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# Quantifying cognitive function in concussed athletes before and after acute exercise using a choice reaction time task

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**QUANTIFYING COGNITIVE FUNCTION IN CONCUSSED ATHLETES  
BEFORE AND AFTER ACUTE EXERCISE USING A CHOICE REACTION  
TIME TASK**

by

Stephanie Ramautar  
HBSc., McMaster University, 2012

THESIS/DISSERATION

Submitted to the Department of Kinesiology and Physical Education in partial fulfillment  
of the requirements for Masters of Science in Kinesiology

Wilfrid Laurier University

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## Glossary of Terms and Abbreviations

<b><u>Term</u></b>	<b><u>Definition</u></b>
<b>ANAM</b>	<b>Automated Neuropsychological Assessment Metrics:</b> computer-based assessments of cognitive function
<b>ANS</b>	<b>Autonomic nervous system:</b> part of the peripheral nervous system in the body
<b>ASMB</b>	<b>ANAM Sports Medicine Battery:</b> subset of ANAM assessments used specifically for detection of concussions
<b>BA6</b>	<b>Brodmann Area 6:</b> part of the frontal cortex in the human brain
<b>CBF</b>	<b>Cerebral blood flow:</b> blood supply to the brain in a given time
<b>CNS</b>	<b>Central Nervous System:</b> Part of the nervous system that includes the brain and spinal cord
<b>CRT</b>	<b>Choice reaction time:</b> reaction time task involving multiple response choices
<b>EEG</b>	<b>Electroencephalography:</b> recording of electrical activity along the scalp
<b>EMG</b>	<b>Electromyography:</b> A technique used to record the electrical activity within muscles
<b>ERP</b>	<b>Event-related potential:</b> the measured brain response as a direct result of a specific sensory, cognitive, or motor event
<b>fMRI</b>	<b>Functional magnetic resonance imaging:</b> functional neuroimaging procedure using MRI technology
<b>GCS</b>	<b>Glasgow Coma Scale:</b> neurological scale that measures the conscious state of a person
<b>HLI</b>	<b>Hopkins learning index:</b> neuropsychological learning assessment
<b>HR</b>	<b>Heart rate:</b> number of heart beats per unit of time
<b>ImPACT</b>	<b>Immediate Post-Concussion Assessment and Cognitive Testing:</b> A computerized neurocognitive assessment tool

<b>K-D</b>	<b>King-Devick:</b> a tool for the evaluation of saccades
<b>LOC</b>	<b>Loss of consciousness:</b> the condition of not being conscious
<b>MACE</b>	<b>Military acute concussion evaluation:</b> medical screening and documentation used to gauge severity of symptoms and cognitive deficits following a concussion
<b>MRI</b>	<b>Magnetic Resonance Imaging:</b> Use of strong magnetic fields and waves to form images of the body
<b>MT</b>	<b>Missed time:</b> time away from a game or practice
<b>mTBI</b>	<b>Mild Traumatic Brain Injury:</b> Medical term used to describe a concussion. Often used interchangeably
<b>NC</b>	<b>Non-concussed:</b> participants categorized as non-concussed
<b>PET</b>	<b>Positron emission tomography:</b> functional imaging technique using a positron-emitting tracer
<b>PCS</b>	<b>Post-concussion syndrome:</b> individuals experiencing long-lasting concussion-based symptoms
<b>PPC</b>	<b>Posterior Parietal Cortex:</b> Key role in the production of planned movements
<b>QE</b>	<b>Quiet Eye:</b> final fixation of the eye on a target just prior to movement
<b>RC</b>	<b>Recently concussed:</b> participants categorized as having sustained a concussion within 3 months prior to testing
<b>RPM</b>	<b>Repetitions per minute</b>
<b>RT</b>	<b>Response time:</b> time taken to elicit a response
<b>RTP</b>	<b>Return to Play:</b> The amount of time needed from injury until medical clearance to play
<b>SAC</b>	<b>Standard assessment of concussion:</b> sideline evaluation tool used for detecting a concussion
<b>SCAT3</b>	<b>Sport Concussion Assessment Tool Version 3:</b> A screening tool using multiple test batteries for concussion evaluation

## Abstract

Following a concussion, cognitive deficits have been shown to last longer than symptom resolution. Currently clinicians rely heavily on symptom emergence following the fundamental exercises of the return to play (RTP) protocol, which may leave athletes at risk of returning to play too early if cognitive deficits have not been detected. The purpose of this study was to assess the effects of exercise on choice reaction time (CRT) both at rest and following an acute exercise in 3 populations: non-concussed (NC), recently concussed (RC), and post-concussion syndrome (PCS) individuals. A CRT task in the form of an iPad application measured each individual's decision-making capabilities at four blocks: (1) 10 minutes prior to exercise, (2) Immediately prior to exercise, (3) immediately post exercise, and (4) 5 minutes post exercise. Participants were also fitted with an eye-tracking system during CRT task performance at rest in order to assess higher levels of cognitive processing. Results demonstrated a facilitative effect of learning and exercise arousal on CRT task performance in both NC and PCS but not in RC. Average RT in RC was not significantly different from NC while average RT in PCS was found to be significantly higher than NC. Gaze behaviour was significantly worse in PCS compared to NC while RC and NC were not significantly different. The absence of symptoms does not inherently mean that cognitive performance under acute physical stress has completely recovered in recently concussed individuals. On the other hand, PCS individuals continue to experience concussion-related symptoms, but appear to display partially recovered cognitive performance. Findings from the current study encourage the use of cognitive assessments following acute exercise during the RTP protocol in order to detect possibly lingering cognitive deficits.



## CHAPTER I

### BACKGROUND

A concussion is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces and is a form of mild traumatic brain injury (mTBI) (McCrory et al., 2013). According to the Centers for Disease Control and Prevention (CDC), over 170,000 cases of sports- and recreation- related traumatic brain injuries in children and adolescents are reported to US emergency departments each year (CDC, 2012). Sport related causes of a concussion include direct or indirect blows to the head, face, neck, or other body parts with an 'impulsive' force transmitted to the head (McCrory et al., 2012). It is estimated that over 300,000 cases of sport-related concussions occur annually (Marar, McIlvain, Fields & Comstock, 2012). The common misconception that concussions must result in a loss of consciousness (LOC) likely leads to underreporting of concussion cases. Other reasons for underreporting a concussion include warranting the injury as not serious enough, not wanting to leave the game or let down teammates, and not knowing they had sustained a concussion (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004). The number and severity of concussion symptoms vary from athlete to athlete, depending on the biomechanical forces, and areas of the brain affected (Zasler, Katz, Zafonte, 2012). Symptoms lasting longer than the expected recovery timeline of 2-4 weeks following a concussion are considered to have post-concussion syndrome (PCS) (Ryan and Warden, 2003). Upon sustaining a concussion, every concussed individual will experience a symptomatic phase and most will undergo an asymptomatic phase.

### *Symptomatic phase*

The time period in which an athlete experiences concussive symptoms at rest is referred to as the symptomatic phase and has been reported to last between 3 and 15 days post injury (Signoretti, Lazzaino, Tavazzi, & Vagnozzi, 2011; McCrea et al., 2003).

Symptoms can be categorized as physical, cognitive, or emotional and include: headaches, dizziness, irritability, trouble concentrating, fatigue, visual disturbances, and memory deficits (Ryan and Warden, 2003).

### *Asymptomatic phase*

Upon resolution of symptoms at rest, athletes enter into the asymptomatic phase where they undergo a six-stage, step-wise return to play (RTP) protocol (Table 1). Each stage of the protocol introduces an increase in either physical or cognitive load using different functional exercises. The objective of the RTP protocol is to complete the functional exercises of each stage without symptom emergence, as determined by an athletic therapist or sport physician. Upon successful completion of one rehabilitation stage, the athlete may progress to the successive stage 24 hours later. However, in the case of symptom emergence at any stage of the protocol, athletes are required to regress back to the previous stage and attempt to progress again after 24 hours of rest (McCrary et al., 2012). A sport physician assesses the athletes just prior to stage 6 in order to determine if he or she will be cleared to return to play. However, RTP assessments may vary between clinicians and rely heavily on subjective measures as a means of monitoring athlete progression, which may leave athletes at risk of returning too early.

Table 1: An outline of the return to play protocol from the 2012 consensus statement on concussion in sport (McCroory et al., 2012).

<b>Rehabilitation Stage</b>	<b>Fundamental Exercise</b>	<b>Objective</b>
1. No activity	Complete physical and cognitive rest	Recovery
2. Light aerobic exercise	Walking, swimming, stationary bike; intensity <70% max heart rate No resistance training	Increase HR
3. Sport-specific exercise	Skating drills (ice hockey) Running drills (soccer) No head impact activities	Add movement
4. Non-contact training drills	More complex training drills Passing drills (football and ice hockey) May begin progressive resistance training	Exercise, coordination and cognitive load
5. Full-contact practice	Following medical clearance participate in normal training	Restore confidence and assess functional skill by coaching staff
6. Return to play	Normal game play	

## INTRODUCTION

### PHYSIOLOGY OF A CONCUSSION

#### *Neurophysiology*

The acceleration/deceleration forces brought on by a head injury are the primary mechanism of axon stretching (Zasler, Katz, and Zafonte, 2012) and can be incurred through player-player contact, player-equipment contact, or player-playing surface contact (Marar, McIlvain, Fields, and Comstock, 2012). Axon stretching can initiate pathophysiologic processes including reversible changes in metabolic state such a neurotransmitter release and uncontrolled ion fluxes (Zasler, Katz, and Zafonte, 2012). Staal and colleagues (2010) used experimental axon stretch injuries in vitro to demonstrate changes in metabolic state, specifically a rise in intracellular calcium following a concussion. These results suggest that this disruption is a potential mechanism for neuronal dysfunction following a brain injury.

Cantu (2000) provides an overview of the neurometabolic cascade that occurs upon suffering an mTBI. Upon sustaining an mTBI, there is a release of excitatory neurotransmitters that results in neuronal depolarization via calcium ion influx. The sodium-potassium pump works intensely to restore normal membrane potential, utilizing glucose metabolism for its required energy demand. This state of hyperglycolysis lasts for 24 hours (Yoshino, Hovda, Kawamata and Katayama, 1991) after which a state of decreased glucose metabolism occurs that may last 2-4 weeks post injury as seen through positron emission tomography (PET) in humans (Bergsneider, Hovda, & Lee, 2000). It is unknown as to whether this hypometabolic state leaves the patient at risk of incurring

another injury due to the inability to respond to further energy demands or neurocognitive deficits (Cantu, 2000).

Coupled with changes in glucose metabolism, changes in cerebral blood flow (CBF) have also been documented (Slobounov, 2008; Sokoloff et al., 1977). Upon sustaining a severe traumatic brain injury, CBF changes appeared to follow three phases: 1) a decrease in CBF by approximately 50% within the first 12 hours of injury; 2) a period of increased CBF during the next 4-5 days; and 3) a second decrease in CBF over the next 1-2 weeks post injury (Kelly et al., 1987; Orbrist et al., 1984). In a state of increased energy demand and decreased CBF levels, this mismatch in energy is suggested to be the mechanism for post-concussion vulnerability including decreased performance and increased risk of incurring a second injury (Giza and Hovda, 2001). In relation to return to play timelines, it is possible for an athlete to progress through all 6 stages within two weeks of injury using current assessment methods. Considering that hypometabolic states and decreased CBF have been reported to last beyond 2 weeks post injury there may be athletes returning to play before full resolution of physiological impairments.

### ***Pathophysiology***

Functional magnetic resonance imaging (fMRI) is a procedure that detects changes in blood flow in the brain whereby increased blood flow is suggested to be coupled with increased neuronal activation. Lovell and colleagues (2007) revealed a significant correlation between posterior parietal cortex (PPC) activation, using fMRI, and cognitive (e.g. fatigue, drowsiness, memory problems) and somatic (e.g. blurred vision, headache) symptom severity in concussed varsity athletes. The greater the

symptom severity the lower the activation in the PPC (Lovell et al., 2007); supporting Giza and Hovda's (2001) suggestion that a decreased energy supply is part of the mechanism for post-concussion vulnerability. Individuals with hyperactivation in Brodmann's area 6 (BA6) (i.e., premotor cortex and supplementary motor area) were found to take significantly longer to return to play than those with less activation (Lovell et al., 2007). BA6, thought to be primarily a high-order motor area, has shown increasing evidence of having non-motor cognitive functions, specifically verbal and spatial representations (Tanaka, Honda, and Sadato, 2005). Thus, hyperactivation in BA6 during cognitive tasks may be part of an underlying physiological mechanism for remaining cognitive deficits post injury.

With regards to the effects of glucose metabolism on the pathophysiology of concussion, findings from Echemendia and colleagues (2001) revealed a greater decline in cognitive performance, using the Hopkins Learning Index (HLI) measure, at 48 hours post-injury compared to 2 hours post injury. Erlanger and colleagues (2003) suggested that these differences in cognitive performance coincide with the phases of glucose metabolism post injury. With hypoglycolytic states lasting up to 4 weeks post injury in concussed athletes it may be important to incorporate the use of neurocognitive assessments beyond the symptomatic phase.

## **CURRENT ASSESSMENTS OF mTBI**

### ***ANAM***

The Automated Neuropsychological Assessment Metrics (ANAM) test system is a compilation of computerized tests and test batteries for the purposes of serial testing and measuring cognitive processing (Reeves, Winter, Bleiburg, Kane, 2007).

Specifically, the ANAM Sport Medicine Battery (ASMB) was designed for baseline assessment of athletes and recovery from concussion. The ASMB assesses attention, mental flexibility, cognitive processing efficiency, arousal/fatigue level, learning, recall, and working memory. Results from both a spatial and mathematical processing task in the ASMB demonstrated that the task has the ability to identify differences between non-concussed and concussed individuals on the day of the injury as well as 1-2 days post injury (Cernich, Reeves, Sun et al., 2007). However, cognitive performance on both tasks appeared to recover between 3-7 days post injury (Cernich, Reeves, Sun et al., 2007), similar to other studies, which utilized components of the Sport Concussion Assessment Tool 2 (SCAT2) assessment to monitor impairments (McCrea et al., 2003).

Expected learning effects were observed in both the non-concussed and concussed groups in both the spatial and mathematical processing tasks (Cernich, Reeves, Sun et al., 2007). However, there were differences in the magnitude of learning effects between non-concussed and concussed individuals. Non-concussed individuals displayed a larger learning effect compared to concussed individuals. Within the concussed group those with a history of previous concussion displayed no learning effects on the mathematical task while concussed individuals with no previous concussion history displayed learning effects, suggesting that the task is sensitive to the cumulative effects of concussions

(Cernich, Reeves, Sun et al., 2007). Limitations including maturation, history of previous concussions, motivation, and test-retest reliability have been suggested to impact the validity of such neurocognitive assessments. Cernich and colleagues (2007) also noted that outcome measures of these neurocognitive tests are best when administered by the developers of the instrument and that the effectiveness of these products administered by users with minimal training should be investigated.

### ***King-Devick***

The King-Devick (K-D) test is a suggested sideline assessment tool that utilizes visual tracking to perform rapid number naming as a measure of cognitive function. Test takers are asked to read out loud a series of numbers from left to right on three different test cards, the entire process of which takes less than two minutes. The sums of the 3 test card time scores are combined to make a summary score and the numbers of errors made are also recorded. Galetta and colleagues (2011) looked at the use of the K-D task in a collegiate athlete population, comparing baseline scores to post season scores and those that sustained a concussion. Sideline assessment scores in concussed athletes displayed higher (worse) scores on the K-D task compared to baseline scores obtained pre-season. Athletes that had not sustained a concussion displayed better scores post-season compared to pre-season assessment demonstrating a mild learning effect (Galetta et al., 2011). A second study supported K-D's use as a visual screening tool during a sideline assessment in boxers and MMA fighters (Galetta et al., 2011). K-D scores were compared pre- versus post-fight with higher (worse) scores recorded for those that had sustained a head injury during their fight and lower (improved) scores for those that had



not sustained a head injury. The task also displayed even higher scores for those that had experienced LOC (Galetta et al., 2011), suggesting K-D's sensitivity in detecting severity of head injury. The K-D test correlated well against another established concussion assessment tool, the military acute concussion evaluation (MACE) that measures cognitive history, memory and orientation (Galetta et al., 2011). It is important to note that testing was performed on a group of individuals who displayed more obvious signs of head injury, however further testing on individuals with less obvious symptom presentation (i.e. athletes) should be performed (Galetta et al., 2011).

### ***ImPACT***

The Immediate Post-concussion Assessment and Cognitive Testing (ImPACT) tool is the most widely used neurocognitive assessment tool for sport-related concussions. ImPACT is a computerized concussion evaluation system that measures several cognitive function aspects including: attention span, working memory, response variability, non-verbal problem-solving, and reaction time (ImPACT, 2013). McGrath and colleagues (2012) examined neurocognitive performance, using ImPACT, after physical exertion (PE) in a group of asymptomatic concussed high school student-athletes. Individuals were categorized as PE-pass or PE-fail based on PE cognitive performance. Individuals demonstrating no reliable change indices (RCIs) on PE ImPACT scores were put into the PE-pass group, and individuals with one or more RCIs were placed into the PE-fail group. Verbal and visual memory scores were significantly lower in the PE-fail group while performance on the visual motor speed composite, RT composite, impulse control composite, and post-concussion symptom scale (PCSS) did not differ between groups.

Results showed that almost 30% of the symptom-free concussed athletes who had scored similar to their baseline levels on ImPACT at rest demonstrated cognitive decline on ImPACT after moderate exercise. It is important to note that cognitive decline was not associated with symptom recurrence thus demonstrating the use of physical exercise to elicit latent deficits (McGrath et al., 2012). It is important to consider the lack of a non-concussed control group to compare concussed individuals' cognitive performance following PE, given that ImPACT requires high levels of test-retest reliability (Mayers and Redick, 2012). Mayers and Redick (2012) reviewed three studies on the clinical application of ImPACT reporting inconsistent findings; all three studies utilized arbitrary timelines for testing (i.e. baseline, day 1-2, 3-7, and 14 days post-injury) rather than the structured RTP timeline. Testing at these arbitrary time points does not account for the fact that both symptomatic and asymptomatic phase durations vary between individuals, depending on injury severity and response to the injury, and would be a confounding variable for performance outcomes on cognitive tasks.

### ***Issues with current neurocognitive tests***

The issue with the aforementioned neurocognitive tests is that they are primarily used during the symptomatic phase of a concussion as a tool for the initial head injury detection. Some neurocognitive tests (i.e. ANAM) require baseline measurements but may lack the ability to reduce significant practice effects, allowing task scores to be potentially skewed by athletes during baseline or post-injury measures. It appears that these neurocognitive tasks are performed for all athletes at baseline (pre-injury), during the acute phase in concussed athletes, and just prior to returning to play. However,

cognitive function post-concussion recovers slowly and little research on cognitive function changes during the RTP protocol exists. Currently there is one study that utilized the ImPACT assessment to monitor cognitive function during the RTP protocol (McGrath et al., 2012), however the study's lack of a non-concussed control group leaves little room for comparison between normal and injured populations. There is a need for task-relevant cognitive testing during the RTP protocol that is not contaminated by learning effects.

### ***Simple versus choice reaction time tasks***

Simple RT tasks require less processing time compared to CRT tasks. While many studies have demonstrated the effectiveness of both types in displaying cognitive changes, the use of simple RT tasks may be less task-specific (Tomporowski and Ellis, 1986). Studies that utilized simple RT tasks may have displayed no changes in cognitive function, or no differences between groups, due to the minimal effort and processing time required. The current study will be using a CRT task in the form of a collision avoidance task in order to assess each individual's decision-making capabilities.

## **EXERCISE AND COGNITIVE FUNCTION**

Participation in sports requires the ability to perform physically demanding exercises as well as simultaneously use perceptual information to elicit appropriate decisions. It is well documented that the changes in cognitive performance during exercise are affected by the nature of the cognitive task as well as the intensity and duration of the exercise (Davranche, 2006; Covassin, 2007). Easterbrook's cue utilization

theory explains that moderate-intensity exercise may improve cognitive performance while higher-intensity exercises could lead to decreased performance. The theory suggests that as arousal level increases attention narrows to task relevant objects thereby optimizing performance (Easterbrook, 1959).

### ***Arousal level and resource allocation***

Electroencephalography (EEG) is a technique for recording electrical activity in the brain, measuring voltage fluctuations. Event related potentials (ERPs) are an example of a brain response to sensory, cognitive, or motor events (Luck, 2005). The P300 component of ERPs reflects neural activity underlying basic aspects of cognition (Magnie, Bermon, Martin et al., 2000). P300 has been used to reflect arousal levels and the amount of attention given to a certain task, whereby increased arousal can increase task-specific attention (Kamijo et al., 2004). Changes in P300 amplitude reflect changes in resource allocation while changes in P300 latency reflect processing speed (Yagi, Coburn, Estes and Arruda, 1999). Yagi and colleagues (1999) demonstrated decreased P300 latencies during moderate aerobic exercise, paralleling the knowledge that RTs decrease during exercise. Increased P300 amplitude after moderate-intensity exercise has also been observed (Kamijo et al., 2004), reflecting both increased attention to the task and indirectly optimal arousal levels. These studies supported the idea of optimal arousal levels during exercise in healthy populations by displaying the inverted U-shaped behaviour with changes in exercise intensity (Kamijo et al., 2004), supporting Easterbrook's cue utilization theory. It is important to consider that there is a strong relationship between optimal arousal levels, produced by moderate exercise, and

increased task-specific attention; changes to these expected outcomes may provide indication of cognitive dysfunction.

### ***Effects of exercise intensity and duration on cognitive performance***

The use of intense exercises and their acute effects on cognitive function are less understood. This may be due to the rapid recovery from fatigue that follows acute bouts of anaerobic exercise (Tomprowski, 2003). Gutin (1973) suggested that low activation exercise, characterized by a HR between 90 and 120 beats per minute (bpm), produces better performance on information processing tasks. Long duration (>15 minutes) and higher activation exercises (i.e., HR greater than 160bpm) should lead to decrements in tasks requiring information processing (Gutin, 1973). In support of Gutin (1973) the effects of long-duration, steady state exercise have been shown to decrease cognitive performance due to dehydration and depleted energy stores (Tomprowski, 2003). Thus cognitive performance following moderate intensity exercise, such as those used during the RTP protocol, should allow for optimal cognitive performance when measured immediately post exercise.

Monitoring HR during exercise rather than using absolute workloads is a better way to control for individual reactions to different levels of exercise (Salmela and Ndoye, 1986). Salmela and Ndoye (1986) demonstrated changes in cognitive performance, in the form of a verbal 5-choice RT task, with changes in HR. RT was significantly decreased (i.e., increased performance) at a HR of 115bpm compared to rest and HRs over 145bpm. Considering the varying levels of training in a varsity athlete population, monitoring HR during and after exercise will ensure optimal arousal levels. Improved cognitive

performance can be expected in healthy non-concussed individuals and potentially decreased cognitive performance can be expected in concussed athletes following exercise.

### ***Visual Acuity and Exercise***

Dynamic visual acuity, the ability to detect characteristics of a moving object including speed, colour, texture, and direction, has also been studied following exercise (Millslalde, DeLaRosby, and VonBank, 2005). Using a checkerboard square target slide, with varying target location, dynamic visual acuity was assessed across exercise loads at 30, 60 and 90% of the participants' maximal HR (Millslalde, DeLaRosby, and VonBank, 2005). Results demonstrated progressively increasing dynamic visual acuity scores with increasing exercise load as well as increasing range of scores with increasing exercise load. These findings support similar changes observed in resolution acuity with varying workload (Vlahov, 1979) suggesting that physiological mechanisms for visual acuity improvement is due to an increase in the reticular activating system, allowing individuals to become more alert and prepared to manage visual stimuli (Millslalde, DeLaRosby, and VonBank, 2005). However, it is important to consider that dynamic visual acuity differs from kinetic visual acuity. Dynamic visual acuity involves following a target horizontally across the visual field, maintaining target size, allowing the eyes to move synchronously in either direction. Kinetic visual acuity involves convergence or divergence of the eyes as they follow a target moving closer or further away, respectively (Millslalde, DeLaRosby, and VonBank, 2005). Kinetic acuity visual task performance has been shown to decrease across varying exercise intensities (Watanabe, 1983; Ishigaki, 1991).

The current study will involve the use of a collision avoidance task conducted on an iPad. Athletes will be required to perform the task before and after an acute bout of exercise. A possible mechanism for changes in task performance can be attributed to changes in visual acuity post exercise.

### ***Effects of exercise in concussed athletes***

Several studies have suggested cardiovascular dysfunction in asymptomatic concussed athletes during exercise when compared to rest (Gall, Parkhouse, and Goodman, 2004). Goldstein and colleagues (1998) found that the degree of uncoupling between the autonomic nervous system (ANS) and cardiovascular systems is proportionate to head injury severity. Individuals with a greater degree of head injury, as measured by the Glasgow Coma Scale (GSC), displayed less HR and blood pressure variability, signifying a lack of regulation of the baroreflex, the principle determinant of sympathetic outflow (Goldstein et al., 1998). However, there is little understanding of the pathophysiology of this dysfunction. Another study looked at changes in HR between asymptomatic, concussed athletes that experienced missed time (MT) from practice and games and matched controls. During steady-state exercise, MT concussed athletes displayed a significantly greater rise in HR, and a higher average HR, over time compared to their matched controls (Gall, Parkhouse, and Goodman, 2004). During the recovery period there was no significant difference in average HR between the two groups. Symptom assessment was also conducted before and after steady-state exercise, with no significant differences between the concussed and non-concussed individuals, despite the difference in physiological response during the exercises (e.g. steady-state

exercise, several high intensity exercise bouts) (Gall, Parkhouse, and Goodman, 2004). As mentioned previously, current methods of monitoring athletes during the RTP protocol rely mostly on symptom assessment following exercise, however results from Gall, Parkhouse, and Goodman (2004) suggest that reliance on self-reported symptoms for monitoring concussed athlete response to physiological stress is not sufficient seeing as HR response to exercise was different between the concussed and non-concussed group.

Looking at neurocognitive performance, Majerske and colleagues (2008) revealed a relationship between intensity of exercise activity post-concussion and certain ImPACT scores (e.g. visual memory and RT). Performance on the visual memory and RT tasks were significantly worse in the group with the highest activity levels, demonstrating a relationship between post-concussion activity and neurocognitive performance. The best neurocognitive performance was seen in the athletes performing moderate-intensity exercise post-concussion (Majerske et al., 2008). These findings emphasize the importance of monitoring HR during RTP exercises so that concussed athletes perform at moderate exercise intensities.

## **GAZE BEHAVIOURS**

An athlete's success is based on their ability to integrate complex movements in the environment while distributing attention appropriately in order to be successful with their actions (Faubert and Sidebottom, 2012). The "Quiet Eye" is defined as the final fixation of the eye on an object or target within a 3-degree visual angle for a minimum of 100ms (Vickers, 2009). Onset and duration of the quiet eye occur earlier and longer,



respectively, in elite athletes in comparison to near-elite athletes (Vickers, 2009). Vickers (2009) also demonstrated that elite athletes displayed “Quiet Eye” behaviours by fixating fewer environmental objects for a longer duration than novice athletes and these objects were task relevant. It is thought that longer fixation durations indicate that more information is being gathered from visual display (Mann, Williams, Ward, and Janelle, 2007). Between periods of fixations are rapid eye movements called saccades. Saccades are thought to suppress information processing which supports the idea that elite athletes spend more time fixating and less time using saccadic eye movements in order to extract more relevant information from the environment (Mann, Williams, Ward, and Janelle, 2007). The “Quiet Eye” period is thought to represent the time between visual fixation and initiation of an appropriate motor response (Vickers, 1996). Previously concussed athletes are thought to be at a higher risk of incurring additional concussions, as multiple concussions have been associated with cumulative effects on cerebral function and cognition (Barkhoudarian, Hovda, and Giza, 2011). Analyzing gaze behaviours in concussed athletes during neurocognitive assessments that require visual tracking may provide insight into where these athletes are gathering information. Inability to fixate task-relevant objects efficiently may result in longer processing times; a potential mechanism for increased risk of further injury.

## **CONCLUSION AND RATIONALE**

It is evident that there have been vast improvements in concussion detection at the time of injury in the sport setting. However, less research has been conducted on assessing an athlete’s cognitive recovery during their asymptomatic phase prior to return

to play (RTP). Currently clinicians rely heavily on symptom emergence following the fundamental exercises of the protocol. Relying on subjective self-reported symptoms of athletes may leave them at risk of returning to play too early. More objective measures such as balance assessments also may not be sufficient in detecting continued impairments because cognitive deficits persist beyond balance impairments (McCrea et al., 2003). Therefore, cognitive assessment upon symptom resolution may provide a more objective measure of athlete recovery upon sustaining a concussion.

### ***Research Objectives***

Upon sustaining a concussion, individuals may experience either acute or chronic levels of concussion-based symptoms. In order to accurately assess the effects of concussion on cognitive performance, the current study chose to separate recently concussed (RC) individuals from individuals with post-concussion syndrome (PCS) into two studies (Part A and B).

### Chapter III: NC and RC individuals

This study assessed differences between non-concussed (NC) individuals and RC individuals. While there has been much research on the use of current concussion assessments (e.g. SCAT3, UofT SAC, ANAM, ImPACT) to monitor athletes during the symptomatic phase, these assessments rely heavily on subjective assessments of physical and cognitive recovery and are not suited for monitoring recovery during the asymptomatic phase. There is little research on the use of objective measures that could be used to detect possible lingering cognitive deficits. Given that exercise is the basis of

the RTP protocol, combining the use of this physical challenge with an attentional challenge may allow for the detection of possible cognitive deficits.

#### CHAPTER IV: NC and PCS individuals

This study assessed differences between NC individuals and PCS individuals who experience chronic, ongoing concussion-based symptoms. While much research has been conducted on functional neuroimaging studies, little research on cognitive function in individuals with PCS has been conducted.

The objectives of the proposed studies are: 1) to determine whether a choice reaction time (CRT) task can accurately quantify cognitive function in non-concussed (NC) and previously concussed individuals; and 2) to determine whether gaze behaviours are related to performance on the CRT task. The proposed studies will focus on detecting cognitive deficits that may emerge following physical activity in both asymptomatic and symptomatic individuals who have suffered a concussion. This will be accomplished through the use of a CRT iPad task, as a means of measuring cognitive function. Cognitive function will be quantified using both average RT and accuracy before and after an acute bout of exercise. The objective is to challenge attentional resources during times of physiological stress in order to identify cognitive deficits, if any. The CRT task is a collision avoidance task in which individuals use perception-action integration to make a decision as to whether or not a collision would occur. A gaze tracker will be used to track gaze fixations during task performance in order to evaluate if differences exist

between NC and previously concussed individuals in higher levels of cognitive processing.

Therefore, these studies will provide insight into the response of the attentional system during times of stress as well as introduce the use of a cognitive task as a means of assessing the recovery of cognitive function, in both asymptomatic (RC) and chronic symptomatic (PCS) individuals.

### *Hypotheses*

#### Chapter III: NC and RC individuals

##### *CRT performance*

- I. Recently concussed athletes will display either a greater response time or no change post acute exercise compared to pre exercise. Non-concussed athletes will demonstrate improved performance (decreased RT) post exercise compared to pre exercise, as noted previously (Salmela and Ndoye, 1986).
- II. Recently concussed athletes will display decreased CRT task accuracy, as measured by percent correct, both pre and post exercise, in comparison to non-concussed individuals.

##### *Gaze behaviours*

- III. The duration of gaze fixations will be correlated with CRT task performance; non-concussed athletes will demonstrate “Quiet Eye” behaviours while recently concussed athletes will display shorter fixation periods.

## Chapter IV: NC and PCS individuals

### *CRT performance*

- I. Individuals with PCS will display either a greater response time or no change post acute exercise compared to pre exercise. Non-concussed athletes will demonstrate improved performance (decreased RT) post exercise compared to pre exercise, as noted previously (Salmela and Ndoye, 1986).
- II. Individuals with PCS will display decreased CRT task accuracy, as measured by percent correct, both pre and post exercise, in comparison to non-concussed individuals.

### *Gaze Behaviours*

- III. The duration of gaze fixations will be correlated with CRT task performance; non-concussed athletes will demonstrate “Quiet Eye” behaviours while individuals with PCS will display shorter fixation periods.

## CHAPTER II

### General methodology

#### *Participants*

A total of 39 undergraduate and graduate students from Wilfrid Laurier University were recruited for this study. Participants were categorized into one of three groups based on the presence or absence of concussion-based symptoms. Twenty-one students met the inclusion criteria for the non-concussed, active population. Inclusion criteria were: 1) not having incurred a concussion within the 6 months prior to testing and, 2) not experiencing any concussion-based symptoms during or after moderate-intensity exercise, 3) Currently involved in a form of intramural sport or exercise routine. Eight students met the inclusion criteria for the recently concussed (RC) population which included both varsity and non-varsity athletes. Inclusion criteria for varsity athletes were: 1) having sustained a concussion during the 2013-14 intercollegiate sporting season; 2) experiencing no post concussive symptoms at rest as monitored using the SCAT 3 symptoms checklist (Appendix A, Figure 1-1); 3) cleared by an athletic therapist to begin the RTP protocol. Inclusion criteria for non-varsity athletes included: 1) having sustained a recent concussion; and 2) experiencing no concussion-based symptoms at rest. Recently concussed varsity athletes were diagnosed as having a concussion by a WLU athletic therapist while recently concussed non-athletes were medically diagnosed by a physician and were cleared to take part in the current study. The remaining 9 participants were categorized into the post-concussion symptom (PCS) group, inclusion criteria for which included: 1) experiencing reoccurring concussion-based symptoms at rest and/or during exercise for 3 months or longer and, 2) having the ability to perform

moderate-intensity, low impact exercise. All participants with PCS were medically diagnosed as having sustained a concussion and were cleared to participate in the current study by their medical professional. Written informed consent as well as a Health History Questionnaire was obtained from all participants just prior to testing for demographic purposes (Table 2).

Table 2: An overview of the demographic information for each population: 1) non-concussed, 2) recently concussed, and 3) PCS participants

	Non-Concussed	RC	PCS
Gender	Male n = 10 Female n = 11	Males n = 5 Female n = 3	Female n = 9
Age	23.6 ± 1.8	19.5 ± 1.2	22.6 ± 2.0
Previous concussions	Yes = 7 No = 13 Unsure = 1	Yes = 7 Unsure = 1	Yes = 9
Number of previous concussions	0.6 ± 1.0	1.6 ± 1.3	3.1 ± 2.7
Number of symptoms in the past 6 months	0.38 ± 0.9	5.6 ± 2.5	5.8 ± 3.3
Number of symptoms at time of testing	3.0 ± 4.5	3.6 ± 3.6	9.1 ± 3.5
SCAT 3 symptom severity score at time of testing	4.8 ± 9.3	5.5 ± 7.3	17.8 ± 8.6

### ***Protocol***

Participants were required to fill out a health history questionnaire prior to beginning the study, which included: demographic information and an informed consent letter (Appendix B). All participants were asked to perform the CRT task for 4 blocks, each block being 3.5 minutes in length. Within each block, depending on each participant's response time (RT), approximately 24-30 measures of RT and accuracy were obtained. The CRT task was performed while standing with arms extended at a comfortable viewing angle and rested on a stand set just below eye level. Participants were instructed to respond as quickly and accurately as possible upon being prompted. No instructions were given as to whether individuals should scale themselves to the iPad task or if they were allowed to visualize rotating their trunk just prior to passage. If such questions arose, participants were instructed to maintain the strategy they had been using.

During block 1, participants were asked to perform the CRT task while fitted with the Eye Tracker system. Block 2 was performed 5 minutes after trial 1 in order to assess whether any learning effects took place. A Polar HR monitor was added at block 2 and was worn for the remainder of the testing session in order to ensure exercise was being performed at a moderate intensity. Participants were then asked to perform the 15-minute exercise bout. Immediately upon completing the exercise bout, participants were asked to perform the CRT task in the same standing position as the previous trials in order to assess each participant's cognitive response to physiological stress. The final block was completed 10 minutes after trial 3 in order to determine whether recovery following exercise affects cognitive performance. The Eye Tracker system was not worn during



blocks 3 and 4 as the effects of optimal arousal produced by the exercise bout would have dissipated given the amount of time required to set up the system.

### ***Experimental design***

The CRT task, created by Dr. Michael Cinelli, is a collision avoidance task in the form of an iPad application designed to measure a participants' decision-making capabilities, specifically RT and accuracy, to assess cognitive function. The task has not been validated, however, the task was a novel design created for the purposes of this study in order to assess cognitive function without the use of baseline measures. The opening screen required individuals to fill in demographic information including: name, gender, date of birth, sport (if applicable), and shoulder width. The task is a first person perspective of the participant traveling towards two closing doors in the distance (Appendix A, Figure 1-2). Stationary figures were set at varying distances from the closing doors in order to serve as distractions (Appendix A, Figure 1-3). Within each trial, both the distance from the doors and the speed of approach towards the doors varied. As the individual perceived themselves approaching the closing doors, a response prompt appeared just prior to passage where the individual had to indicate "yes" or "no" as to whether he or she could pass through the doors without colliding (Appendix A, Figure 1-4). Upon being prompted, the time taken to select "yes" or "no" was recorded as the individual's RT. Accuracy was recorded as a correct or incorrect decision based on whether the individual was able to accurately accept or decline 'safe passage' through the shrinking gap. The application determined a safe passage if the number of pixels that separated the two door edges at the theoretical time of crossing (i.e., when participants would have passed through the doors if the screen did not go blank) was greater than 4

pixels. The participants were unaware of this determinant, however if their decision corresponded with the decision calculated by the task it would be recorded as a correct decision. The task did not provide feedback to the participants on the accuracy of their response as this may have negatively affected their arousal if participants were not performing well. Feedback was also not provided because the purpose of this study was to assess the effect of exercise arousal on response time rather than accuracy, as the iPad task was designed to be challenging with minimal room for improvement in accuracy across the blocks.

The exercise bout utilized for this study was based off of the stage 2 RTP fundamental exercises used by the Certified Athletic Therapists at Wilfrid Laurier University. Stage 2 of the RTP protocol requires athletes to complete a 15-minute moderate-intensity, cycle ergometer exercise. The 15-minute session was broken down into: 1) a 5-minute warm up at “flat road” resistance; 2) a 5-minute interval during which the cycle ergometer resistance was increased every minute until a moderate-intensity HR was achieved (110-150bpm); 3) a 5-minute cool down at “flat road” resistance. Participants were asked to maintain the same pace throughout the entire exercise at approximately 65-75 RPM.

Along with collecting RT and accuracy data from the CRT task, participants were fitted with a head-mounted Eye Tracker system (ASL Mobile Eye-XG) in order to assess gaze fixations during the first two CRT task performances.

A Polar FT1 heart rate monitor was also used in order to obtain HR during baseline, exercise, and recovery. Heart rate was measured during the exercise bout in

order to ensure that all individuals were performing the exercise at a moderate intensity level (HR between 110-150bpm).

Testing occurred during the asymptomatic phase of the concussion. No specific time point (i.e. stage 2 of RTP) was used to determine test date; this was done in order to achieve data that displays recovery of cognitive function over time.

### ***Data Analysis***

CRT performance, specifically average RT, was analyzed using several descriptive statistic variables including: mean, standard deviation, sample variance, and median. Accuracy was expressed as a percent, calculated as the number of correct trials over the total number of trials for each block.

Data from the Eye Tracker system was recorded onto a digital videocassette recorder during testing and was later converted into digital files for analysis using a VB Multimedia player. Data collection occurred at 60 Hz. The current study defined a fixation as the participants' eye angle remaining within 1° in the horizontal plane for a minimum of 100 ms. Salthouse & Ellis (1980) report that a 100 ms fixation is the shortest amount of time needed to process visual information in the nervous system.

Using the VB Multimedia player, gaze data was analyzed as a video file. Data analysis on this software was performed at 30 Hz resulting in each frame of the video frame 30ms in length. Thus, if a saccade remained within a 1° horizontal range for 3 frames or longer, it was considered a fixation. Only Quiet Eye (QE) was measured for the purposes of this study, which is defined as the final fixation that occurs just prior to movement (Vickers, 2009). Each RT trial varied in duration based upon the distance from

the doors and speed of approach towards the closing doors; due to this variation QE was calculated as a percentage of each trial duration to normalize the data:

$$\text{Normalized QE (\%)} = \frac{\text{Final fixation duration (ms)}}{\text{Measurement duration (ms)}}$$

Absolute Quiet Eye duration was also recorded in order to assess the number of trials within each block that displayed Quiet Eye and was calculated as:

$$\text{QE in each trial (\%)} = \frac{\text{Measures displaying QE (n)}}{\text{Total Measures within each trial (n)}}$$

Upon removing any trials that did not display QE, the remaining trials were then used to calculate average normalized QE to determine if differences exist between the 3 groups without non-QE trials.

### ***Statistical Analyses***

#### *Descriptive analyses*

Independent samples t-tests were used to assess differences in age, number of previous concussions, number of symptoms in the past 6 months, number of symptoms at time of testing, as well as symptom severity at time of testing. In Part A, these variables were assessed between NC and RC. In Part B, these variables were assessed between NC and PCS.

#### *Response time and Accuracy*

A one-way repeated measures factorial ANOVA was carried out to assess any changes in CRT performance, specifically average RT, across each block of trials, in both

Part A and B. The dependent variable was average RT and the independent variable was block.

Accuracy scores were measured as percent correct on the CRT task, calculated as the number of correct trials over the total number of trials. This data was considered proportional data and was therefore transformed using arcsine transformation in order to run parametric analysis. The transformed accuracy data was analyzed using repeated measures ANOVA to assess any changes in accuracy across each of the four blocks. The dependent variable was block and the independent variable was accuracy.

#### *Gaze behaviour*

Two independent samples t-tests were used to assess any differences in gaze patterns between groups for each study. This was done in order to determine whether pre-exercise gaze patterns differed between groups. The dependent variable was QE duration and the independent variable is group (Part A: NC and RC; Part B: NC and PCS).

#### *Health history questionnaire*

Using data obtained from the health history questionnaire, a Pearson's correlation was also used to determine if time since concussion was related to average RT and accuracy in RC individuals. This was done to determine whether accuracy improves with increased time since last concussion. Pearson's correlation was also used to determine if the number of symptoms at time of testing was related to average RT or accuracy in PCS individuals. This was done in order to determine whether average RT or accuracy decline

with increased number of symptoms. Symptom severity at time of testing was also correlated with average RT and accuracy.

### **CHAPTER III**

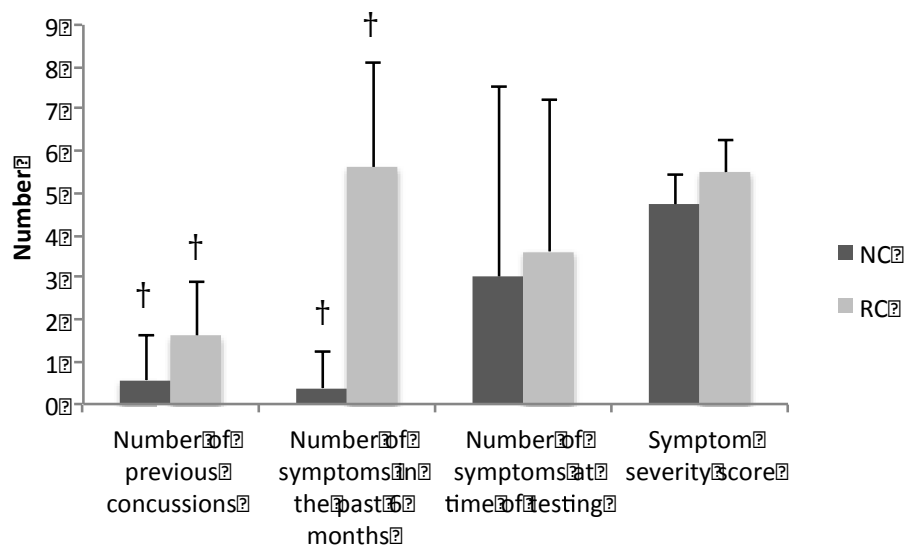
#### **Non-concussed and Recently Concussed Individuals**

## **RESULTS**

### **Descriptive Analysis: Non-concussed (NC) and Recently Concussed (RC) Groups**

Demographic information, previous concussion and symptom history, and current symptom assessment are displayed in Table 3-1. A total of 21 NC and 8 RC individuals were tested. All participants were able to complete the four blocks of CRT testing and gaze data was obtained for 18 of the 21 NC individuals and all 8 of the RC individuals. Gaze data for three participants was not recorded due to technical difficulties in calibrating the ASL Mobile Eye Tracker. Independent samples t-tests displayed a significant ( $t(27) = 6.037, p < .05$ ) difference in age between the two groups where average age in NC individuals ( $\mu = 23.57, s = 1.75$ ) was significantly higher than RC individuals ( $\mu = 19.50, s = 1.20$ ). The reason for this was due to recruitment of NC individuals from a convenience sample of undergraduate and graduate students enrolled in a Kinesiology program while individuals in the RC group were largely recruited from various 2013-14 intercollegiate sports teams including football, soccer, and rugby. The NC group consisted of 10 males and 11 females while RC consisted of 4 males and 4 females. Independent samples t-tests also indicated significant differences in number of previous concussions ( $t(27) = -2.293, p < .05$ ) and number of symptoms in the 6 months

prior to testing ( $t(27) = -8.551, p < .05$ ). Both the number of symptoms at time of testing and symptom severity were not significantly different ( $p > .05$ ) between the two groups as individuals assigned to the RC group were required to be asymptomatic at rest at the time of testing (Figure 3-1).



**Figure 3-1.** Demographic information comparing both NC and RC individuals including: number of previous concussions, number of symptoms experienced in the 6 months prior to testing, number of symptoms at time of testing, and symptom severity scores at time of testing, with their respective bars of standard deviation. There was a significant difference between NC and RC in the number of previous concussions sustained and the number of symptoms in the past 6 months.

† Indicates a significant difference ( $p < .05$ )

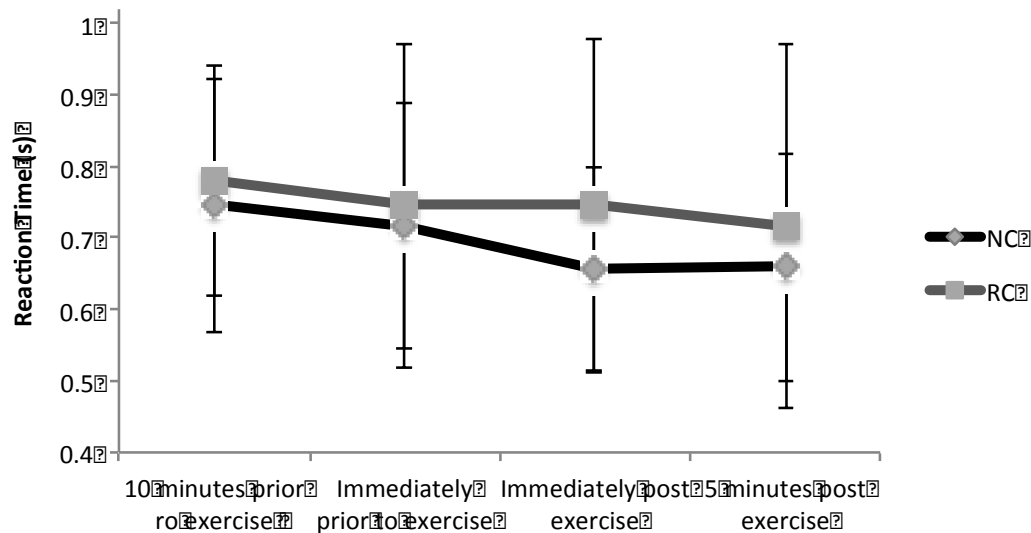
### Response Time (RT) Across the Trial Blocks

Previous literature has suggested that CRT is a more sensitive measure to determine if concussed individuals have cognitively recovered from a recent concussion. Erlanger and colleagues (2001) revealed that the Complex RT index was able the most sensitive in identifying concussed athletes that took significantly longer to respond to the

task. Thus, it is expected that even though symptoms had resolved in the RC group, average RT on the CRT task would be greater in the NC group. Repeated measures ANOVA indicated significant differences on CRT task performance, as measured by average RT, across the four blocks in both groups. With the NC group's data, Mauchley's test indicated that the assumption of sphericity had been violated,  $\chi^2(5) = 18.965, p < .05$ , therefore the F-ratio and degrees of freedom were corrected for using the Greenhouse-Geisser estimates ( $\epsilon = .59$ ). The results indicated that average RT was significantly different across the trial blocks,  $F(1.769, 35.371) = 10.332, p < .05$ . Pairwise comparisons revealed that the NC group approached significance ( $p = .071$ ) when comparing average RT immediately following exercise (block 3) ( $\mu = .657s, s = .142s$ ) to average RT immediately prior to exercise (block 2) ( $\mu = .718s, s = .170s$ ). No effect of learning was observed, as indicated by no significant change in RT from block 1 ( $\mu = .747s, s = .165s$ ) to block 2 ( $\mu = .718s, s = .170s$ ). The combined influence of learning effect and exercise resulted in a significant difference ( $p < .05$ ) in average RT from block 1 ( $\mu = .747s, s = .165s$ ) to block 3 ( $\mu = .657s, s = .142s$ ) ( $d = 0.58, r = .28$ ) and from block 1 ( $\mu = .747s, s = .165s$ ) to block 4 ( $\mu = .659s, s = .156s$ ) ( $d = 0.55, r = .26$ ) as this combined influence persisted for 5 minutes post exercise, indicated by no increase in RT from block 3 ( $\mu = .657s, s = .142s$ ) to block 4 ( $\mu = .659s, s = .156s$ ) (Figure 3-2).

With the RC group's data, repeated measures ANOVA revealed no significant main effect of block on CRT task performance,  $F(3, 21) = 1.005, p > .05$ , suggesting that, unlike the NC group, average RT in the RC group did not improve (decrease) with learning or exercise arousal (Figure 3-2).



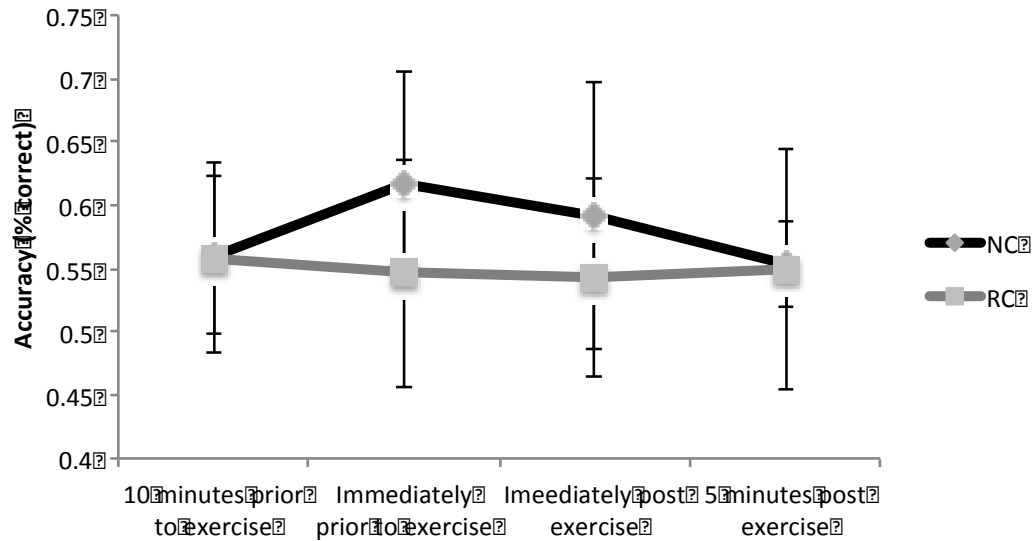


**Figure 3-2.** Average RT (s) scores of both NC and RC individuals across the four blocks of trials (block 1: 10 minutes prior to exercise; block 2: immediately prior to exercise; block 3: immediately following moderate exercise; and block 4: 5 minutes after exercise). A significant main effect of block was observed in NC ( $p < .05$ ) however no significant main effect of block was found in RC ( $p < .05$ ). No significant difference in average RT was observed between the two groups at any of the four blocks ( $p < .05$ ).

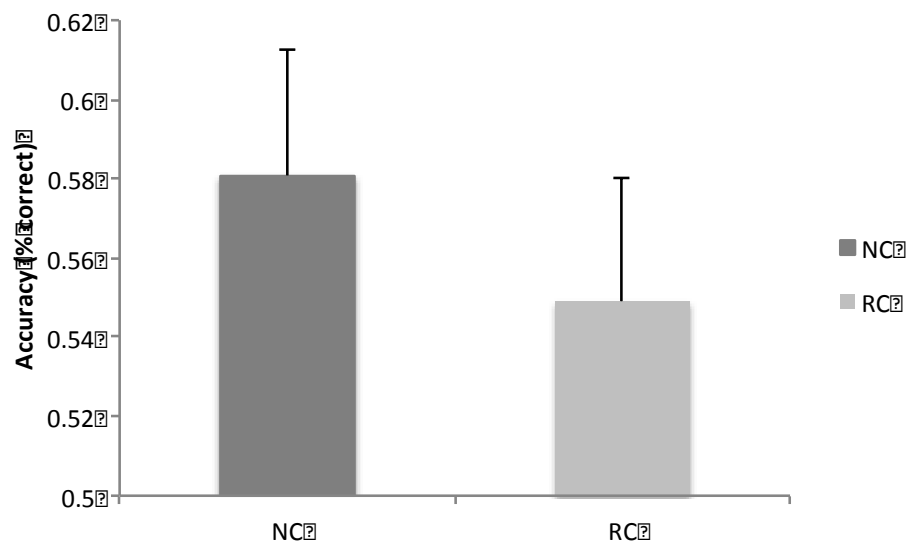
During the block 1 test trials, RC individuals did not display any significant difference ( $p > .05$ ) in average RT compared to NC individuals, suggesting that they appear to perform similarly to NC individuals at rest. As reported above, a significant main effect of block on average RT was observed in NC individuals and not with RC individuals, with a significant change in average RT revealed in NC individuals post exercise (block 3). However, the difference in average RT at block 3 between RC and NC individuals was not significantly different ( $p > .05$ ) despite RC individuals displaying higher average RT values ( $\mu = .746s$ ,  $s = .233s$ ) compared to NC individuals at block 3 ( $\mu = .657s$ ,  $s = .165s$ ) (Figure 3-2).

### Accuracy Across the Blocks

Output measures on various neuropsychological tests (i.e. CogSport, ImPACT) utilize both time to perform task as well as task accuracy. Previous research has revealed impaired performance on psychometric test up to two weeks post-concussion. In the current study, it is expected that RC individuals would display decreased CRT task accuracy compared to NC individuals. Accuracy measures were recorded as a percent correct; in order to compare these proportional values across the four blocks, accuracy data was converted using arcsine transformation before running parametric analysis. Repeated measures ANOVA indicated no significant main effect of block on accuracy in both NC ( $F(3, 60) = 2.098, p > .05$ ) and RC ( $F(3, 21) = .062, p > .05$ ) individuals on the CRT task. Neither a learning effect nor exercise arousal affected accuracy in both NC and RC groups (Figure 3-3). There was a significant main effect of group ( $p < .05$ ) where accuracy on the CRT task was greater in NC individuals ( $\mu = .581, s = .032$ ) in comparison to RC individuals ( $\mu = .549, s = .0311$ ) when averaged across the four blocks (Figure 3-4). Calculated effect size indicated a medium effect size ( $d = 1.01, r = 0.45$ ).



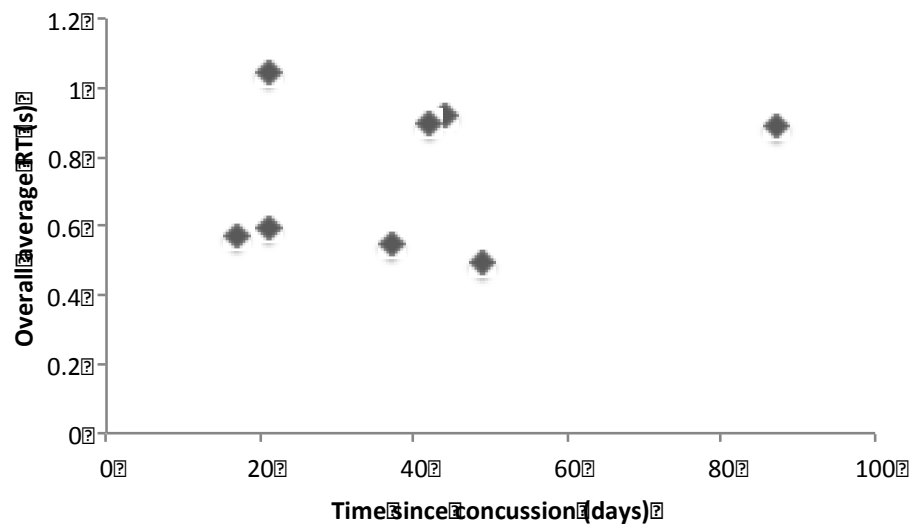
**Figure 3-3.** CRT Accuracy (% correct) scores across the four trial blocks of trials (block 1: 10 minutes prior to exercise; block 2: immediately prior to exercise; block 3: immediately following moderate exercise; and block 4: 5 minutes after exercise) for both NC and RC. No significant main effect of block ( $p > .05$ ) was observed in either NC or RC individuals



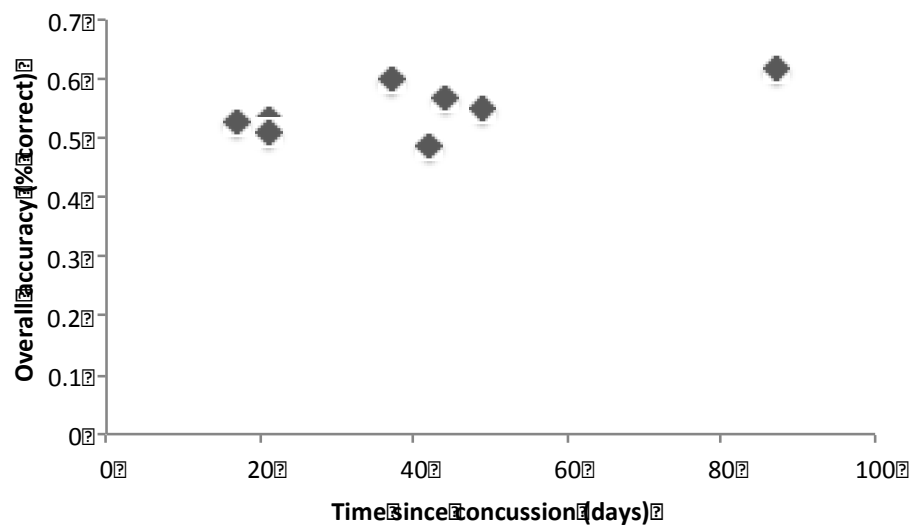
**Figure 3-4.** Overall accuracy (% correct) averaged across the four trial blocks, with standard deviation bars. Overall accuracy was significantly greater ( $p < .05$ ) in NC individuals compared to RC individuals, revealing a 3.2% difference.

### Symptom Assessment and CRT Task Performance

Cognitive deficits are suggested to extend beyond the symptomatic phase (McCrea et al., 2003). Correlation analysis was performed to determine if time since concussion was related to average RT at each of the four blocks. No significant relationships between average RT and time since concussion were observed at any of the four blocks (block 1:  $r_1 = .479$ ; block 2:  $r_2 = .162$ ;  $r_3 = .129$ ;  $r_4 = .160$ ; all  $p > .05$ ). When collapsed across the four blocks, overall average RT was also not significantly related to time since concussion ( $r = .217$ ,  $p > .05$ ) (Figure 3-5). Correlation analysis on task accuracy was also performed, however, no significant relationships were observed at any of the four blocks (block 1:  $r_1 = .110$ ; block 2:  $r_2 = .313$ ;  $r_3 = .618$ ;  $r_4 = .483$ ; all  $ps > .05$  ( $p > .05$ ). When collapsed across the four blocks, overall accuracy was also not significantly related to time since concussion ( $r = .654$ ,  $p > .05$ ) (Figure 3-6). Both findings suggest that longer time since concussion does not reflect recovery of cognitive performance.



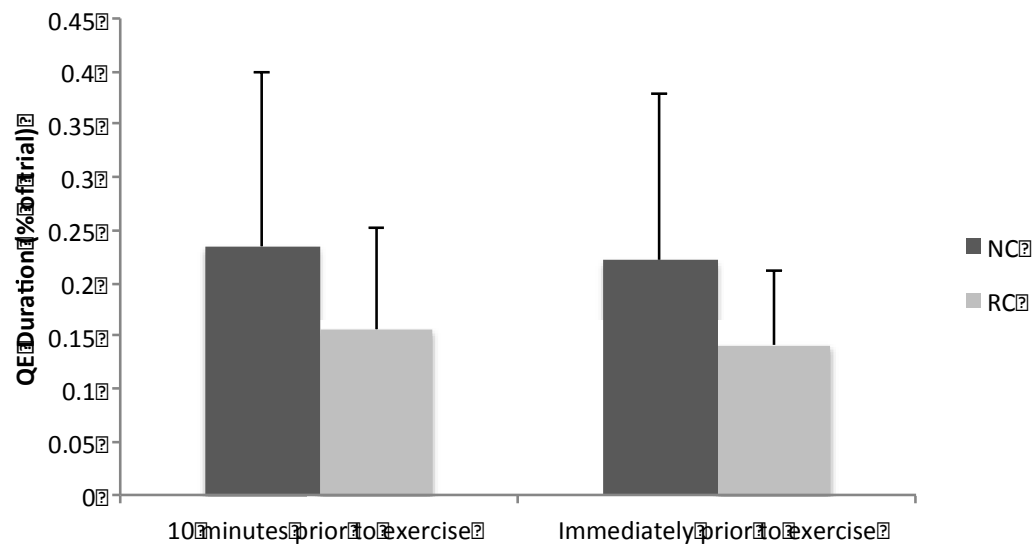
**Figure 3-5.** Scatterplot depicting overall average RT scores (s) in relation to time since concussion (days). Overall average RT was not significantly related to time since concussion ( $r = .217, p > .05$ )



**Figure 3-6.** Scatterplot depicting overall accuracy scores (% correct) in relation to time since concussion (days). Overall accuracy was not significantly related to time since concussion ( $r = .654, p > .05$ )

### **Gaze Behaviour and CRT Task Performance**

The Quiet Eye (QE) period is the onset of the final fixation on a task-relevant object just prior to the final movement of a skill. Previous research has suggested that QE behaviour in athletes is an indicator of performance success/accuracy (Vickers, 1996a). Recall that no significant difference in CRT performance was observed between RC and NC individuals. Since this was the case, higher levels of cognitive processing, as measured by gaze behaviour in the current study, should not differ. Gaze behaviour was analyzed in order to determine whether differences in higher levels of cognitive processing might still exist. Final Quiet Eye (QE) fixation duration, measured as a percentage of trial duration, was recorded during blocks 1 and 2 for 18 of the 21 NC and 8 RC individuals. Regression analysis indicated no significant main effect of block on QE duration between NC and RC individuals ( $p > .05$ ). No significant main effect of group ( $p > .05$ ) on QE duration was observed indicating that fundamental levels of cognitive processing had recovered in the RC group to similar levels of those in the NC group (Figure 3-7).



**Figure 3-7.** Quiet Eye (QE) duration (% of trial) was assessed at block 1 (10 minutes prior to exercise) and block 2 (Immediately prior to exercise) in both NC and RC individuals, including standard deviation bars. QE duration was not significantly higher in NC compared to RC at both blocks ( $p > .05$ )

## DISCUSSION

The objective of this portion of the current study was to determine whether CRT task performance, both at rest and after acute moderate levels of exercise, could elicit latent deficits in cognitive function in asymptomatic RC individuals. McMorris and Graydon (1996a) assessed the effect of exercise on the latency of a decision in a 4-choice soccer-related decision-making task. Results demonstrated a significant decrease in speed of decision with no effect on task accuracy post exercise. Covassin and colleagues (2007) assessed the effect of acute physical exertion on ImPACT test performance in non-concussed recreational athletes. In this study participants performed the neurocognitive assessment before and after acute exercise. However, the purpose of their study was to assess the attenuating effects

of maximal exercise on ImPACT measures, suggesting that administration of the assessment should not occur immediately after practice or game sessions. Findings demonstrated a significant decrease in the verbal memory composite post-exertion in the exercise group compared to a control group. In a later study, Majerske and colleagues (2008) assessed the effect of multiple, continuous physical activity levels following head injury on neurocognitive performance, revealing that higher levels of physical activity following concussion result in poorer ImPACT scores. More recently McGrath and colleagues (2012) examined post-exertion neurocognitive performance, using ImPACT, in recently concussed athletes who were asymptomatic at rest. The results from this study revealed that nearly one-third of these student-athletes who had returned to baseline ImPACT scores at rest demonstrated declined ImPACT performance following acute exercise. This study suggests that shortly following a concussion the CNS is unable to respond to exercise appropriately even if symptoms are not present at rest. Collectively, these studies suggest that accurate neurocognitive measures should be assessed both at rest and following exercise. However, it may be possible that these findings were unique to the ImPACT assessment and similar findings may not occur with other cognitive tests. The objective of the current study incorporated a novel assessment of neurocognitive function following acute physical exertion; using a CRT task that does not require individuals to have completed baseline pre-season neurocognitive testing because individuals could be compared to themselves across the four blocks of trials.



### **Do differences in RT and Accuracy exist between NC and RC individuals?**

Performance on cognitive tasks is expected to improve following an acute bout of moderate-intensity exercise (Easterbrook, 1959) in healthy individuals free from cognitive impairments. The current study introduced the assessment of cognitive function during the asymptomatic phase both at rest and after an acute bout of moderate-intensity exercise in order to evaluate whether cognitive deficits may persist after the symptomatic phase. Assessments used during the asymptomatic phase following a concussion (i.e., the Return to Play protocol) rely heavily on self-reported symptoms before and after various bouts of exercise. However, it is well known that cognitive function deficits may persist longer than the presence of symptoms (McCrea et al., 2003). Current neurocognitive tests, including ANAM and ImPACT, utilize simple RT tasks to assess cognitive function. However, simple RT tasks require less cognitive processing compared to CRT tasks due to differences in pre-motor programming (Klapp, 1995). Simple RT responses can be identified by the participant in advance of a prompt or signal, indicating the beginning of the RT interval, while with CRT tasks there is the additional preparation involving which of the possible responses is required. This notion may explain why current neurocognitive assessments are insufficient in detecting lingering cognitive deficits after the symptomatic phase. In order to evaluate possible differences in cognitive processing between NC and RC individuals, the current study utilized a CRT decision-making task. The task required that the individuals use body-size information to make an appropriate decision and it was similar to decisions that an athlete would have to make during a game or

competition. Tomporowski and Ellis (1986) hypothesized that the more challenging a cognitive task is, the more attentional resources are required. Cognitive tasks that are not challenging to the attentional system will display no change during exercise, meaning that more complex tasks performed during exercise may require a shift in attentional resources. In the current study, performance on the CRT task was assessed immediately post an acute bout of exercise. It was expected that RC individuals would display either no change or an increase in average RT (poorer performance) following acute exercise. Findings from the current study revealed that RC individuals did not display the combined effect of learning and exercise arousal displayed in NC individuals. One explanation could be that RC individuals are not yet experiencing optimal arousal following moderate-intensity exercise but rather fatigue, which would result in decreased cognitive task performance. A second suggestion, in compliance with Tomporowski and Ellis (1986), could be the inability of RC individuals to allocate attention resources under physical stress.

The current study utilized an iPad application that was designed with a certain level of task difficulty, which would result in minimal or no learning effect to occur. The CRT task was designed with 90 possible scenarios of RT and accuracy, 24-30 of which were randomly assigned within each block. It was expected that accuracy on the CRT task should not be affected by practice or exercise arousal. Findings from the current study revealed no change in accuracy across the four blocks of trials in both NC and RC groups (Figure 3-3). This suggests that the CRT task was sufficient in consistently and accurately assessing each individual's decision-making capabilities. The effect of concussion on task accuracy, as measured

by percent correct, was assessed in 20 professional rugby league players having suffered a head injury (Hinton-Bayre, Geffen, Geffen, McFarland, and Frijs, 2010). The study utilized three psychometric tests (Speed of comprehension, Symbol Digit, and Digit Symbol) to examine cognitive recovery, demonstrating impaired performance up to 1-2 weeks post-concussion. When comparing between groups, it was expected that RC individuals would display decreased accuracy on the CRT task compared to NC individuals due to lingering neurocognitive deficits. Previous research by Chen and colleagues (2003) revealed slightly lower accuracy scores on a working spatial memory task in mTBI patients when compared to controls, attributing these changes in task accuracy to differences in cerebral metabolism. Results from the current study revealed that task accuracy in RC individuals was significantly lower than NC individuals, displaying a 3.2% difference when averaged across the four blocks. Decision-making capabilities in RC individuals appear to be impaired compared to NC individuals possibly due to an inability of the CNS to attend to the cognitive task. It has previously been suggested that impaired psychometric performance might predict reduced playing ability, risk of further injury, or cumulative effects (Hinton-Bayre, Geffen, Geffen, McFarland, Frijs, 2010) suggesting the importance of assessing both response time and accuracy during the RTP protocol.

### **Is time since concussion correlated with CRT task performance?**

Previous research in individuals with PCS has revealed that time since concussion is not related to the recovery of cognitive function (Ryan and Warden, 2003). However, this finding may be due to more long-lasting symptoms

experienced by individuals with PCS compared to recently concussed individuals who experience temporary deficits. McCrea and colleagues (2003) revealed recovery of cognitive function, as measured by the Standard Assessment of Concussion (SAC) with an increase in time post injury. In the current study it was expected that time since concussion would be related to average RT due to the recovery of cognitive function over time (i.e. an increase in time post injury would be demonstrate decreased, or improved, average RT). However, the current study revealed no significant correlation between time since concussion and CRT task performance (Figure 3-5 and 3-6), suggesting that cognitive recovery does not follow a linear timeline.

### **Is gaze behaviour altered in recently concussed (RC) individuals?**

Fixation durations are suggested to be a reflection of the amount of attention being allocated toward a feature within a visual display (Mann, Williams, Ward, and Janelle, 2007). The longer the fixation the more overt attention is being allocated towards the fixated target/object. Quiet Eye (QE) was measured in each trial of the first two blocks in order to assess whether differences in average RT could be attributed to lack of attention to the task. It was expected that increased RT (poorer performance) on the CRT task would coincide with shorter QE duration. However, CRT task performance at blocks 1 and 2 were not significantly difference between NC and RC individuals (Figure 3-7), suggesting that higher levels of cognitive processing at rest may have fully recovered to normal baseline levels in the RC population.

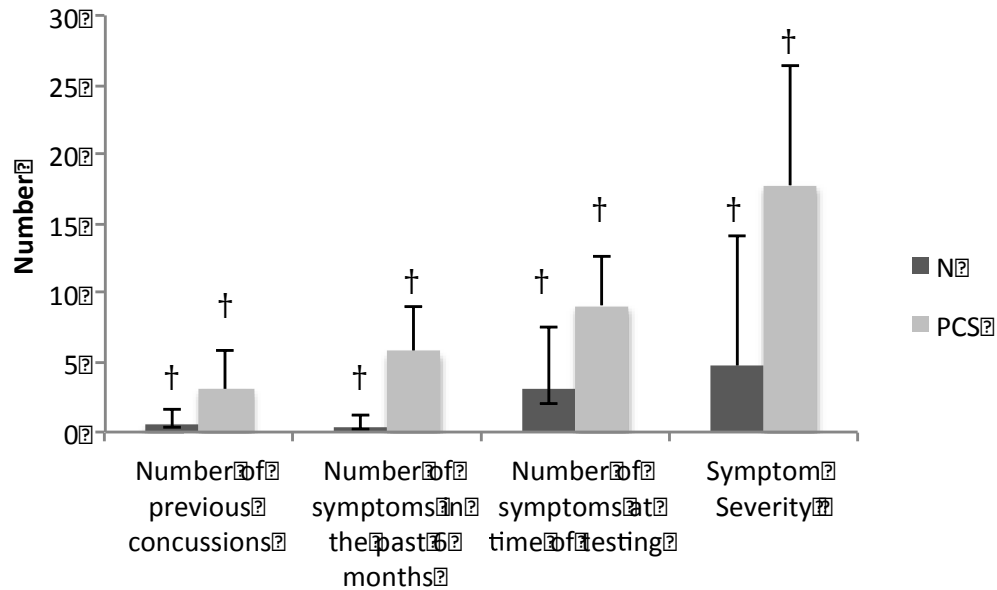
## CHAPTER IV

### Non-concussed Individuals and Individuals with Post-Concussion Syndrome

#### RESULTS

##### Descriptive Analyses: Non-concussed (NC) and PCS Groups

Demographic information, previous concussion and symptom history, and current symptom assessment are displayed in Table 4-1. A total of 21 NC and 9 PCS individuals were tested. All participants were able to complete the four blocks of CRT testing and gaze data was obtained for 18 of the 21 NC and 8 of the 9 PCS individuals. Those four individuals whose gaze data was not recorded was due to technical difficulties in calibrating the Eye Tracker. No significant difference in age ( $p > .05$ ) was found between the two groups. The NC group consisted of 10 males and 11 females while the PCS group was entirely female. Independent samples t-tests indicated significant group differences in number of previous concussions ( $t(9) = -2.726, p < .05$ ), number of symptoms in the six months prior to testing ( $t(8.4) = -4.771, p < .05$ ), and number of symptoms at time of testing ( $t(28) = -3.584, p < .05$ ) (Figure 4-1).



**Figure 4-1.** Demographic information comparing both NC and PCS groups including: number of previous concussions, number of symptoms experienced in the 6 months prior to testing, number of symptoms at time of testing, and symptom severity scores at time of testing, including their respective standard deviation bars. There was a significant main effect of group in all 4 variables.  
† Indicates a significant difference ( $p < .05$ )

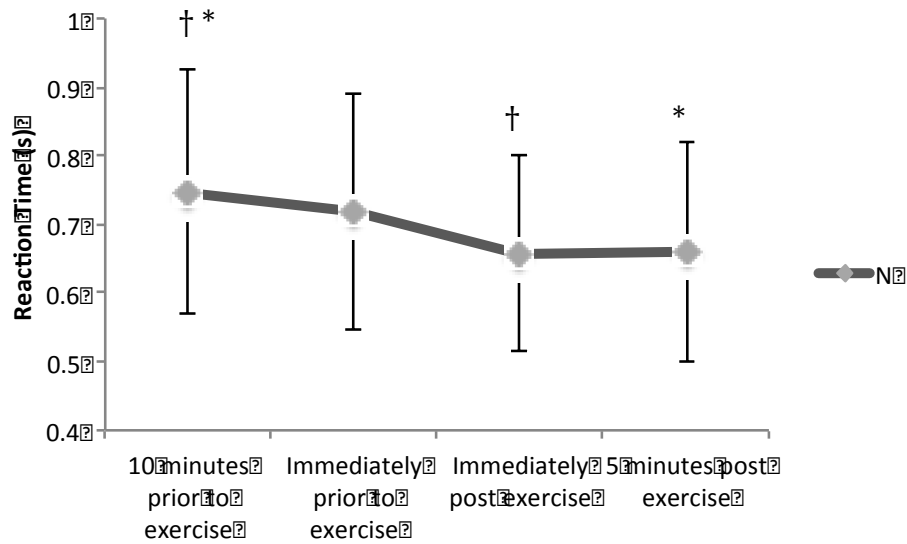
### Response Time (RT) Across the Trial Blocks

Repeated measures ANOVA indicated significant differences in CRT task performance, as measured by average RT, across the four blocks in NC individuals (Figure 4-2a) (see *Part I: Non-concussed Individuals and Recently Concussed Individuals - Response Time (RT) Across the Trial Blocks* for further detail).

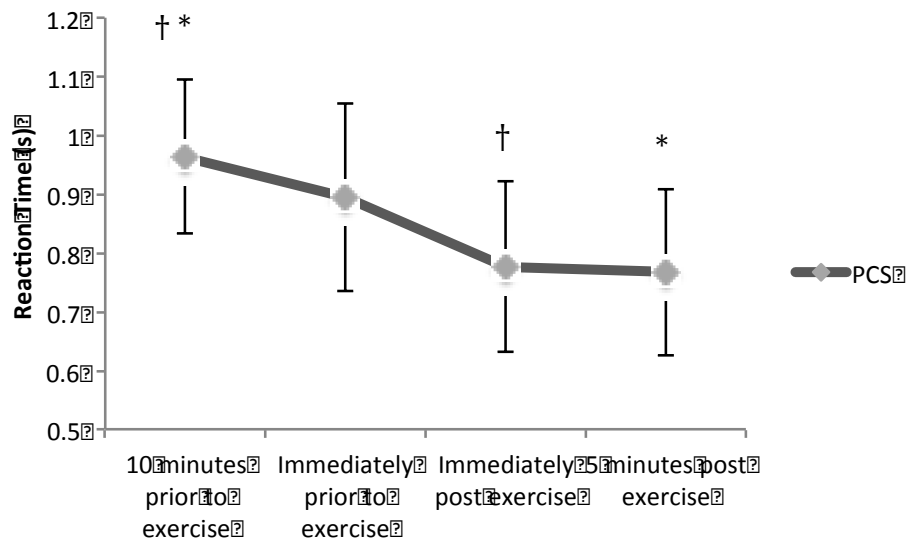
In the PCS group, results indicated that CRT task performance, as measured by average RT, was also significantly affected by block,  $F(3, 24) = 9.250, p < .05$ . Pairwise comparisons revealed no significant effect of learning ( $p > .05$ ) from block 1 ( $\mu = .964s, s = .165s$ ) to block 2 ( $\mu = .895s, s = .168s$ ). Average RT immediately post exercise (block 3) ( $\mu = .778s, s = .144s$ ) was not significantly lower ( $p > .05$ ) than immediately prior to

exercise (block 2) ( $\mu = .895s$ ,  $s = .168s$ ) despite a mean difference of .117s between the two blocks. The combined influence of leaning effect and exercise on facilitated CRT performance resulted in a significant difference ( $p < .05$ ) in average RT from block 1 ( $\mu = .964s$ ,  $s = .165s$ ) to block 3 ( $\mu = .778s$ ,  $s = .144s$ ) ( $d = 1.20$ ,  $r = .51$ ) and from block 1 ( $\mu = .964s$ ,  $s = .165s$ ) to block 4 ( $\mu = .768s$ ,  $s = .156s$ ) ( $d = 1.22$ ,  $r = .52$ ), again with this combined influence persisting for 5 minutes post exercise; indicated by no change in RT from block 3 ( $\mu = .778s$ ,  $s = .144s$ ) to block 4 ( $\mu = .768s$ ,  $s = .156s$ ) (Figure 4-2b).

A



B



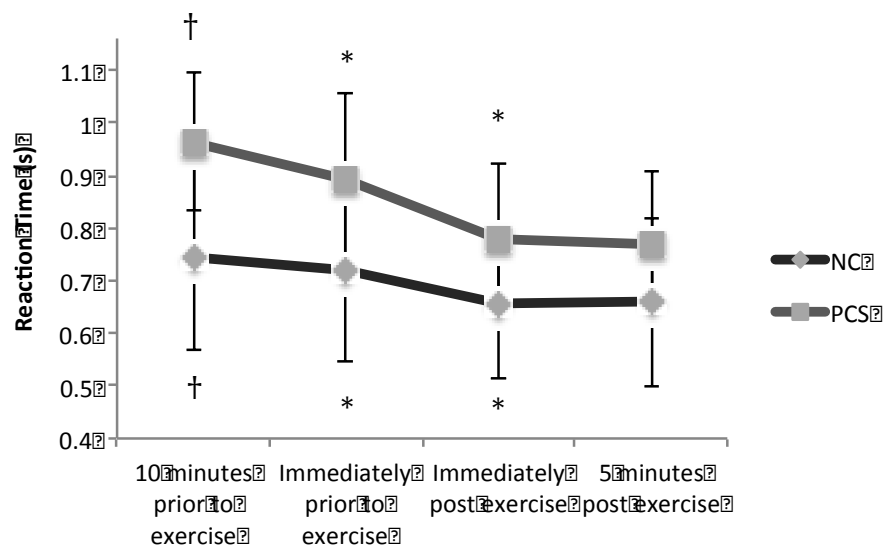
**Figure 4-2a and 4-2b.** Average RT scores (s) at the four blocks (block 1: 10 minutes prior to exercise; block 2: immediately prior to exercise; block 3: immediately following moderate exercise; and block 4: 5 minutes after exercise). Figure A depicts average RT across the four blocks in NC. Figure B depicts average RT across the four blocks in PCS. Both groups displayed a significant main effect of block ( $p < .05$ ) revealing a combined effect of learning and exercise on average RT, as indicated by the significant decrease in average RT from block 1 to block 3 and from block 1 to block 4.

† Indicates a significant difference between block 1 and 4 ( $p < .01$ )

\* Indicates a significant difference between block 1 and 3 ( $p < .01$ )



Although both NC and PCS individuals displayed similar learning and exercise effects on average RT, independent samples t-tests indicated that average RT in block 1 was significantly higher ( $t(28) = -3.293, p < .05$ ) in PCS individuals ( $\mu = .964s, s = .131s$ ) compared to NC individuals ( $\mu = .747s, s = .178s$ ) ( $d = 1.39, r = .57$ ). Similar results were found between groups at blocks 2 and 3 where average RT in the PCS group was significantly higher ( $p < .05$ ) than that of the NC group. At block 2, average RT in PCS individuals ( $\mu = .895s, s = .160s$ ) was significantly greater ( $t(28) = -2.640, p < .05$ ) compared to NC individuals ( $\mu = .718s, s = .172s$ ) ( $d = 1.06, r = .47$ ). At block 3, average RT in PCS individuals ( $\mu = .778s, s = .146s$ ) was significantly greater ( $t(28) = -2.118, p < .05$ ) compared to NC individuals ( $\mu = .657s, s = .143s$ ) ( $d = 0.84, r = .39$ ). Finally, at block 4, average RT in PCS individuals ( $\mu = .768s, s = .142s$ ) was not significantly different than that of the NC individuals ( $\mu = .659s, s = .160s$ ) (Figure 4-3).



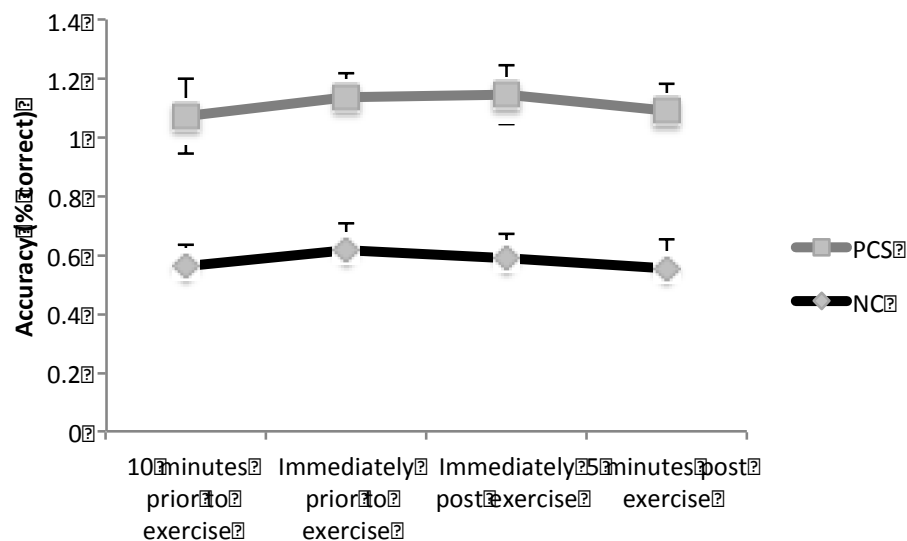
**Figure 4-3.** Independent samples t-tests indicated significantly greater average RT scores (s) in PCS individuals compared to NC individuals at the four trial blocks (block 1: 10 minutes prior to exercise; block 2: immediately prior to exercise; block 3: immediately following moderate exercise; and block 4: 5 minutes after exercise). The graph also depicts a similar trend of average RT across the blocks.

† Indicates a significant difference between groups at block 1 ( $p < .01$ )

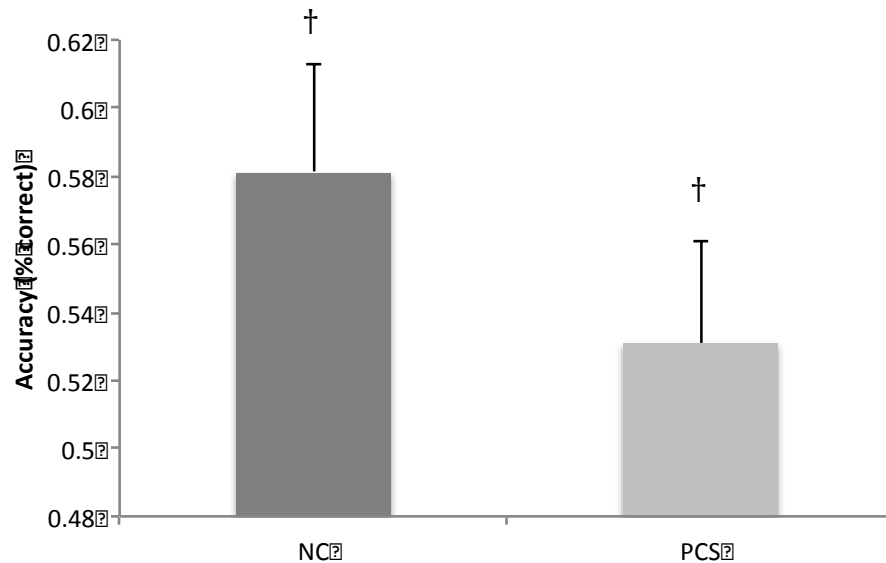
\* Indicates a significant difference between groups at block 2 ( $p < .05$ )

### Accuracy Across the Blocks

As mentioned in Chapter III, all accuracy data was converted using arcsin transformation in order to run parametric analysis. Repeated measures ANOVA indicated no significant main effect of block ( $p > .05$ ) on accuracy on the CRT task in both NC and PCS groups. Neither a learning effect nor exercise arousal affected accuracy in both NC ( $F(3, 60) = 2.098, p > .05$ ) and PCS ( $F(3, 24) = .263, p > .05$ ) groups (Figure 4-4). There was a significant main effect of group ( $F(1, 28) = 15.765, p < .05$ ) where accuracy on the CRT task was greater in NC individuals ( $\mu = .581, s = .032$ ) than PCS individuals ( $\mu = .531, s = .03$ ) when averaged across the four blocks (Figure 4-5). Calculated effect size indicated a moderate effect size ( $d = 1.61, r = 0.63$ ).



**Figure 4-4.** Accuracy (% correct) in the CRT task across the four blocks of trials (block 1: 10 minutes prior to exercise; block 2: immediately prior to exercise; block 3: immediately following moderate exercise; and block 4: 5 minutes after exercise). No significant main effect of block ( $p > .05$ ) was observed in either NC or PCS.



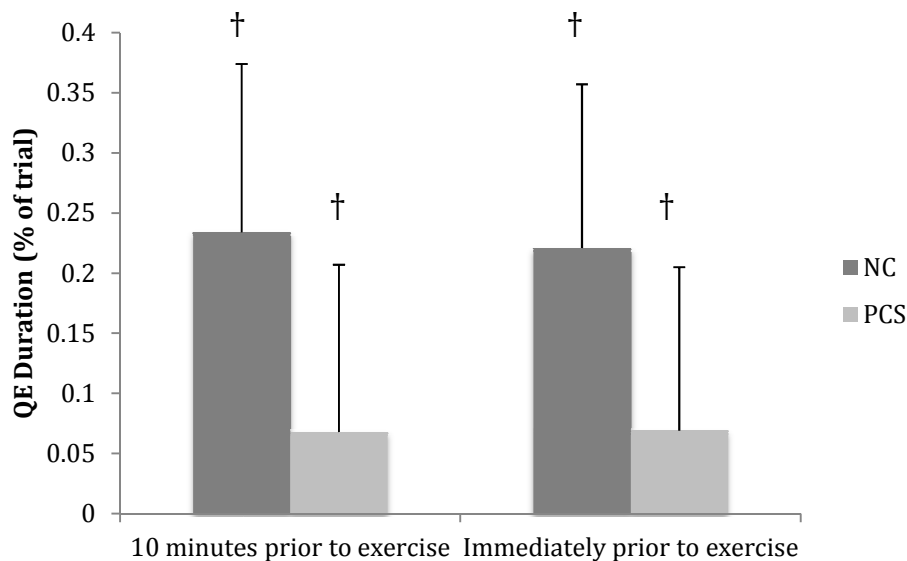
**Figure 4-5.** Overall accuracy (% correct) averaged across the four trial blocks, including standard deviation bars. Overall accuracy was significantly greater ( $p < .05$ ) in NC individuals compared to PCS individuals, revealing a 5.0% difference. † Indicates a significant difference between groups at block 1 ( $p < .05$ )

### Symptom Assessment and CRT Task Performance

PCS is a complex disorder characterized by the reoccurrence of concussion-based symptoms for weeks or months following a head injury. Correlation analysis was used to determine if CRT task performance was related to the presence of symptoms at time of testing. Number of symptoms at time of testing was ranked in both NC and PCS individuals separately. There was no significant relationship between the number of symptoms at time of testing and RT average or accuracy at each of the four blocks ( $p > .05$ ) in both NC and PCS individuals. Correlation analysis was also used to determine if CRT task performance was related to symptom severity at time of testing. There was a significant relationship between symptom severity and average RT at block 1 ( $r = .534, p < .01$ ) and symptom severity and average RT at block 2 ( $r = .513, p < .01$ ) suggesting that with greater symptom severity average RT increases when individuals are at rest.

## Gaze Behaviour and CRT Task Performance

Gaze behaviour was analyzed in order to determine whether differences in CRT task performance between NC and PCS individuals could be attributed to differences in higher levels of cognitive processing. Final Quiet Eye (QE) fixation duration, measured as a percentage of trial duration, was recorded during block 1 and 2 for 18 NC and 8 PCS individuals. Regression analysis indicated no significant main effect of block on average QE duration ( $p > .05$ ). There was a significant main effect of group ( $F(1, 24) = 8.978, p < .05$ ) indicating that fundamental levels of cognitive processing differ between NC and PCS populations. Average QE duration was greater in NC ( $\mu = .234, s = .140$ ) compared to individuals in PCS ( $\mu = .068, s = .139$ ) at block 1 ( $d = 1.19, r = 0.51$ ) as well as block 2 (NC:  $\mu = .221, s = .136$ ; PCS:  $\mu = .069, s = .136$ ) ( $d = 1.12, r = 0.49$ ) (Figure 4-6).



**Figure 4-6.** Quiet Eye duration (% of trials) was assessed at block 1 (10 minutes prior to exercise) and block 2 (Immediately prior to exercise) in both NC and PCS individuals. QE duration was significantly higher ( $p < .05$ ) in NC compared to PCS during both blocks ( $p > .05$ ), including standard deviation bars  
† Indicates a main effect of group ( $p < .05$ )

## DISCUSSION

The objective of this portion of the current study was twofold: 1) to provide evidence that differences in cognitive function, as measured by a CRT task, exist between NC and PCS individuals, both at rest and after acute exercise; and 2) to determine whether any differences in CRT task performance can be attributed to differences in gaze behaviours. The former objective provided a novel comparison within groups by assessing CRT performance both at rest and after moderate-intensity exercise.

### **Do differences in RT and Accuracy exist between NC and PCS?**

Individuals with PCS are known to have long lasting, concussion-induced symptoms, which include impairments in neurobehavioural and neurocognitive functioning (Ryan and Warden, 2003). In order to evaluate possible differences in cognitive processing between NC and PCS individuals, the current study utilized a CRT decision-making task. Performance on cognitive tasks is expected to improve following an acute bout of moderate-intensity exercise with healthy individuals free from cognitive impairments (Easterbrook, 1959). McGrath and colleagues (2012) examined post-exertion neurocognitive performance, using ImPACT, in recently concussed athletes revealing that not all asymptomatic concussed individuals were able to perform at baseline levels following physical activity. In the current study, it was expected that individuals with PCS would display either no change or decreased CRT task performance following acute exercise. The PCS group displayed similar changes in average RT across the four blocks to the NC group, thus suggesting that

regardless of persisting concussion-based symptoms or absence of symptoms, exercise affects RT in both groups equally. The combined influence of learning effect and exercise was able to facilitate task performance as indicated by decreased average RT immediately post exercise. However, differences lay in the initial average RT scores (Figure 4-3) such that average RT was significantly higher in the PCS group in comparison to the NC group at blocks 1, 2, and 3, approaching a near significant difference at block 4. One explanation could be that individuals with PCS display a more cautious and time-consuming approach to performing novel tasks.

The current study utilized a CRT task designed such that performance on the task should not be affected by practice (i.e., only a subset of the 90 possible scenarios was randomly selected for any given block of trials). Findings from the current study indicated no change in accuracy across the four blocks of trials in both NC and PCS individuals (Figure 4-4) demonstrating that the CRT task was sufficient in consistently and accurately reporting each individual's decision-making capabilities. When comparing between groups, it was expected that PCS individuals would display decreased accuracy on the CRT task compared to NC due to persistent neurocognitive deficits. Task accuracy in PCS individuals was significantly lower than NC individuals, displaying a 5% difference across the four blocks. This finding coincides with previous findings that individuals with PCS suffer from cognitive impairments in information processing (Mathias, Beall, and Bigler, 2003). In this case the cognitive impairment was an inability to integrate optical information (optic flow and rate of gap closure) and body size knowledge to make an accurate judgment about the pass-ability of an aperture.

### **Does average RT or accuracy decline with increased number of symptoms at time of testing?**

Previous research by Fazio and colleagues (2007) demonstrated that symptomatic concussed individuals demonstrated poorer performance on the Processing Speed Composite and Reaction Time Composite portions of the ImpACT neurocognitive assessment compared to asymptomatic concussed individuals and non-concussed controls. It is expected that an increased number of symptoms at time of testing will reduce cognitive performance. However, the participants used in the aforementioned study were recently concussed and had been evaluated within one week of sustaining their head injury. The current study assessed individuals with long-term, reoccurring symptoms, which suggests that individuals with PCS displayed poorer CRT task performance due to cognitive deficits rather than due to the presence of symptoms. Individuals with PCS were able to respond to exercise arousal similarly to NC individuals despite experiencing a significantly greater number of symptoms and symptom severity at time of testing. The finding that the presence of symptoms is independent of facilitated cognitive performance challenges the use of symptom assessments alone during the RTP protocol as a means of monitoring recovery. Incorporating a CRT task during the RTP protocol would provide clinicians with information on each individual's response speed.

### **Can gaze behaviour explain differences in CRT task performance?**

As mentioned in Chapter I, fixation durations indicate the amount of attention being gathered from a visual display (Mann, Williams, Ward, and Janelle, 2007). The longer the fixation the more overt attention is being allocated towards

the fixated target/object. In relation to sports, “Quiet Eye” has been reported as the final fixation of the eye on a task-relevant target that occurs just prior to movement (Vickers, 2007) and has been shown to be a strong indicator of athlete success (Vickers, 1996a). In the current study, participants were required to make a decision regarding “safe passage” through a closing aperture and execute that decision by selecting a “yes” or “no” response as quickly as possible. QE was measured in each trial of the first two blocks in order to assess whether differences in average RT could be attributed to lack of attention to the task-relevant objects. It was expected that poorer performance on the CRT task would coincide with shorter QE duration. Findings from the current study demonstrated that average QE duration was significantly shorter in PCS individuals compared to NC individuals. This finding is reflected in overall poorer accuracy performance on the CRT task in PCS individuals. Therefore, the shorter QE duration observed in PCS individuals could suggest that they were distracted by other environmental objects and unable to appropriately attend/concentrate on the task-relevant objects and thus unable to elicit accurate decisions. The combination of these two findings suggests that these individuals may not elicit appropriate decisions when navigating through an environment, potentially leading to further risk of injury.



## CHAPTER V

### GENERAL DISCUSSION

Current neurocognitive assessments are largely used during the symptomatic phase following a concussion for the detection of head injury and are not widely used in monitoring or assessing the recovery of cognitive function upon resolution of physical concussion-based symptoms. Methods of monitoring recovery from a head injury during the asymptomatic phase use a step-wise RTP protocol, which involve self-reported symptom assessments before and after acute bouts of exercise rather than neurocognitive assessments. However, as the current study suggests, this may not be a wise practice to determine the resolution of a concussion because the recovery of cognitive function appears to persist independent of the presence of symptoms. Therefore, assessment of cognitive function and not symptom assessments after an acute bout of exercise may be a more reliable means of clearing athletes for return to play.

The next major question that remains is, which cognitive assessment is best to use during the asymptomatic phase to determine if the athlete is able to return to play? A study by McGrath and colleagues (2012) revealed the use of ImPACT in detecting latent cognitive deficits immediately following an acute bout of exercise in asymptomatic concussed athletes. However, the downfall of using neurocognitive assessments such as ImPACT is having to obtain baseline pre-season measures of each athlete when they are free from head injury. This may not be possible in all situations. The current study set out to quantify cognitive function using a CRT task that was sensitive in detecting deficits in three distinct groups: 1) non-concussed

(asymptomatic and no concussions in last 6 months); 2) recently concussed (asymptomatic > 24 hours and concussion < 90 days before testing); and 3) individuals with PCS (symptomatic >90 days and concussion >90 prior to testing) that did not require previous baseline measures but would rely on normative data instead. It appears as though a CRT task prior to and following exercise may be a viable protocol for assessing cognitive recovery following a concussion (see Chapters 3 and 4 for details).

Chapter 3 compared the effects of learning and exercise arousal in non-concussed (NC) and recently concussed (RC) individuals. This chapter revealed the inability of RC individuals to demonstrate facilitated cognitive performance despite symptom resolution. Higher levels of cognitive function, as measured by gaze behaviour, appeared to have returned to baseline during rest. This RC population was free from symptoms yet was unable to perform at a similar cognitive level to NC individuals following the added stress of physical activity; suggesting that attentional resources after physical stress are not sufficiently being allocated to the cognitive task at hand. Chapter 4 compared the effects of learning and exercise arousal in NC individuals and individuals with PCS. The findings from this section revealed that while individuals with PCS displayed similar improvements in cognitive performance to NC individuals, overall performance was significantly reduced in individuals with PCS, which can be attributed to a disruption in higher levels of cognitive processing (i.e., shorter Quiet Eye durations).

Overall, both concussion-induced symptoms and facilitated cognitive performance are independent factors that should be treated separately in assessing

recovery from a head injury. The absence of symptoms does not inherently mean that cognitive performance under acute physical stress has completely recovered in recently concussed individuals. On the other hand, PCS individuals continue to experience concussion-related symptoms, but appear to display partially recovered cognitive performance (i.e., RT but not accuracy). However, the only consistent finding is that the persistence of symptoms appears to be related to deficits in higher levels of cognitive processing as observed in gaze behaviours.

One limitation of the current study is the inability to distinguish between changes in CRT performance due to the effects of learning and the effects exercise arousal. Further studies should utilize a control day, without the added effect of exercise, to see if a true effect of learning exists. Once the effect of learning has been teased out, any changes in CRT performance following acute exercise can then be attributed to exercise arousal. With regards to task accuracy, the task was not normalized to each individual's shoulder width suggesting that the task may not be a true representation of an individual's ability to make accurate decisions on a virtual task. Task accuracy in the non-concussed group was low (below 60%) while previously concussed individuals displayed accuracy scores below 50%. Despite the significant difference between the non-concussed and previously concussed individuals accuracy scores on the task suggests that correct answers may be due to chance. The significance of the current study is not immediate application but rather it is the first study to assess a potential tool (an iPad task) for use during the RTP protocol in order to assess the recovery of cognitive function.

Moving forward, incorporating a CRT task into current assessments of cognitive function may be beneficial in RC populations. In a RC population, CRT tasks used before and after acute exercise could aid in identifying the ability of the athlete's cognitive system to allocate sufficient resources to decision-making capabilities under physical stress and possibly avoid another head injury. In a PCS population, the use of a CRT task could be used for the identification of deficits in higher level processing, however this may require a database of normative data from a non-concussed age-matched population.

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## APPENDIX A

## SYMPTOM EVALUATION

**3 How do you feel?**  
*"You should score yourself on the following symptoms, based on how you feel now".*

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

**Total number of symptoms** (Maximum possible 22)

**Symptom severity score** (Maximum possible 132)

Do the symptoms get worse with physical activity?  Y  N

Do the symptoms get worse with mental activity?  Y  N

self rated  self rated and clinician monitored

clinician interview  self rated with parent input

**Overall rating:** If you know the athlete well prior to the injury, how different is the athlete acting compared to his/her usual self?

Please circle one response:

no different  very different  unsure  N/A

Figure 1-1. Symptom checklist from SCAT-3 used to monitor symptom recovery in previously concussed individuals

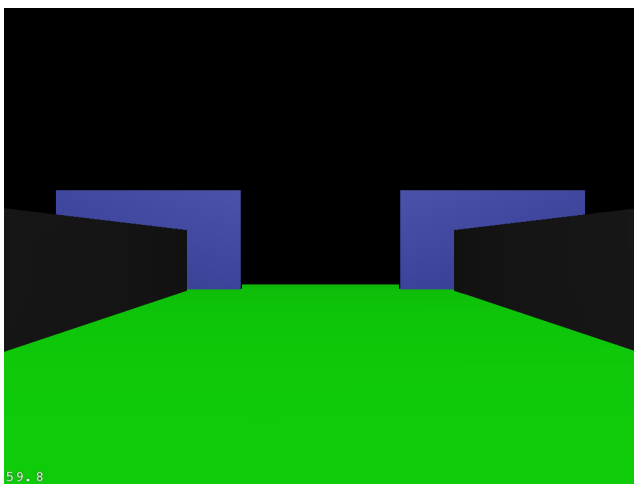
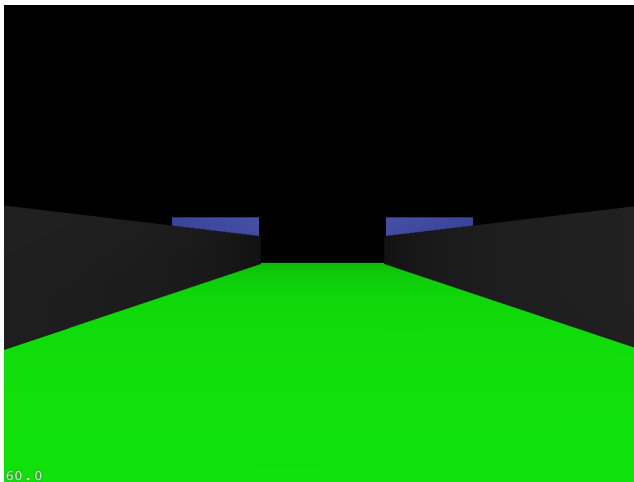


Figure 1-2. View of the iPad CRT task. First person perspective of the individual traveling towards two closing doors.

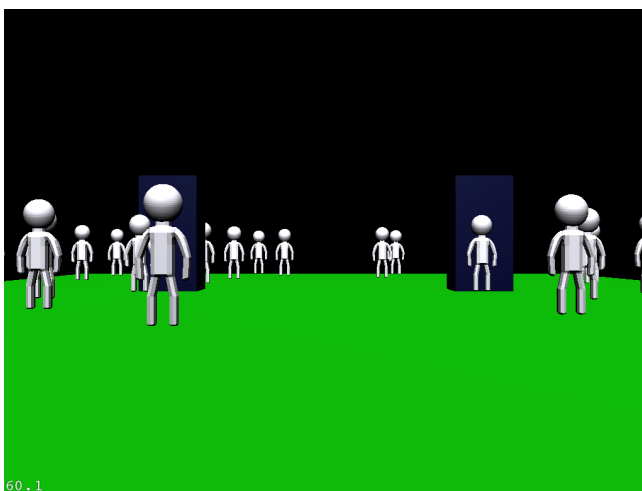


Figure 1-3. People mode of the individual traveling towards two closing doors.

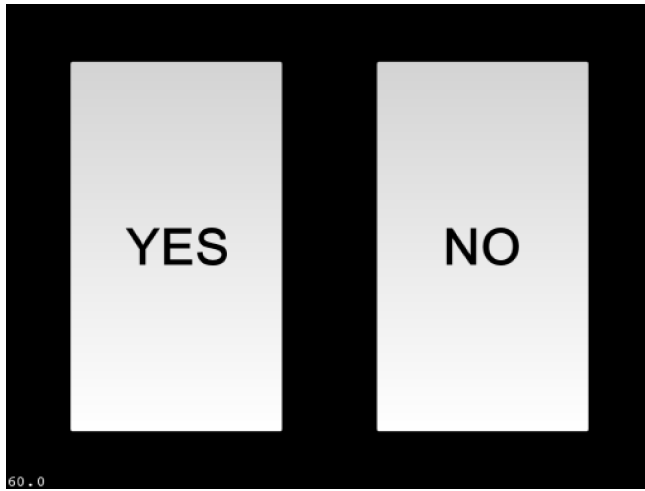


Figure 1-4. Just prior to reaching the closing doors, the individual is prompted to select “yes” or “no” regarding whether they think they could have passed through the door without a collision or not.

## APPENDIX B

### INFORMED CONSENT STATEMENT

WILFRID LAURIER UNIVERSITY

Quantifying cognitive function in concussed varsity athletes  
Stephanie Ramautar, H.B.Sc and Michael Cinelli, PhD

#### **Information**

You are invited to participate in a research study. An iPad application was designed to measure an individual's decision-making capabilities. The task is a first-person perspective that shows an individual moving through space and approaching 2 closing doors. The person must determine whether he or she could fit through the doors without colliding with the doors. The iPad task measures reaction time and accuracy in order to assess levels of cognitive function, specifically perception and action integration.

Participants will be asked to perform the task while seated with the iPad held out comfortably in front of them at a comfortable viewing angle. The opening screen asks the participant to fill in background information including: name, birth date, gender, shoulder width and sport (if applicable). One trial on the iPad task consists of 26 consecutive measures of a participant's reaction time and accuracy, which will take approximately 3 minutes to complete.

Participants will be asked to complete 4 trials of the iPad task: 1) seated with the iPad held out comfortably in front of them, 2) 10 minutes after performing trial 1, 3) within the first 5 minutes of recovery after an acute bout of exercise, and finally 4) at 15 minutes post acute exercise. An acute exercise bout, approximately 15 minutes in length, will be used to elicit changes in cognitive performance. You will be asked to perform a moderate intensity exercise bout on a cycle ergometer, the protocol for which will be determined by your WLU Athletic Therapist. For trials 1 and 2, you will be asked to visit the LPMB lab on the same day that you begin stage 2 of the Return to Play protocol. Trials 3 and 4 will be conducted in the Athletic Therapist Clinic at Wilfrid Laurier University.

During iPad task performance in trials 1 and 2, each athlete will be fitted with an Eye Tracker system that will analyze gaze behaviour. Athletes will be fitted with a heart rate monitor throughout all 4 trials.

#### **Purpose and Objective**

The purpose of the proposed study is to use this iPad application to quantify cognition function in concussed varsity athletes known to have cognitive deficits. Both cognitive function scores and gaze behaviour will be compared in asymptomatic post-concussion athletes to that of a healthy population. The objective is to identify if either cognitive performance or gaze behaviours differ among healthy, physically active young adults and asymptomatic concussed varsity athletes.

## **Risks**

Physical risk may include eyestrain, as the task requires participants to stare at the screen in order to complete consecutive measures. There is also the risk of boredom, as the task requires participants to complete 26 consecutive measures of reaction time and accuracy to complete 1 trial of the task.

Physical risk of post concussion symptoms (i.e. headache, dizziness) may reemerge during cognitive task performance. It is important to note that symptom reappearance is a known potential side effect of the exercises performed during the RTP protocol; the fundamental exercises are used to put moderate physiological stress on concussed athletes in order to assess reemergence of symptoms.

There is a risk of demoralization as typically failure to complete such physical and neuropsychological assessments suggests that an athlete is unable to return to normal game play. Although failure to complete the assessments (e.g. iPad task) of the proposed study will not affect the decision to return to play, failure on any assessment post concussion could reduce the confidence of the athlete hoping to return to normal game play.

Participation in this study should be reviewed with your physician.

## **Benefits**

Researchers will benefit from having a portable tool that uses objective measures to assess a participants' perception and action integration function. Results from each participant can be easily obtained and analyzed considering the output is in the form of an excel spreadsheet. Researchers will also benefit from the fundamental application provided by Eye Tracker data, which will provide insight into gaze behaviours seen in both concussed and non-concussed varsity athletes. Results from this study may provide a gateway into using portable technology for monitoring cognitive recovery in concussed athletes, which can be utilized by coaches, parents, and/or training staff in the future.

## **Confidentiality**

Assigning participants a code that corresponds to their data will ensure confidentiality. The primary researcher and project supervisor will have access to the data, which will be stored on password-protected computers in the LPMB Lab (NC104). Records identifying each participant will also be stored in the same lab. Upon completion of the project, data will be retained indefinitely in the LPMB lab in coded format and may be accessed (with permission) for future research in this area. The project data will become part of a database and access to this data will be granted by the project supervisor, Dr. Michael Cinelli for both current and secondary analyses. In terms of publication and distribution of results, participant results will be presented as means and percentages; no individual results will be reported. Upon signing the informed consent, one copy will be kept on file by the researchers of the study and a second copy will be provided to the participant.

### **Contact**

Questions or concerns about the study and its procedures can be directed to the Research Ethics Board (REB) Chair, Dr. Robert Basso, at rbasso@wlu.ca or call 519-884-1970 x4994. General questions can be directed to the primary researcher, Stephanie Ramautar, at rama6300@mylaurier.ca or call 519-884-0710 x4775.

### **Participation**

Participation in this study is voluntary; you may decline participation at any point in time without penalty. If you decide to withdraw from the study, any obtained data will be removed from the study and be destroyed.

### **Feedback and Publication**

Results of the study may be presented at upcoming conferences. Results will also be included in the primary researchers' thesis paper and sent out for publication in a reputable and appropriate journal.

### **Consent**

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's signature \_\_\_\_\_ Date \_\_\_\_\_

Investigator's signature \_\_\_\_\_ Date \_\_\_\_\_



## Heath History Questionnaire

Participant: \_\_\_\_\_ M/F  
D.O.B.: \_\_\_\_\_ (mm/dd/yyyy)

Date: \_\_\_\_\_  
Team/Position: \_\_\_\_\_

1. At what age did you begin playing organized sport? \_\_\_\_\_
2. How many years have you played your sport? \_\_\_\_\_
3. Do you wear a mouth guard while playing?  
 yes       no  
 If yes, what kind?  
 stock       boil & bite  
 custom, front teeth       custom, all
4. Have you suffered from neck pain within the past 6 months?  yes       no
5. Have you suffered a concussion?  
 yes       no       not sure
6. If yes to #5,  
 a) How many times total? \_\_\_\_\_  
 b) How many times while playing sport in the past 6 months? \_\_\_\_\_  
 c) Date of last concussion? \_\_\_\_\_  
 d) How long did the symptoms last (for last concussion)?  
 1-3 days       4-7 days       8-10 days  
 11-14 days       more than 2 weeks  
 Please specify \_\_\_\_\_
- e) After the last concussion, how long did you refrain from physical activity?  
 4-7 days       8-10 days       11-14 days  
 15-21 days       more than 3 weeks  
 Please specify \_\_\_\_\_
7. Have you ever been knocked unconscious?  
 yes       no
8. If yes to #7,  
 a) How many times in the past 6 months? \_\_\_\_\_  
 b) What is the longest duration you've been knocked unconscious? \_\_\_\_\_

9. In the past 6 months, after being hit in the head in sports, have you experienced any of the following symptoms:

<input type="checkbox"/> confusion	<input type="checkbox"/> getting 'dinged'
<input type="checkbox"/> headaches	<input type="checkbox"/> balance problem
<input type="checkbox"/> nausea	<input type="checkbox"/> getting 'bell rung'
<input type="checkbox"/> dizziness	<input type="checkbox"/> ringing in the ears
<input type="checkbox"/> blurry vision	<input type="checkbox"/> poor memory
<input type="checkbox"/> other: _____	

10. In regards to how you feel NOW, please rate the following:

	None	Mild	Severe
Headache	0	1 2 3	4 5 6
"Pressure in head"	0	1 2 3	4 5 6
Neck pain	0	1 2 3	4 5 6
Nausea/vomiting	0	1 2 3	4 5 6
Dizziness	0	1 2 3	4 5 6
Blurred vision	0	1 2 3	4 5 6
Balance problems	0	1 2 3	4 5 6
Sensitivity to light	0	1 2 3	4 5 6
Sensitivity to noise	0	1 2 3	4 5 6
Feeling slowed down	0	1 2 3	4 5 6
"Don't feel right"	0	1 2 3	4 5 6
Hard to concentrate	0	1 2 3	4 5 6
Feeling "in a fog"	0	1 2 3	4 5 6
Trouble remembering	0	1 2 3	4 5 6
Fatigue/low energy	0	1 2 3	4 5 6
Confusion	0	1 2 3	4 5 6
Drowsiness	0	1 2 3	4 5 6
Trouble falling asleep	0	1 2 3	4 5 6
More emotional	0	1 2 3	4 5 6
Irritability	0	1 2 3	4 5 6
Sadness	0	1 2 3	4 5 6
Nervous/anxious	0	1 2 3	4 5 6

11. Do the above symptoms get worse with physical activity?  yes       no

12. Do the above symptoms get worse with mental activity?  yes       no