTIONNAIRE.

Code for Missing Data

(CLINICAL STAFF USE ONLY)

ALL QUESTIONS BELOW ARE ASKED TO THE PARENT / LEGAL GUARDIAN IF CHILD IS < 16.

Concussion history

Ohio State Short Form - Screening for previous TBI

Except for the current concussion:

Has your child ever been hospitalized or treated in an emergency room following an injury to his/her head or neck? Think about any childhood injuries you remember or were told about. Yes No

Has your child ever injured his/her head or neck in a car accident or from some other moving vehicle accident, e.g. car, truck, bicycle, van, all terrain vehicle? Yes No

Has your child ever injured his/her head or neck in a fall or from being hit by something? For example slipping on ice, a wet floor, the street, etc, or while walking. Falling from a curb, stairs, stair, roof, etc. Falling on a hard floor, ice, rocks, etc. Yes No

Has your child ever injured his/her head or neck in sports, e.g. football, soccer, skiing, blading, boarding, basketball, baseball, biking, horseback riding. Yes No

Has your child ever injured his/her head or neck in a fight, assault, from being hit by someone or being shaken violently? Yes No

Was your child knocked out or unconscious following any of the injuries you mentioned above? Do not include losing consciousness due to drug overdose or from being choked. Yes No

Was your child dazed, confused or did he/she have a gap in memory from the injury(ies) you mentioned above? [Rule out alcohol blackouts] Yes No

Concussion History

Previous Number of Concussions

0 1 2 3
 4 5 6+

I will now ask you details about the most recent injuries (1, 2 or 3). For each injury, I would like to know about the age of your child, about:

How long was your child knocked out or did he/she lose consciousness? (If identified multiple injuries with loss of consciousness, ask for each. If not sure of the time frame, encourage them to make their best guess.)

and about:

How long was your child dazed or confused? (If identified multiple injuries with period of confusion, ask for each. If not sure of the time frame, encourage them to make their best guess.)

Injury #1 How old was your child?	_____
	((in years))
Injury #1 How long was your child dazed and confused?	_____
	((in minutes))
Injury #1 How long was your child knocked out?	_____
	((in minutes))
Injury #2 How old was your child?	_____
	((in years))
Injury #2 How long was your child dazed and confused?	_____
	((in minutes))
Injury #2 How long was your child knocked out?	_____
	((in minutes))
Injury #3 How old was your child?	_____
	((in years))
Injury #3 How long was your child dazed and confused?	_____
	((in minutes))
Injury #3 How long was your child knocked out?	_____
	((in minutes))
Longest period of unconsciousness? (considering all previous concussions)	_____
	((in minutes))
Longest period confused? (considering all previous concussions)	_____
	((in minutes))
Longest Symptom Duration (considering all previous concussions)	<input type="checkbox"/> Less than 1 week <input type="checkbox"/> Between 1 - 2 weeks <input type="checkbox"/> Between 3 - 4 weeks <input type="checkbox"/> Between 5 - 8 weeks <input type="checkbox"/> More than 8 weeks
What was the date of the most recent previous concussion (before the current one)?	_____
	(dd-mm-yyyy)
Was the current concussion caused by a less forceful blow than previous concussions?	<input type="checkbox"/> Yes <input type="checkbox"/> No

Child Headache History

	Yes	No	
Child prior treatment for headache	<input type="checkbox"/>	<input type="checkbox"/>	
Child personal history of migraine headache	<input type="checkbox"/>	<input type="checkbox"/>	
	Yes	No	Unknown
Any family history of migraine headaches	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
If family history of migraine headache, please specify	_____		

Child Developmental History

	Yes	No
Prior diagnosis of Learning Disabilities	<input type="checkbox"/>	<input type="checkbox"/>
Prior diagnosis of Attention-Deficit / Hyperactivity Disorder	<input type="checkbox"/>	<input type="checkbox"/>
Other developmental disorder	<input type="checkbox"/>	<input type="checkbox"/>
Specify other developmental disorder	_____	
If developmental disorder is significant then participant is not eligible for the study		

Child Psychiatric History

	Yes	No
Prior diagnosis of Anxiety	<input type="checkbox"/>	<input type="checkbox"/>
Prior diagnosis of Depression	<input type="checkbox"/>	<input type="checkbox"/>
Prior diagnosis of Sleep Disorder	<input type="checkbox"/>	<input type="checkbox"/>
Prior diagnosis of Other Psychiatric Disorder	<input type="checkbox"/>	<input type="checkbox"/>
Specify other psychiatric disorder	_____	

Loss of consciousness

After your child's current head injury did he/she lose consciousness?

- Yes
 No
 Unknown

Specify duration of consciousness loss in minutes*

_____ (minutes (Expected range: 0-10)Verify with medical records if outside this range.)

*Note: Record minute fractions as decimals:
15 seconds = 0.25 minutes
30 seconds = 0.5 minutes
45 seconds = 0.75 minutes

Parent Questionnaire Part 2

THE PATIENT DID NOT CONSENT/ASSENT TO THE STUDY - DO NOT COMPLETE THIS QUESTIONNAIRE.

Code for Missing Data

(CLINICAL STAFF USE ONLY)

After your child's head injury did he/she have a seizure?

- Yes
 No

Has your child exhibited any of the following symptoms since the time of injury?

- Appears dazed and confused
 Is confused about events
 Answers questions slowly
 Repeats questions
 Forgetful of recent information
 None of these symptoms
(Check all that apply)

Exertion

	Yes	No	Unsure	Incident just happened
Do these symptoms worsen with physical activity?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Do these symptoms worsen with cognitive activity (school/homework/computer/hand-held device)?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Cause of injury (mechanism)

Mechanism of Injury. Please describe how your child was injured.

- Sports/Recreational Play
 Non-Sport related injury/Non-Sport related fall
 Motor Vehicle Collision
 Assault
 Other

Type of sport

- Hockey
 Football
 Soccer
 Ski/Snowboarding
 Skating
 Baseball/Softball
 Bicycling
 Horse Back Riding
 Skateboarding/rollerblading
 Basketball
 Trampoline
 Gymnastics
 Tobogganing
 Recreational Play (gym, recess)
 Other

Describe type of recreational play

Specify other sport

Specify type of non-sport related fall	<input type="checkbox"/> Slipped/fell/tripped on floor/ground <input type="checkbox"/> Struck head against wall/door <input type="checkbox"/> Fall from height (e.g. fall from bed or tree) <input type="checkbox"/> Struck head against household object (e.g. furniture) <input type="checkbox"/> Fall down stairs <input type="checkbox"/> Struck by object
Did mechanism of injury involve a fall?	<input type="checkbox"/> Yes <input type="checkbox"/> No
Initial point of contact when fall occurred	<input type="checkbox"/> Head <input type="checkbox"/> Other
Specify other point of initial contact when fall occurred	_____
Fall - Drop (cm)	_____
	(cm if unknown, enter 999. If the fall is from own height, then the DROP is 0 cm. If fall is from balcony that is 300 cm off the ground, then drop is 300 cm.)
Fall - Impact Surface	<input type="checkbox"/> Sand <input type="checkbox"/> Grass <input type="checkbox"/> Gravel <input type="checkbox"/> Concrete <input type="checkbox"/> Ice <input type="checkbox"/> Steel <input type="checkbox"/> Other (specify)
Fall - Specify other impact surface	_____
Specify context of motor vehicle collision	<input type="checkbox"/> Passenger in car <input type="checkbox"/> Driver of car <input type="checkbox"/> Pedestrian <input type="checkbox"/> Cyclist <input type="checkbox"/> Other
Speed of vehicle child was in	<input type="checkbox"/> Low speed: < 40 km/hr <input type="checkbox"/> Moderate speed: 40-80 km/hr <input type="checkbox"/> High speed: > 80km/hr <input type="checkbox"/> Unknown
Speed of vehicle child was driving	<input type="checkbox"/> Low speed: < 40 km/hr <input type="checkbox"/> Moderate speed: 40-80 km/hr <input type="checkbox"/> High speed: > 80km/hr <input type="checkbox"/> Unknown
Speed of vehicle that hit child	<input type="checkbox"/> Low speed: < 40 km/hr <input type="checkbox"/> Moderate speed: 40-80 km/hr <input type="checkbox"/> High speed: > 80km/hr <input type="checkbox"/> Unknown
Speed of vehicle that hit child on bike	<input type="checkbox"/> Low speed: < 40 km/hr <input type="checkbox"/> Moderate speed: 40-80 km/hr <input type="checkbox"/> High speed: > 80km/hr <input type="checkbox"/> Unknown
Specify other context of motor vehicle collision	_____
Speed of vehicle in other scenario	<input type="checkbox"/> Low speed: < 40 km/hr <input type="checkbox"/> Moderate speed: 40-80 km/hr <input type="checkbox"/> High speed: > 80km/hr <input type="checkbox"/> Unknown
Specify other mechanism of injury	_____

Anthropometric measures

Child's height (cm) _____
(cm)

Child's weight (kg) _____
(kg)

BMI (kg/m²) Calculated in REDCap _____
(kg/m²)

Protective equipment

Helmet use? Yes
 No

Mouth guard use? Yes
 No

Location of injury

Primary location of injury Frontal
 Lft Temporal
 Rt Temporal
 Lft Parietal
 Rt Parietal
 Occipital
 Neck
 Indirect Force
 Other Body Part

Add details of indirect force _____

Specify other body part _____

Is there evidence of intracranial injury on CT or MRI? Yes
 No
 Unknown
 No CT or MRI was done

Verify in Medical Records

Is there evidence of skull fracture on xray or CT? Yes
 No
 Unknown
 No xray or CT was done

Verify in Medical Records

Is there evidence of neck injury on xray? Yes
 No
 Unknown
 No xray was done

Verify in Medical Records

Comorbidities (are there other injuries?) _____

Routine medication

List any routine medications

- None
 Ativan/Lorazepam
 Concerta
 Melatonin
 Ventolin/Salbutamol
 Flovent
 Reactine
 Other medication
 ((Check all that apply))

Specify other routine medication(s)

 ((Separate multiple meds with a comma))

Initial Services Used
Instructions: Only ask this series of questions if recruited ≥ 48 hours (not ED)
We would like to know what health care services you used right away when your child got injured.

Did you seek any medical care immediately after the injury?

- Yes
 No

Where did you receive services from?

Hospital Emergency Department

- Yes
 No

Hospital name

Date

Were you admitted to hospital?

- Yes
 No

Did your child receive any other services? Check all that apply:

- Walk in medical clinic
 Pediatrician Office
 Family physician
 Other health care professional

State what other health care professional

Treatments in the ED or Physician's Office

What treatments did you receive in the ED or Physician's office

- Pain management
 Nausea management
 Diagnostic imaging
 Observation only
 No Treatment
 Other
 (Check all that apply)

Specify other treatment in ED

Specify method of pain management

- PO (by mouth)
 IV
 (Check all that apply)

21- General Difference

	0 No difference	1	2	3	4 Major difference
In general, to what degree do you feel "differently" than before the injury (not feeling like yourself)?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Select your answer with "0" indicating "Normal" (No difference) and "4" indicating "Very Different" (Major Difference)

Total Score

Total score _____

**Appendix D.
Post-Concussion Symptom Inventory – SR13, Modified for
Administration to Healthy Adolescents***

Participant ID#: **Name:** **Date of Testing:**

Email:

Phone Number:

Self-Report Symptom Rating – [Baseline/Follow-Up] Testing (Neurotracker Study)

[Baseline] Instructions: I am going to ask you to tell me about your symptoms at two points in time. First, I would like to know if you had any of these symptoms **THREE OR FOUR DAYS AGO**. Next, I would like to know if these symptoms have changed from three or four days ago to **TODAY**.

[One-month follow-up] Instructions: I am going to ask you to tell me about your symptoms at two points in time. First, I would like to know if you had any of these symptoms **ONE MONTH AGO** (on the day you did Neurotracker baseline testing at the University of Victoria). Next, I would like to know if these symptoms have changed from one month ago to **TODAY**.

You will be rating the symptoms on a scale from 0 to 6. Zero means “Not a problem,” 3 means “Moderate Problem,” and 6 means “Severe Problem.” (Please circle your rating).

[N.B. At one-month follow-up, “THREE OR FOUR DAYS AGO” was substituted with “ONE MONTH AGO” in all instances]

	0 = Not a problem	1	2	3 = Moderate problem	4	5	6 = Severe problem
1. Headaches –THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Headaches -TODAY	0	1	2	3	4	5	6
2. Nausea –THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6

Nausea - TODAY	0	1	2	3	4	5	6
3. Balance problems – THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Balance problems - TODAY	0	1	2	3	4	5	6
4. Dizziness–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Dizziness - TODAY	0	1	2	3	4	5	6
5. Fatigue–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Fatigue - TODAY	0	1	2	3	4	5	6
6. Drowsiness –THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Drowsiness - TODAY	0	1	2	3	4	5	6
7. Sensitivity to light– THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Sensitivity to light – TODAY	0	1	2	3	4	5	6
8. Sensitivity to noise– THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Sensitivity to noise - TODAY	0	1	2	3	4	5	6
9. Irritability–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Irritability - TODAY	0	1	2	3	4	5	6
10. Sadness–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Sadness – TODAY	0	1	2	3	4	5	6

11. Nervousness – THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Nervousness – TODAY	0	1	2	3	4	5	6
12. Feeling more emotional –THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Feeling more emotional – TODAY	0	1	2	3	4	5	6
13. Feeling slowed down–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Feeling slowed down – TODAY	0	1	2	3	4	5	6
14. Feeling mentally “foggy” –THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Feeling mentally “foggy” – TODAY	0	1	2	3	4	5	6
15. Difficulty concentrating–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Difficulty concentrating– TODAY	0	1	2	3	4	5	6
16. Difficulty remembering –THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Difficulty remembering – TODAY	0	1	2	3	4	5	6
17. Visual problems (double vision, blurring) –THREE OR FOUR	0	1	2	3	4	5	6

DAYS AGO							
Visual problems (double vision, blurring) – TODAY	0	1	2	3	4	5	6
18. Get confused with directions or tasks – THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Get confused with directions or tasks – TODAY	0	1	2	3	4	5	6
19. Move in a clumsy manner–THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Move in a clumsy manner– TODAY	0	1	2	3	4	5	6
20. Answer questions more slowly than usual– THREE OR FOUR DAYS AGO	0	1	2	3	4	5	6
Answer questions more slowly than usual– TODAY	0	1	2	3	4	5	6
		0 = No difference	1	2	3	4 = Major Difference	
21. In general, to what degree do you feel “differently” today compared to 3 or 4 days ago (not feeling like yourself)?	0	1	2	3	4		

<p>22. What do you think is causing the symptoms you have had TODAY <i>and/or</i> THREE OR FOUR DAYS AGO? (list all reasons):</p> <p><input type="checkbox"/> Not applicable (no symptoms)</p>
<p>23. Compared to the symptoms you are experiencing TODAY, what do you expect to happen in the next month:</p>
<p><input type="checkbox"/> My symptoms will get worse (I'll have more symptoms or have them more often).</p>
<p><input type="checkbox"/> My symptoms will get better (I will have fewer symptoms and/or have them less often).</p>
<p><input type="checkbox"/> My symptoms will stay about the same (I will have no more symptoms and have them no more often than I have them today).</p>
<p><input type="checkbox"/> I have no symptoms today and I don't think I'll have any in the next month.</p>

[One-Month Follow-Up Version]

	0 = No difference	1	2	3	4 = Major difference
21. In general, to what degree do you feel "differently" today compared to one month ago (not feeling like yourself)?	0	1	2	3	4
22. What do you think is causing the symptoms you have had TODAY? (list all reasons):					
<p><input type="checkbox"/> Not applicable (no symptoms)</p>					
23. Compared to one month ago, which do you think is most true:					
<p><input type="checkbox"/> My symptoms have gotten worse (I have more symptoms and/or have them more often).</p>					
<p><input type="checkbox"/> My symptoms have gotten better (I have fewer symptoms and/or have them less often).</p>					

- | |
|---|
| <input type="checkbox"/> My symptoms have stayed about the same (I have no more symptoms and have them no more often than I did one month ago). |
| <input type="checkbox"/> I have no symptoms today and had no symptoms one month ago. |

*Post-Concussion Symptom Inventory (PCSI) Self Report Assessment Form Pre and Post-Injury Report Ages 13 - 18 Years Authored / Developed by: Gioia, Janusz, Sady, Vaughan, Schneider, Collins, & Lovell. 2012 (Sady, Vaughan, & Gioia, 2014).

Appendix E. Additional details about outliers

mTBI group

Data of one participant (15.77 year old, English-speaking female) were excluded because including her data created significant differences in the mTBI group between males and females for several symptom cluster rating means, medians, and distributions. The excluded participant's pre-injury symptoms at both time points were especially discrepant (e.g.. Enrollment Total Pre-Injury Symptoms = 61, modified $z = 9.59$ compared to other mTBI females and $z = 19.9$ compared to all mTBI participants; 1-month total pre-injury symptoms = 35, $z = 22.21$ compared with female mTBI participants and $z = 11.1$ compared to all mTBI participants). In fact, her pre-injury symptoms were only 14 severity points fewer than her post-concussion symptoms, despite making both ratings only 5 hours after the incident concussion. This participant had a history of two prior concussions, migraines, and headaches. Three male mTBI group participants had a history of migraines, headaches and at least one previous concussion. A further three male mTBI participants had a history of migraines. However, none of these participants' symptom ratings were outliers. The PCSI asks for symptom ratings for the 24 hours prior to the concussion. It may be that the female mTBI participant had a migraine or some other illness in this period, given the very high ratings for pre-injury headache, dizziness, nausea, etc. If this was the case, then her lack of recall of the severity of symptoms from this narrow window one month later could be the result of forgetting that particular experience. Without knowing whether something unusual and specific had caused the severe pre-injury symptoms, it is impossible to know the extent to which later underestimation of these symptoms was due to expectations/attributions about concussion versus normative memory biases and forgetting. Given the influence of this participant's extreme pre-injury symptoms on the results, it was decided to exclude her data from analyses.

Control group

Two female participants (ages 18.49 and 14.62 years, respectively) each reported unusually elevated symptoms. The 18.49 year old participant's symptom severity ratings were relatively "extreme" at both time points, for current and retrospective ratings of all symptoms except retrospective emotional and sleep-related symptoms at enrollment. Her ratings of current cognitive and sleep-related symptoms at enrollment were only "mild" outliers. In addition, she reported an increase of 33 severity points in total symptoms from enrollment to 1-month and overestimated her baseline symptoms by 26 severity points. This participant provided 1-month follow-up ratings on Boxing Day and reported travel-related fatigue, nausea, dizziness, and other symptoms. Although she reported an extreme number of symptoms at enrollment, the extreme increase in reported symptoms may have been accounted for by travel and the holiday. At enrollment and 1-month follow-up, the 14.62 year old participant reported "extreme" current and retrospective symptom severity ratings for emotional, cognitive, and total symptom clusters. Although she did not report any diagnosed mental health difficulties, she provided explanations for her symptoms highly indicative of emotional difficulties and significant stressors. Inclusion of these participants' data accounted entirely for significant gender differences in the control group on 13 symptom cluster totals. Their data were excluded because they may introduce heterogeneity into the control group not representative of a healthy population and their inclusion had a profound effect on analyses.