A PILOT PROJECT TO INVESTIGATE A NOVEL COMPUTERIZED CONCUSSION ASSESSMENT TOOL FOR USE IN THE EMERGENCY DEPARTMENT AND OTHER OUTPATIENT SETTINGS

by

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Abstract

Background There is currently no standard method of diagnosing the presence or severity of concussion in acute primary care settings. This pilot project is part of a larger study to develop a ***Computerized Concussion Assessment Tool (CCAT)***.

Methods A prospective observational clinical study was conducted to explore the validity of the CCAT among patients presenting to the Emergency Department at Kingston General Hospital and at Hotel Dieu Hospital (Kingston, Ontario) with minor head injury. Twenty-two patients with concussion and eighteen patients with head injury (but not diagnosed with concussion) were recruited to the study. All participants completed a background questionnaire, several neurocognitive tests and the CCAT assessment. Performance on the CCAT was compared between these two groups. Data collected during the development phase of the CCAT from a Normal Volunteers group (n=68) were used in an additional comparison. CCAT Scores for Selective Attention, Divided Attention and Memory were compared with standard neurocognitive tests through correlational analyses. In addition, the validity and clinical yield of the CCAT were investigated relative to gold standard measures.

Results After adjustment for covariates, no statistically significant differences were found between the three participant groups for any of the three primary CCAT Scores (Selective Attention, Divided Attention and Memory). Correlational analyses showed that the CCAT Selective Attention Score and the CCAT Memory Score are moderately correlated with standard neurocognitive tests. There was no correlation observed for the CCAT Divided Attention Score and its associated neurocognitive test.

Conclusion The CCAT was unable to discriminate between concussed patients and non-concussed individuals. However, moderate correlations observed between the CCAT Scores for

Memory and Selective Attention and their respective neurocognitive tests support a view that there should be optimism for the future development of the CCAT. Issues related to the feasibility of the study and its administration in the emergency department setting are discussed.

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Table of Contents

List of Figures

List of Tables

List of Acronyms and Abbreviations

ANAM	Automated Neuropsychological Assessment Metrics
ASMB	Automated Neuropsychological Assessment Metrics Sports Battery
CCAT	Computerized Concussion Assessment Tool
CRI	HeadMinder Concussion Resolution Index
CT	Computed Tomography
DAS	Divided Attention Score
D-KEFS	Delis-Kaplan Executive Functioning System
DSST	Digit Symbol Substitution Test
ED	Emergency Department
ES	Effort Score
eSAC	electronic Standardized Assessment of Concussion
FSIQ	Full-Scale Intelligence Quotient
HDH	Hotel Dieu Hospital
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
IQ	Intelligence Quotient
IQR	Interquartile Range
KFL&A	Kingston, Frontenac, Lennox and Addington
KGH	Kingston General Hospital
LOC	Loss of consciousness
MS	Memory Score
MSVT	Medical Symptom Validity Test
NAART	North American Adult Reading Test
PCS	Patient Care System
PTA	Post-traumatic amnesia
RT	Reaction time
SAC	Standardized Assessment of Concussion
SAS	Selective Attention Score
SCAT	Sport Concussion Assessment Tool
SDMT	Symbol Digit Modality Test
TMT	Trail-Making Test
WHO	World Health Organization
WMS-III	Wechsler Memory Tests III

Chapter 1

General Introduction

Concussions are brain injuries that generally result from some form of contact to the head. They occur most commonly as a result of falls, during athletic competition, and as a result of motor vehicle collisions (1). People of all ages and all segments of society are at risk for concussion, although the injury is most prevalent in young people (2). There are both short and long-term consequences associated with concussion that can be devastating and disabling to concussed individuals (3,4).

Despite the widespread frequency of this injury and its potentially devastating consequences, many aspects of concussion are poorly understood. There are gaps in the medical and research communities' understanding of the physiological associations between injury mechanisms and the anatomic nature of the injury (5); in understanding the precision of wound healing and the underlying biomechanical processes, and (6); and in the ability to diagnose concussion given the broad continuum of brain injury along which it falls (7). Contributing to this dearth of knowledge surrounding concussion is the wide variability in diagnostic procedures (which differ both between health care settings and individual physicians) and a lack of practical assessment tools (8).

Without appropriate diagnostic instruments, treatment strategies have focused largely on the prevention of further brain injury (9). This process too is hampered by a lack of clinical tools for the monitoring of patients' recovery and for informing decisions on return to usual activity (10).

The focus of this thesis will be on the diagnostic assessment of concussions and their severity. A novel Computerized Concussion Assessment Tool (CCAT) has been developed at

Queen's University. The tool uses a video game platform to evaluate memory and attention through a short (~15 minute) virtual driving test. Users' performance on the tasks of the video game is designed to reflect primary cognitive deficits associated with concussion, including memory and attention. The integrated video game format takes advantage of innovative technology to create an assessment tool that is fun and engaging, and which has the potential to diagnose concussion and inform treatment strategies (11).

This pilot study involved primary data collection in the emergency departments at Kingston General Hospital and the Hotel Dieu Hospital in Kingston, Ontario. Forty patients completed the video game concussion assessment, as well as a paper- and pencil-based neurocognitive test battery to assess for cognitive deficits associated with concussion. Data on an additional 68 normal, healthy volunteers who had completed the video game concussion assessment were available from the CCAT development team. Their data were used as a comparison group for selected analyses.

The purpose of this thesis is to explore the validity of the Computerized Concussion Assessment Tool and to inform planning for a larger study of this instrument. The validity of the CCAT will be evaluated in two different ways: 1) by comparing performance on the CCAT between persons who have and have not been diagnosed with concussion using conventional clinical criteria, and; 2) by comparing various aspects of performance on the CCAT with standard neurocognitive tests through correlational analyses. Issues related to feasibility as well as preliminary diagnostic test calculations will provide useful information for the planning and execution of a larger validation study of the CCAT.

Chapter 2
Literature Review

Concussions cover a range of severity and symptoms associated with acute brain injury. However the term most often refers to mild or moderate brain injury (12). Almost all physicians are called on at some time to provide acute care or to treat the complications arising from concussion (13). Despite its prevalence, there is no standard method for evaluating concussive injury in acute care settings. In addition, there are limited tools to aid clinicians in concussion management and follow-up even though it has been shown that cognitive deficits as a result of concussion may be present more than 3 months post-injury (14,15). There is a need for the development of diagnostic tools that are widely accessible and sensitive enough to detect subtle changes in neurocognitive function associated with concussion.

In this chapter, the characteristics and nature of concussion will be described, including the epidemiology and biomechanics of the injury. A review of the various ways through which concussion is diagnosed will follow. Concussion assessment as it is evaluated on-scene at athletic events and in the emergency department setting will also be discussed. The various tools that are available to diagnose the injury will be addressed, followed by a brief discussion on the advantages of computerized testing and the gaps in knowledge towards which future research should focus. Finally, a novel concussion assessment tool, the Computerized Concussion Assessment Tool, is presented.

2.1 Overview of Concussion

A concussion refers specifically to a brain injury. Head injury includes both brain and non-brain injuries (such as injuries to the eye, face and scalp lacerations). There are many terms used by clinicians and researchers to describe concussion, including mild traumatic brain injury, mild traumatic head injury and other similar derivatives (12). There are also many definitions for concussion that refer to both the mechanism of the injury, as well as signs and symptoms. The World Health Organisation (WHO) Collaborating Task Force on Mild Traumatic Brain Injury defines concussion as a general term usually described as a "disturbance in neurological function caused by the mechanical force of rapid acceleration/deceleration (12)." A more clinically useful definition of concussion from the American Congress of Rehabilitation Medicine defines concussion as a loss of consciousness of less than 30 minutes or amnesia lasting less than 24 hours, or any period of altered mental status at the time of injury (16).

The spectrum of brain injury severity is wide and exists as a continuum. Markers of injury severity often cannot make clear-cut distinctions within a subset range of this continuum. At one end of this continuum is traumatic brain injury, such as can be seen through the use of anatomical imaging. Patients having sustained traumatic brain injury may be comatose or display limited mental activity and severe functional handicaps. At the other end of the spectrum is mild brain injury, or concussion, for which there is generally no anatomical evidence of the injury (12). In and of themselves, concussions cover a range of symptoms and severities. However, because there is no discernible structural damage to the brain, assessment criteria for the diagnosis of concussion have been developed based on signs and symptoms of the injury.

Diagnostic criteria most commonly used by clinicians in the acute care setting to assess concussion severity are the degree of altered level of consciousness, duration of loss of consciousness and post-traumatic amnesia. However, these criteria are not always indicative of injury severity as measured by the resolution of symptoms and long-term outcome of the patient (17). In addition, many patients who sustain a concussion do not experience amnesia and/or an altered level of consciousness. Moreover, where both symptoms are present, they may not reflect the same degree of injury severity. Standardized neurocognitive assessments have proven to be effective in the diagnosis of concussion. However, they are expensive, time-consuming, and difficult to implement in the acute care setting where they would be most useful.

The process of diagnosing concussion is hampered by a lack of standard diagnostic criteria and is further complicated by the wide range of definitions that exist for the injury. In November 2001, the first International Symposium on Concussion in Sport was held in Austria with the intent of addressing these gaps and thereby improving the health and safety of athletes who have sustained a concussion and/or who are at risk for concussive injury (18). A panel of experts was established to draft a document with the resolutions from the Symposium. This panel developed the following comprehensive definition of concussion:

> Concussion is defined as a complex physiological process affecting the brain, induced by traumatic forces. Several common features that incorporate clinical, pathological, and biomechanical injury constructs that may be used in defining the nature of a concussive head injury include:
>
> 1) Concussion may be caused by a direct blow to the head or elsewhere on the body from an "impulsive" force transmitted to the head;
>
> 2) Concussion may cause an immediate and short-lived impairment of neurological function that resolves spontaneously;
>
> 3) Concussion may cause neuropathologic changes; however, the acute clinical symptoms largely reflect a functional disturbance rather than a structural injury;

4) Concussion may cause a gradient of clinical syndromes that may or may not involve loss of consciousness; resolution of the clinical and cognitive symptoms typically follows a sequential course; and

5) Concussion is most often associated with normal results on conventional neuroimaging studies (18).

2.2 Descriptive Epidemiology

The estimated annual incidence rate of hospital-treated concussion ranges from 100 – 300 per 100,000 (1). This is a global estimate based on a synthesis of reported incidence rates of concussion between 1982 and 2000. This is likely a substantial underestimate of the true incidence of concussion, due to underreporting, a lack of formal diagnostic criteria and evaluation guidelines, and poor case ascertainment (1,19,20). In addition, patients with concussion, particularly among the athletic population, may not present to the emergency department or may be discharged without adequate documentation (21). The true annual population-based rate of concussion is estimated to be greater than 600/100,000 (1).

Concussions affect people of all ages and from all segments of society with a large proportion of injuries occurring among teenagers and young adults (1,2). They are most commonly a result of sports injuries, motor vehicle collisions, and falls. Between 70 and 90 percent of all brain injury cases treated at hospital emergency departments and/or admitted to hospital are due to concussion (1,13,20,22).

2.3 Gender Differences

The incidence of concussion appears to be higher in women's sports as compared with men's equivalent sport (21). This may be due to greater neck strength in males. Another hypothesis suggests that the lager brain mass of men allows it to absorb trauma more effectively (23). Scientific evidence in support of these ideas comes from experimental animal models of concussion. The use of a neck collar has been shown to protect the brain during impact to the head (24).

2.4 Biomechanics of Concussion

Concussion is a diffuse brain injury associated with global disruption of neurological function. In contrast, focal brain injury is characterised by cerebral contusions or haematomas that form under the site of impact. The two biomechanical mechanisms that may result in concussion are 1) those related to head-contact injuries, and 2) those related to head-movement injuries. Different types of head movements involve acceleration forces, deceleration forces, and/or rotations of the head and can cause rotational, compressive, shear, and tensile stress to the cerebral tissue (4,6,13,24,25). The severity of the injury is characterised by the direction, magnitude and speed with which the head moves.

Concussions result from movement of the brain within the skull and are not typically associated with macroscopically visible brain lesions; however, lesions caused by the inertial or accelerative effects of a mechanical input to the head may result in some brain contusion (6). Cerebral contusions after acceleration-deceleration injuries tend to occur at the tips of the frontal and temporal lobes where the brain impacts with the interior of the skull (6).

2.4.1 Pathophysiology

Within minutes of concussion, a neurometabolic cascade begins and results in a state of metabolic depression and increased glucose utilisation that contributes to increased neuronal vulnerability; this often lasts for several days (23-25). This vulnerability appears to be due to a combination of the increased demand for glucose following injury, and a relative reduction in cerebral blood flow. The precise mechanisms of this metabolic dysfunction are not fully understood (26). Overall, abnormal brain metabolism may be present between 1.5 and 3 months post-injury indicating continued neuronal dysfunction (27). This neurochemical and structural cascade has parallels in neurocognitive functioning (28).

2.4.2 Neural Basis of Cognitive Disabilities in Concussion

Social and behavioural changes, affective changes, and cognitive changes as a result of concussion indicate a classic pattern of abnormalities that correspond to frontal lobe damage (27,29). Frontal lobe lesions are associated with difficulties in cognitive flexibility, memory and attention, as well as abnormalities in information processing and executive functioning (26,29). In addition, alterations in behaviour including irritability, aggressiveness, and loss of inhibition and judgment also result from frontal lobe damage (26,29).

Like concussion, diffuse axonal injury is likely caused by the same type of acceleration-deceleration forces as those which cause concussion. However, it is a much more severe injury than concussion that involves damage to cerebral white matter and is characterized by lengthy coma duration (4). Considering the similar mechanical causes for concussion and diffuse axonal injury, it is interesting that studies using magnetic resonance imaging have shown that abnormalities in cerebral white matter are associated with deficits in the speed of information processing, attention and concentration, memory retrieval, and abstract reasoning (29). Moreover, it has been proposed that, as diffuse axonal injury occurs along a continuum, this type of injury may be involved in many cases of milder head injury (6).

2.5 Diagnosis of Brain Injury

Appropriate tools are available to identify and investigate patients with moderate and severe head injuries who might require neurosurgical intervention or hospitalisation. Computed tomography scans are useful in establishing an anatomical diagnosis and guiding appropriate therapeutic interventions for these high-risk patients (4).

Analogous investigative tools are not accessible to support clinicians in the assessment of concussion severity where there is no detectable anatomic injury, or to direct the initial management of these patients (30). Doctors must rely on signs and symptoms to inform their assessment of head injury severity. A wide array of different assessment tools have been developed to aid clinicians in this process. Each measurement scale involves different criteria and has different clinical utility. Among these, there is no widely accepted standard tool to be used in the diagnosis and monitoring of concussion. In addition, available diagnostic tools are not suitable for evaluating head injury in the field and in most acute care settings.

2.5.1 Diagnostic Imaging Studies

Although useful in identifying brain injury in more severe cases, computed tomography (CT) and magnetic resonance imaging (MRI) scans are not often helpful in identifying the more subtle brain injury of concussion (31). Rather, brain-related changes associated with concussion are thought to occur on a metabolic rather than anatomic level (5). Even where concussed patients experience abnormal MRI results, these results do not correlate well with deficiencies found on neurocognitive testing (25).

2.5.2 Functional Imaging Studies

Studies investigating the use of functional neuroimaging techniques such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT) have shown perfusion deficits that extend beyond any structural damage shown by CT or MRI (31,32). The most commonly reported finding is frontal hypometabolism or a decrease in frontal cerebral blood flow (33). More recently, studies using functional magnetic resonance imaging (fMRI) have shown abnormal brain activation in the right frontal and parietal cortex of concussed patients performing memory tasks (5,33).

Functional neuroimaging techniques that examine the metabolic and physiological state of the brain may have great potential for demonstrating brain abnormalities that may be undetectable by morphological imaging techniques. Ultimately, they may be used as a potential diagnostic tool and/or as a method to quantify concussive injury. However, these techniques are expensive to perform and require sophisticated technology. In addition, more research is needed to investigate the validity and reliability of these techniques before they may be adopted as clinical tools (5).

2.5.3 Symptomatic Evaluation of Concussion

The most commonly documented symptoms of simple concussions are headaches, dizziness, fatigue, disturbances of vision or equilibrium, nausea, hyperesthesia, emotional lability, impaired attention or concentration, information-processing speed and memory deficits (20,26,34,35).

There are currently at least 25 different grading scales for the symptomatic evaluation of concussion (32). This lack of consensus results from the absence of evidence-based data (20,22,36). These assessment tools differ in many important ways: some scales were designed to assess acute injury, while others were intended for documenting changes in the post-acute phases of injury recovery. None of these grading scales is sensitive enough to effectively inform the initial diagnosis and medical management of mild head injury such as concussion (37).

Short concussion symptom scales that are used for the immediate on-site evaluation of concussed athletes show that there is a relationship between sideline markers of concussion (i.e. initial signs and symptoms of concussive injury such as headache, disorientation, etc.), and specific neurocognitive deficits of memory on tests administered within the first few days after injury. This is particularly true in the domains of acquisition memory, delayed memory, and global cognitive functioning (34).

2.5.4 Level of Consciousness

Immediately following their injury, concussed patients experience some degree of deficit in arousal. This change in mental status can range in severity from a brief feeling of being dazed to a complete loss of consciousness generally lasting no longer than 30 minutes (12). The length of time that the injured patient remains unconscious has been used as an indicator of concussion severity and remains a standard criterion included on all concussion grading scales (12). However, recent prospective studies suggest that a brief loss of consciousness is not necessarily associated with concussion severity (7,17,38-41). Moreover, many patients who sustain concussions will not suffer any loss of consciousness; more than 90% of sports-related concussions result in no observable loss of consciousness (41).

The Glasgow Coma Scale (GCS) is routinely used to assess level of consciousness in the emergency department setting (37). The GCS is a 15-point scale that measures eye, motor and verbal responses. Mild brain injury is defined as a GCS score of 13-15 (12). However, there are limitations associated with this tool: It is not sensitive enough to detect mild concussive injury and it is not recommended for use in the playing field to inform return-to-play decisions nor to direct the initial and follow-up management of concussion (32).

2.5.5 Post-Traumatic Amnesia

Post-traumatic amnesia (PTA) includes retrograde amnesia (memory loss before injury) and anterograde amnesia (deficit in forming new memory after the injury) (26). As with the duration of loss of consciousness, the duration of post-traumatic amnesia is also a standard criterion included on concussion grading scales. However, like loss of consciousness, there is conflicting evidence for and against using PTA as an indicator of concussion severity (17). There is some evidence to suggest that PTA is a better prognostic factor than loss of consciousness (17,26,28).

2.5.6 Neurocognitive Evaluation

Loss of consciousness and post-traumatic amnesia are not reliable predictors of the resolution of concussive symptoms (17,38-40). The only proven *objective* measure significantly related to duration of concussive symptoms is a decline in performance on neurocognitive testing (17). The cognitive domain most consistently affected after a concussive injury is memory (31). Other neurocognitive impairments that are frequently observed following head injury include deficits in information processing as well as reaction response speed and accuracy. Attention deficits are also common (40,42-45). Sohlberg and Mateer (1989) describe an hierarchical model of attention processes that may be used to evaluate attention in patients with different neurocognitive pathologies. These are: focused attention (the ability to respond discretely to specific visual, auditory or tactile stimuli), sustained attention (the ability to maintain a consistent behavioural response during continuous and repetitive activity), selective attention (the ability to attend to one stimulus from among a mass of competing or distracting stimuli), alternating attention (the ability to shift one's focus of attention and move between tasks having different cognitive requirements), and divided attention (the ability to attend to multiple stimuli simultaneously) (46).

Neurological symptoms are more difficult to detect; however, it has been demonstrated that tests of attention, memory and reaction response speed and accuracy may remain abnormal for several weeks and sometimes months after perceived symptoms have resolved (3,39,40,43,47-49).

2.5.7 Postural Stability

In the acute stages of concussion (<3 days post-injury), patients have demonstrated postural instability, reflecting injury to the areas of the brain responsible for maintaining postural equilibrium (34,50). Traditionally, the Romberg test has been used to measure equilibrium. However, recently developed computerized programs are now able to offer a more objective and quantifiable assessment. Some examples include the Sensory Organization Test and the Balance Error Scoring System (34). These tests do not appear to be as sensitive as neurocognitive testing and it has been suggested that these tests be used as an adjunct to neurocognitive assessment during the acute injury stage (25,34). However, the development and implementation of these computerized tools demonstrates the current widespread interest in the application of technology to concussion evaluations and management of the injury.

2.6 Prognosis and Concussion Management

Resolution of symptoms following concussion varies widely between individuals. Factors that influence the course of recovery include the nature and severity of the injury, variability in individuals' recovery patterns, as well as other unknown variables (3). It is not known how long cognitive symptoms typically last as there have not been prognostic studies that have investigated this question. Gradual recovery occurs within several hours of injury and full recovery to baseline cognitive and functional status typically is reached within a few days, although cognitive deficits may take up to 3 months or even longer to resolve post-injury (3,35).

There is no "cure" for concussion. The management of concussion consists primarily of making the initial diagnosis and subsequent monitoring of symptoms outside of the hospital setting in order to make appropriate decisions on the timing of return to usual activity. The only treatment is prevention of further injury. Therefore, decisions on return to usual activity often lie with an athletic trainer or general practitioner. As such, they are largely subjective decisions and cannot include a detailed assessment of neurocognitive function.

2.6.1 Return to Usual Activity

Traditionally, the decision on when a patient may return to their usual activities is made according to the presence or absence of symptoms which is a difficult and complicated process given the lack of standardised diagnostic criteria (8). This is highly subjective and requires some "guesswork" by the clinician, particularly in cases of mild concussion where there are few, if any, physiological manifestations of injury (20).

2.6.2 Postconcussive Syndrome and Second Impact Syndrome

An individual who returns to usual activity before having fully recovered increases his or her chances for re-injury and is at increased risk for persistent symptoms, re-injury, and/or permanent neurological impairment from cumulative trauma (20,21,44,51). Postconcussive syndrome refers to a constellation of symptoms that may occur during recovery from concussion (4). Symptoms include headache, fatigue, irritability, insomnia, personality change, and concentration and memory difficulty (52). It is not known whether postconcussive syndrome is a direct consequence of brain injury or whether the symptoms have a psychological basis (32). However, Ingebrigsten et al. (1998) found that 40% of patients were still experiencing 3 or more symptoms at 3 months post-injury (15). Other sources estimate that between 23% and 90% of patients with concussive head injury develop postconcussive syndrome (4,53,54).

Patients who return to usual activity prematurely also put themselves at risk for further injury, including death from second-impact syndrome (7,20). This condition mainly occurs among athletes. Death from second-impact syndrome may occur when an athlete returns to competition prematurely and sustains a second impact before their initial concussion symptoms have resolved. Following the second injury, the patient may seem merely dazed but will then experience an abrupt collapse associated with coma, loss of eye movement and respiratory failure (4). Although second-impact syndrome is uncommon, it must be recognised because of its potentially lethal consequences to the individual (4).

Subtle cognitive deficits often go unrecognised and patients may return to usual activity unaware of persisting concentration and memory problems. In such a condition, poor performance at school and at work may have adverse consequences. The latter is associated with poor grades, job loss, and emotional and psychosocial dysfunction (2,53,55,56). The full extent of these poor health outcomes and their consequences is not understood (14).

2.7 Concussions in Athletics

Concussions in athletics are common; they are the most frequently reported head injury excluding oculofacial and scalp injuries (36,38,57). Sports-related head injuries represent approximately 20% of the estimated 1.54 million head injuries that occur yearly in the United States (58). It is conservatively estimated that 300,000 sports-related brain injuries occur per year in the United States with approximately 85% of these classified as “mild” (21,25,34). High risk sports include ice hockey, football, and soccer (34,38). Football is particularly dangerous; it has been variously estimated that 4 to 20% of football athletes sustain a concussion each season (38). Other sports associated with brain injury include wrestling, softball, baseball, basketball, field hockey, rugby, and volleyball (58-60). For this reason, there have been several recent initiatives to develop tools to assist in concussion assessment and management for head-injured athletes.

2.7.1 On-Scene Assessment of Concussion

It is important for the concussion assessment to occur as soon as possible following a head injury in order to rule out more serious injury and to inform return-to-play decisions. Concussed athletes may be put at considerable risk as a result of premature return-to-play. Several guidelines have been developed for the evaluation of the head-injured athlete and return-to-play decisions (28,34,61).

There are particular challenges associated with on-scene assessment of concussion and concussion management within the athletic population. It is important to consider the context of the injured athlete as it relates to the decision for his or her return to play. It is unrealistic to assume that return-to-play decisions involve only medical considerations (28). Sports may be highly competitive and frequently emotional, perhaps causing players to minimize symptoms in order to return to play sooner (62). If the injured athlete is a high profile athlete, teammates may pressure him or her to "shake it off" or to just sit it out until the pain desists (21). Yet, it has been established that cognitive deficits observed following concussion may persist longer than self-reported concussion symptoms. In addition, recent research suggests that concussion signs and symptoms may evolve over time and may not be evident initially after injury (63). Furthermore, the people involved in the decision to return an athlete to play may have competing agendas. For example, coaches may have different attitudes with respect to concussion management and injury time off; athletes do not always accurately report symptoms, and; busy athletic trainers may not have the time (or the necessary tools) to be able to accurately assess an athlete. Computerized testing provides a systematic, objective, standardised approach to the administration and scoring of test protocols, factors which are particularly important in the athletic environment (58).

2.7.2 Baseline Assessment of Concussion

Among athletes, it is necessary to perform a baseline assessment of neurocognitive function. This is essential in order to have a benchmark or standard to which the player must return following head injury (58,64). It is important to know an athlete's pre-morbid level of functioning in order to determine whether an impairment seen on the concussion testing is a result of injury. Without individual baseline data, scores will be compared with a "normal" population; it is possible that the athlete may not be "normal" because of very high or very low cognitive functioning, previous head injury, psychiatric problems, test anxiety, or a host of other problems (21,58).

2.7.3 Serial Assessment of Concussion

Besides the use of computerized tests as stand-alone instruments to assess for concussion immediately following head injury (which would be particularly useful in the acute care setting), computerized testing allows for pre-injury baseline testing and serial follow-up assessments that would be extremely useful in the athletic population to inform return to play decisions. Serial assessments can demonstrate gradual changes in mental status over time and allow for better differentiation of cognitive deficits in order to assist in the treatment and management of concussions (58).

The frequency of repeat testing to assess recovery from concussion has been debated (21,58). Recovery times vary according to many factors ranging from 5-10 days and beyond (21,61,65). It is thus important for each athlete to be considered individually when making return-to-play decisions. This also highlights the need for baseline testing so that there are individualised performance standards to which an athlete must return in order to signify recovery (21,34).

2.7.4 Multiple Concussions

There is conflicting evidence to suggest whether there is an increased risk of cognitive dysfunction for people who sustain multiple concussions (28). Guskiewicz et al (2000) found a 3-fold increased risk of concussion with a history of 3 or more concussions and Collins et al (1999) found that a history of multiple concussions related to poorer performance on baseline neurocognitive testing (57,66). In contrast, Macciocchi et al (2001) found no relationship between the number of previously sustained concussions and neurocognitive test performance (67).

There are several contextual factors that should also be considered. First, in any contact sport, the risk of concussion is directly proportional to the amount of time playing the sport. That is, contact sport athletes will be at higher risk of sustaining a head injury regardless of any concussion history. Second, a player's style of play may increase the player's risk of initial and subsequent injury (24). Together, these factors demonstrate the complexity associated with studying whether individuals are at higher risk of sustaining multiple concussions following their first concussion.

2.8 The Emergency Department Setting

Concussion is commonly observed in patients presenting to hospital emergency departments (53). Several research studies have successfully recruited and studied patients with concussion in emergency departments in order to evaluate diagnostic tools. There are many advantages associated with conducting research studies in this setting. First, it is necessary to identify and recruit patients with very recent head injury so that the medical assessment is not biased by the healing process. Second, emergency departments are perhaps the only location where patients with recent head injury systematically present for a formal medical evaluation. In the athletic field setting, where concussions occur frequently, many athletes do not follow up with a trained health professional who is able to clinically assess the injury.

There are also challenges associated with conducting research in the emergency department setting. These relate to case identification of concussed individuals, recruitment of study participants in a fast-paced environment, and the execution of the study itself. Case identification is perhaps the most contentious of these challenges. Because there is no "gold standard" concussion diagnosis with which to compare novel diagnostic tools, it is essential that specific criteria used for case participant eligibility be outlined a priori. Several criteria schemes have been implemented in previous studies (47,68).

2.9 Existing Concussion Assessment Tools

The "gold standard" for assessing concussion has historically been, and remains, neurocognitive testing. However, test batteries for this are time-consuming and expensive to administer. They are not practical for the use in the acute care setting, nor on the sidelines of athletic events, two places where they are most needed. The advent of brief on-scene concussion assessment tools gave athletic trainers and clinicians considerable flexibility in diagnosing concussion. Yet these instruments, while much more practical than neurocognitive testing in that they were portable and efficient, sacrificed the accuracy of traditional test batteries in exchange for their convenience. Recently, several different computer programs have been developed for the assessment of concussion. These are essentially paper and pencil-based test batteries moved onto a computer platform. The benefits and drawbacks are further discussed below.

2.9.1 Paper and Pencil-Based Neurocognitive Testing

Standardised neurocognitive tests administered in a paper and pencil format have proven useful in the detection of cognitive impairment following concussion (28). However, these tests require trained personnel to administer and are very time consuming. They are generally not practical for serial assessment over time to evaluate subtle changes and are unable to provide measurements of reaction response speed and accuracy, factors which may be important in the evaluation of concussion.

In the past, traditional paper and pencil-based tests were used to measure more subtle effects of concussion including deficits in memory, attention and processing speed (62). However, there are several disadvantages to paper and pencil based testing. Concussion is a diffuse injury requiring the administration of several tests to capture multiple cognitive domains. Depending on the battery, these tests could take more than 2 hours to administer per athlete (28,51). In addition, the tests must be administered and interpreted by a trained neuropsychologist in a suitable testing environment. Thus, widescale testing of entire sports teams may be prohibitively expensive and time consuming for most athletic organisations as well as being impractical as an assessment tool for concussion in the acute care setting. Paper and pencil-based tests are also susceptible to practice effects. This creates difficulty with the reliable assessment of changes in neurocognitive performance over multiple administrations. These tests are also unable to measure response times which may be an important indicator of concussion severity and/or recovery (49,62).

2.9.2 On-Scene Assessment Tools

In the past, athletic trainers and clinicians have made use of simple, non-standardized decision aids such as counting backwards by seven or three, or having the athlete recall the score in a match, or day of the week, in order to assess memory and orientation in time, person and place (62,69). However, these tests are influenced by the intelligence of the athlete and they have poor specificity (i.e. uninjured athletes may also perform poorly) (70). More recently, objective tools have been developed specifically for the on-scene evaluation of athletes. The Standardized Assessment of Concussion (SAC) is a brief (5 minute) test of orientation, concentration, and memory designed to be administered at the sideline of athletic events and used in conjunction with other clinical criteria including neuropsychological test measures and a complete physical examination (41,71). An electronic version of the SAC, the eSAC has been developed recently (58). The Sport Concussion Assessment Tool (SCAT) is the most recently developed on-scene assessment tool and is a more comprehensive abbreviated neurocognitive test developed using a combination of the most widely used tools (34). These tests require an initial baseline assessment which can then be compared to the performance result at the time of injury. They are not designed to replace standard test batteries as they are not sensitive enough to detect subtle cognitive deficits, and they are also unable to assess important functions of reaction time and speed of information processing (72). As well, these instruments have not been validated with respect to standard testing criteria of reliability, sensitivity, specificity and validity (10,64).

2.9.3 Computerized Applications of Assessment Tools

The Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is a computerized test first designed specifically for athletic populations (62). The ImPACT assessment takes approximately 20 minutes and consists of 3 parts: demographic data, neurocognitive tests, and the Post-Concussion Symptom Scale. The test provides an assessment of attention, memory, processing speed and reaction time (73). Athletes are tested at baseline in order to establish values with which to compare test results following head injury. Neurocognitive testing can also be done without a baseline score; in this case, results may be compared to a large normative database.

Other computerized tools that exist may be used to diagnose and track cognitive deficits associated with concussion. The HeadMinder Concussion Resolution Index (CRI) is administered online and requires approximately 25 minutes (74). It is able to measure memory, reaction time, speed of decision-making and speed of information processing (74). CogSport is another software product that measures reaction time, attention, memory and information processing. Administration requires approximately 20 minutes. Test results for these products must be submitted to administrative databases for scoring and analysis.

Even though several computer assessments have been developed, the tasks that patients are required to complete are largely the same; the only difference is that the tasks of the assessment have been moved onto a computer platform. This limits patients' interest and compliance, factors which are important where repeat testing is required. In addition, these tools require expert interpretation through a formal process of submission via the internet for comparison with research databases (75-77).

Another drawback to the existing computerized tools is that most patients do not have access to such testing and few sport organisations can afford the cost (78-80). In addition, these tests have not been tested against standard testing criteria of sensitivity, specificity, reliability and validity (10,81).

2.9.4 Advantages of Computerized Testing

Compared to traditional paper- and pencil-based tests, computerized versions of tests have been found to be psychometrically equivalent (82). Moreover, standardised computer assessment tools have proven to be efficient and effective at detecting very mild changes in cognition as a result of concussion (83).

Computerized testing offers several advantages over standard neurocognitive tests. Advantages include standardised self-administration, rapid testing, internet-based delivery, and centralised data storage, analysis and interpretation (41,78). Computerized testing also allows infinite variations of the test to be produced which is particularly important where sequential testing is necessary in order to prevent learned responses. In addition, the tests permit a wide range of responses (i.e. not just yes/no or true/false), and may provide accurate assessments of reaction response speed and accuracy (65).

There are also unique advantages of computerized neurocognitive testing in the athletic environment. For example, there are considerable time, personnel and cost constraints associated with the administration of tests to entire athletic teams or organisations using traditional assessment tools in order to generate baseline information (58). Costs for baseline testing and evaluation of a football team of 100 athletes range from $750 ($US) to $4,000 (21). With computers, these challenges can be minimized, whereby athletes undergo approximately 20 minutes of computerized testing using the same software package. This scenario is already in place in many college and professional sport organisations (21,35). In addition, computerized tests may be developed so that the availability of personnel required to administer and evaluate the tests can be practically accommodated. Finally, computerized testing offers the advantage of portability, both of the tool itself (i.e. computerized tests may be installed on a standard laptop), and of the athletes' test performances (65). If a player moves from one team to another (an event that often occurs on professional sports teams), baseline data and any subsequent testing trials may be easily transferred from one database to another (58).

2.10 Gaps in Knowledge

There is currently no consistent and accurate method for the assessment of concussions in the acute primary care setting, nor are there tools available to monitor recovery. Evaluation methods are extremely variable and ineffective at making an accurate injury diagnosis (60,70). Thus, the initial evaluation of mild brain injury is non-standardised, may vary from site to site, and in many cases, the diagnosis of concussion is still largely subjective. Perhaps equally or even more challenging is the medical management and follow-up with concussed patients. At follow-up visits, the clinician must base treatment advice on subjective clinical evaluations that may employ a variety of different grading schemes. The clinician may even be reliant solely on the patient's own account of their injury event. Patients suffering from memory and/or attention deficits and/or persistent headache may not be able to give an accurate assessment of their injury. Finally, researchers *require* standardized tools in order to investigate prognostic factors and begin to understand more about the recovery process for concussed patients.

The Computerized Concussion Assessment Tool is an instrument that has the potential to address many of these gaps in knowledge related to concussion management. Using innovative technology to create a novel evaluation platform (i.e. a video game), there is potential for improved accuracy in the initial diagnosis and long-term follow-up. However, before this tool can be put to use in the acute care setting or on the sideline of athletic events, its diagnostic validity and psychometric properties must first be explored. Because the CCAT has only yet been tested among a sample of normal, healthy volunteers, it is not known whether this tool is able to discriminate between concussed patients and control subjects. In addition, while the CCAT was designed to assess deficits in several key neurocognitive domains associated with concussion (i.e. memory, divided attention and selective attention), it is not known whether the CCAT is actually measuring these domains.

2.11 Computerized Concussion Assessment Tool

The CCAT is a novel concussion assessment tool developed at Queen's University by the *Brain Injury and Concussion Research Centre* and the *Clinical Evaluation Centre*. It is designed to be self-administered with minimal instruction and requires only a laptop computer equipped with a standard video game controller to administer. The CCAT consists of a simulation of driving a car around a racetrack. The user must simultaneously respond to, remember, and ignore specific stimuli. As well as functioning as a preliminary assessment of concussion severity, it is expected that the CCAT will be able to measure the persistent effects of concussion through serial assessment over a one- or two-week period in order to monitor recovery and inform decisions on patients' return to usual activity. The entire assessment takes approximately 15 minutes.

Performance is assessed based on users' attention to driving along the centre of the road and their ability to remember specific visual stimuli.

Figure 1 Interface of the Computerized Concussion Assessment Tool

In addition to computerization, the CCAT has several advantages over existing concussion assessment tools. First, the race car game is fun, thus encouraging maximal effort and resulting in a more accurate injury assessment (21,84). Because the assessment is made under the guise of a game format rather than through the use of a traditional test format as all other standardised concussion tests employ, it is difficult for the player to guess or deliberately distort his or her responses. This is particularly important with respect to testing athletes at baseline who may be inclined to perform poorly so that subsequent test scores will not impact on return to play decisions.

Second, the CCAT is an interactive computerized assessment that is expected to be able to functionally test the athlete in a game-like situation without the risk of re-injury (21). It has recently been suggested that virtual reality environments may have better ecological validity than standard diagnostic instruments and may thus be the most reliable assessment of real-world function following brain injury (11).

Third, the assessment is not biased by language or cultural aspects. Aside from the initial instructions (which may be translated as necessary), the neurocognitive evaluation “underneath” the video game relies entirely on images.

Finally, the game does not require trained personnel for administration and interpretation. Participants are required to go through instructions before the assessment begins. They must also complete an interactive practice round of driving. The neurocognitive assessment embedded in the game is generated directly from participants’ performance on the game and is immediately available to the user.

The CCAT has the potential to be used as a stand-alone diagnostic tool and/or used in concert with other medical data. It may ultimately be a useful tool in the acute care setting, as well as on athletic sidelines where an initial evaluation of head injury severity is essential to inform treatment strategies. In addition, the ability to systematically monitor recovery of concussed patients in the clinical setting will inform and improve treatment strategies for all head-injured patients. In short, it is expected that ultimately this tool will provide clinical data from which to make complicated decisions regarding clinical management of concussion as well as eventual return-to-play options for the concussed athlete.

2.12 Summary of Background Chapter

All concussion management guidelines are in agreement that patients should be symptom-free before return to usual activity (4). Sensitive mental status testing is thus essential for more accurate injury detection. Too often patients are still symptomatic when they return to usual activity (57). This may be because there is no widely accessible tool that is able to measure subtle impairment.

This pilot study represents the first time that the Computerized Concussion Assessment Tool is being evaluated in concussed patients. The results from the concussed patient sample will be compared to results from a head-injured non-concussed patient sample and a normal, healthy volunteer sample collected during the initial development phase of the CCAT. As well, the component scores on the CCAT reflecting performance on memory, divided attention and selective attention will be compared against selected neurocognitive tests.

There is a need for a concussion assessment tool that may be administered in field settings or in the emergency room that is quick, engaging and portable, and provides objective measurements of key aspects of cognitive function. The Computerized Concussion Assessment Tool is potentially such an instrument. This pilot project is the necessary next step in the development of this novel assessment tool.

Chapter 3
Neurocognitive Assessments for Concussion

The Computerized Concussion Assessment Tool is a novel instrument in that the injury evaluation is performed through a video game program. The hope is that the assessment is fun and interesting for the user, and that it has the potential to be better able to assess concussion severity than any of the currently available computer models.

The tasks presented during the video game have been designed to assess three of the key neurological symptoms associated with concussion (discussed in Chapter 1, page 9). This information could help to determine treatment strategies and the monitoring of patients over the long term. While the CCAT has been administered to healthy volunteers, the instrument has not been tested among concussed patients.

The purpose of this thesis project is to evaluate the CCAT for its validity and psychometric properties: a first step in the evolution of this novel computerized assessment tool. This chapter presents a discussion of the innovative properties of the CCAT and the development of the tool. This is followed by a discussion and brief rationale for the selection of a neurocognitive test battery suitable for the evaluation of concussion. Finally, the validity and psychometric properties of various concussion assessments are discussed.

3.1 A Novel Instrument

The interactive and integrative formats of the CCAT are unique. Existing tools used for the diagnosis of concussion, including traditional paper and pencil-based test batteries as well as computerized assessments, typically examine isolated components of cognitive function (11).

While these traditional measures are able to examine cognitive functions such as verbal memory and visual memory, traditional measures are unable to evaluate how these two systems are used simultaneously by individuals during "real-life" tasks (85). Computerized technologies provide an opportunity to evaluate cognitive functions within a dynamic, interactive environment while maintaining controlled experimental conditions (85). This technological shift could better enable clinicians to predict how a measured deficit will manifest outside the artificial, clinical testing environment and in real-world functional scenarios such as school or work (11,86).

Standard neurocognitive measures do not reproduce the rich array of stimuli that an individual experiences in the real world (85). As a result, a lack of motivation and poor effort may impact upon examinee performance (11,84,87). As the CCAT was developed to be fun and engaging, it was hoped that it would encourage maximal effort from participants who are administered this test.

3.2 Performance Parameters of the Computerized Concussion Assessment Tool

Brain injuries affect different anatomic areas of the brain. Therefore, assessment instruments should evaluate multiple aspects of cognitive function (21). The CCAT records aspects of participants' performance on the video game task which the computer then inputs into variables that reflect two different types of attention (selective attention and divided attention) as well as short-term memory.

Selective attention requires the individual to reject irrelevant information while attending to relevant input. It can be assessed by tasks that require rapid scanning and identification of targets (88). Divided attention refers to the ability of a person to respond to multiple tasks at a time and can be assessed by continuous performance tasks where the individual is assessed on whether he or she can hold information in mind and then process it, even if distracted or required to divide attention (88,89). Short-term memory refers to the ability to learn about and remember information, objects, and events lasting between 30 seconds and one hour (89).

In the CCAT, the central concentration point for participants is to keep the vehicle on the track as they drive around the course. At the same time, participants must acknowledge orange pylons by pressing on their controller, while ignoring blue pylons and orange rectangular objects. These activities represent selective attention. The amount of time that participants spend off the track, or in contact with the edge of the road, provides a measure of divided attention. In addition, participants must remember images on billboards (placed peripherally) and road signs (placed proximally along the roadside) that pass by as they drive; a memory test is included at the end of each of three rounds of driving. Calculations for the performance indicators are provided.

3.3 Traditional Neurocognitive Test Battery

Neurocognitive testing provides an assessment and quantification of brain function by examining brain-behaviour relationships (28). It is particularly useful in the assessment of the acute and recovery phases of concussion as it has been shown that neurocognitive testing is more sensitive than diagnostic imaging (17,28,31). Standardized neurocognitive testing may also be more effective than subjective reporting of symptoms at identifying neurocognitive deficits as a result of concussion. This may be the case among athletes who minimize their symptoms because they are eager to return to the playing field, or in contrast among individuals involved in litigation scenarios (e.g. for a work-related head injury) who may exaggerate their symptoms (28).

Because concussion is a diffuse injury that affects multiple cognitive domains, a battery of tests, rather than any single test, is necessary to assess concussion accurately (28). Traditional paper and pencil-based neurocognitive test batteries assess memory recall, attention and concentration, problem-solving abilities, visual tracking and speed of information processing as well as other measures of cognitive function and are considered the "gold standard" in evaluating concussion (28). Typically the test batteries last 2-3 hours (11,28).

3.3.1 Considerations for Test Battery Selection

The neurocognitive test battery chosen for this pilot project involved consideration of several factors. Because neuropsychological testing was completed in the Emergency Department on patients having suffered very recent head injury, the test instruments chosen needed to be short in duration and produce minimal levels of frustration. It was also necessary that the tests be appropriate for administration in the Emergency Department setting. They had to have sound psychometric properties as well as being easy to administer as testing was done by a researcher without extensive knowledge of psychometrics. Taking account of these various factors, the individual tests were selected according to the recommendations of Dr. Allyson Harrison, a psychologist and professor at Queen's University.

3.3.2 Selective and Divided Attention

Selective attention refers to the ability to attend to one set of stimuli while suppressing awareness of competing distractions (89). The neurocognitive test that will be used to assess this aspect of cognitive control is the Delis-Kaplan Executive Function System (D-KEFS) Trail Making Test Condition 1: Visual Scanning.

Divided attention involves the ability to respond to more than one task at a time or to multiple elements or operations within a task, as in a complex mental task (89). This component of cognitive control will be evaluated using the Delis-Kaplan Executive Functioning System (D-KEFS) Trail Making Test and the Color-Word Interference Test.

3.3.3 D-KEFS Color-Word Interference Test

The D-KEFS Color-Word Interference Test involves four exercises. The first two baseline exercises evaluate key component skills of higher level tasks. These are: 1) basic naming of colour patches, and 2) basic reading of colour words printed in black ink. The third exercise requires the examinee to suppress the more practiced and therefore more natural response of reading the words denoting colours, in order to name the dissonant ink colours in which those words are printed (90). This is the traditional Stroop interference task which essentially requires the inhibition of a more automatic verbal response (i.e. reading) and is the primary executive function[1] measured by this test. Finally, the fourth exercise requires the examinee to switch back and forth between naming the dissonant ink colours and reading the conflicting words. This task is a measure of both inhibition and cognitive flexibility (90).

3.3.4 D-KEFS Trail-Making Test

The D-KEFS Trail Making Test is a test of speed for attention, sequencing, mental flexibility, and of visual search and motor function (88). The primary assessment is based on a visual-motor sequencing procedure whereby the examinee must switch between connecting numbers and letters in their correct sequence. There are four additional exercises that measure visual scanning, number sequencing, letter sequencing, and motor speed in drawing lines.

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[1] Executive functions consist of those capacities that enable a person to engage in independent, purposive, self-serving behaviour (89).

Performance on these component skills allow for an empirical assessment of the score achieved on the visual-motor sequencing procedure (90).

3.3.5 Short-Term Memory

Memory can be categorized as either procedural or declarative. Declarative memory refers to the ability to store and retrieve pieces of information or knowledge, and may be further divided into semantic and episodic memory. Semantic memory involves memories for facts and concepts while episodic memory involves information that is situation- and context-specific (91). The Wechsler Memory Scale – III (WMS-III) is primarily a measure of declarative episodic memory.

The WMS-III and Family Pictures subtests provide measurements of auditory and visual memory. They assess three specific types of short-term memory: immediate memory (based on immediate free recall), delayed memory (based on delayed free recall) and recognition delayed memory (based on memory performance when the examiner provides clues to the examinee) (88,89,91). They are ideal instruments for the clinical research setting because the subtests are short and their administration requires very little training.

3.3.6 WMS-III Logical Memory Subtest

There are two parts to the Logical Memory subtest. In the first part of the test, the examinee is told two stories. The second story is presented twice and the examinee is asked to retell the stories. Twenty-five to thirty minutes later, on the second part of the test, the examinee is asked to retell both stories and to answer yes/no questions about the stories. Administration of the subtest requires approximately 5-10 minutes (91).

3.3.7 WMS-III Family Pictures Subtest

The Family Pictures subtest is also administered in two parts. In the first part, a family photograph and a series of scenes are presented. The examinee is then asked to recall information such as who was in each scene, where they were, and what they were doing. Twenty-five to thirty minutes later (part 2), the examinee is asked the same questions again (the scenes are not shown again). Administration of the subtest requires approximately 5-10 minutes (91).

3.3.8 Intelligence

In the process of validating the CCAT, it was important to have some measure of patients' premorbid intellectual ability. This was to ensure that individuals' game and/or neurocognitive test performance was a true reflection of their functional status as a result of injury, uninfluenced by their inherent (i.e. pre-injury) memory and attention capabilities. One common method used to estimate premorbid intellectual ability is by testing overlearned skills, such as reading which is highly correlated with intelligence (88). It has been proposed that a reading test for irregularly spelled words is a good indicator of premorbid ability because it can assess the level of reading achieved before the onset of brain impairment. There is a high correlation between reading ability and intelligence in the normal population (88). Therefore, word-reading tends to produce a fairly accurate estimate of pre-injury intellectual ability, given the fact that the ability to pronounce irregular words is generally retained (88). Researchers generally report moderate to high correlations (.4 to .8) between the North American Adult Reading Test (NAART) performance and measures of general intellectual ability (88).

3.3.9 North American Adult Reading Test

The NAART was adapted from the National Adult Reading Test in 1989. The test consists of 50 irregular words (e.g. debt, naïve). Assuming that the participant is familiar with the word, accuracy of pronunciation is used to predict intelligence quotient (IQ) (88). IQ refers to a derived score designed to measure a hypothesized general ability of intelligence (89).

Participants are asked to read down the word list. The test administrator marks any pronunciation errors on a scoring sheet. The total number of errors is then tabulated. Administration requires approximately 10 minutes (88).

3.3.10 Effort

Symptom exaggeration or fabrication of cognitive impairment is particularly at issue in the head-injured population. In a large study conducted in 2000, Rohling et al. showed that approximately 50% of the variance in a neurocognitive test battery was explained by effort and cooperation, rather than by brain injury (87). In addition, different populations of head-injured individuals may not accurately report their concussive symptoms for a variety of reasons and may be more or less motivated to perform well on neurocognitive tests. Therefore, it was important to include an objective measure of effort both in the design of the CCAT and in the validation process.

3.3.11 Medical Symptom Validity Test

The MSVT is a stand-alone test of effort, or malingering. It is a brief computerized memory-screening test that is very sensitive to poor effort and exaggeration of cognitive difficulties. However, it is insensitive to all but the most extreme forms of cognitive impairment (92).

Administration requires approximately 10 minutes. Participants are shown a word list composed of word pairs, each representing a single common object (e.g. Ballpoint-Pen). Participants are then presented with two words and asked to choose the word from the original list (Immediate Recognition effort subtest). After a 10 minute period, the participant is given the same task of choosing the word from the original list (Delayed Recognition effort subtest). The participant must also complete two simple memory tasks at this time: 1) the participant is given the first word in the pair and asked to say the second, and 2) the participant is asked to remember as many words as possible from the original list (92).

3.4 Evaluating the Validity of a Diagnostic Tool

When referring to a diagnostic tool, validity is an expression of the degree to which the tool measures what it purports to measure (93). Assessment of the validity of the Computerized Concussion Assessment Tool is important. There are many different methods of evaluating and diagnosing concussion, ranging from symptom checklists used most often in the acute care setting to computerized measurement tools (IMPACT, CogSport) and longer neurocognitive test batteries lasting several hours (28,32,37,62,74). The latter two methods have been designed for use in classical testing environments. In addition to the differences in the design of these various measurement tools, their administration is also widely variable. Many tools require a pre- and post-injury assessment while others need only be administered at the time of injury. In addition, some measurements may be used for serial assessment, while others are not. In short, different tools are designed for administration in different settings; they provide different information to the clinician, and; aside from the traditional neurocognitive test batteries that require standard testing conditions and are extremely time-consuming, each instrument yields a somewhat different result. This raises the question of which instrument, if any, gives the 'correct' answer. It is thus essential that diagnostic tools undergo rigorous validity testing (94). There are 3 different types of measurement validity: content validity, construct validity and criterion-related validity (93).

3.4.1 Content Validity

Content validity refers to the extent to which the measurement tool incorporates the domain of the phenomenon under study (93). It is not based on statistics or empirical testing; rather it is the degree to which the test items adequately represent and relate to the trait or function that is being measured (91). As an assessment of concussion, the CCAT should incorporate aspects that characterize the injury including measurement of attention and memory.

3.4.2 Construct Validity

Construct validity is the extent to which the measurement tool corresponds to theoretical concepts (constructs) concerning the phenomenon under study (93). Unlike objective, measurable physical attributes, construct validation relies on inferences derived from some construct. A construct can be thought of as a 'mini-theory' to explain relationships among various behaviours or attitudes (94).

Concussion is a construct representing a constellation of symptoms that reflect an underlying disorder, or injury. There is no way to measure concussion directly so concussion is diagnosed by considering the multiple manifestations of the injury including physical symptoms and neurocognitive deficits. Evaluation of construct validity involves using indirect measures in order to test the underlying injury. This requires a wide array of validity evidence. The test must be related to similar measures (convergent validity) and also not be correlated with dissimilar, unrelated ones (discriminant validity). It is also important to consider the ability of a test to discriminate between separate populations of examinees (discriminative validity) (94).

3.4.3 Discriminative Validity

Discriminative validity, also referred to as construct validation by extreme groups, involves administration of the new scale to two groups – one of which has the trait or behaviour (i.e. concussion), the other that does not – in order to determine whether the tool is able to differentiate between groups (94). In the context of this study, concussed patients should perform worse on the tasks assessed by the Computerized Concussion Assessment Tool than both the head-injured non-concussed group and the normal volunteer group.

The primary difficulty with this method of validation relates to how the extreme groups are selected. For example, being able to identify concussed versus non-concussed patients implies that there already exists an effective tool for injury diagnosis (94). In the context of this pilot study, the groups were defined using the best available tool: the expert judgment of emergency department physicians (limitations of this assumption will be discussed).

3.4.4 Criterion-Related Validity

Criterion-related validity is the extent to which the measurement tool correlates with an external criterion of the phenomenon under study (93). Ideally, the criterion measure is a “gold standard” that has been used and accepted in the field. It may be another questionnaire or actual criterion behaviour (91,94). Concurrent validity is one of two aspects of criterion-related validity; it refers to the situation where the criterion and the measurement are assessed within a short time of each other. In this case, the accepted criterion measures of memory and attention are the scores on the Wechsler Memory Scale-III Logical Memory and Family Pictures subtests and the Delis-Kaplan Executive Functioning System Stroop and Trails subtests, respectively.

3.5 Other Validation Studies of Computerized Assessment Tools

Interest in the development of computerized assessment tools has only recently emerged. The four most widely used tools have been developed within the past 10 years. They include the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), CogSport, HeadMinder Concussion Resolution Index (CRI) and the Automated Neuropsychological Assessment Metrics (ANAM). Validation by the developers of their respective instruments is ongoing (75-77,95).

3.5.1 Automated Neuropsychological Assessment Metrics

Developed in the United States, the ANAM have been used in a variety of clinical settings (96). Of the four most widely used computerized tools, the ANAM are perhaps the most similar to traditional paper and pencil-based test batteries in that the design of the ANAM enables the user to construct batteries of measures selected for individual applications (96). A recently developed test battery was developed and is undergoing validation using the ANAM. The ANAM-sports medicine battery (ASMB) was shown to be able to discriminate between concussed and non-concussed subjects (95)

There are limited published data on measures of reliability for ANAM and practice effects do occur on multiple measures within this battery (10,95). Strong significant relationships between selected ANAM measures and traditional neuropsychological measures of comparable underlying constructs have been found through a variety of research studies (95,96). A study examining the concurrent validity of selected ANAM subtests showed statistically significant correlations between the subtests and the four of the Woodcock-Johnson III Tests of Cognitive Ability among a sample of 77 university students. Correlations ranged from 0.01 to 0.44 for the between specific ANAM subtests compared to the Woodcock-Johnson III subtests clusters representing General Intellectual Ability, Fluid Reasoning, Comprehension-Knowledge and Cognitive Efficiency (96). In another study investigating the concurrent validity of the ANAM subtests as measured against several common neurocognitive tests, among both a sample of healthy college students and a sample of high school athletes, significant correlations (at a significance level of $p<0.01$) were found between selected ANAM subtests and the traditional neurocognitive test battery. Of particular interest, the Trails subtest and the Stroop Color-Word Interference test showed correlations of between 0.12 and 0.5, and 0.25 and 0.54 respectively (95).

3.5.2 Immediate Post-Concussion Assessment and Cognitive Testing

Developed in the United States, the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is marketed as an effective tool to diagnose concussion in the athletic population by comparing athletes' baseline scores (i.e. pre-injury) with their post-injury scores. It is one of the most well-established computerized instruments for concussion evaluation (10).

Among a sample of 24 healthy high school athletes, the developers of ImPACT have shown that the assessment is resistant to practice effects over a 1-week period. Using repeated-measures ANOVAs, they reported no significant practice effects over four testing sessions ($F=0.88$, $p=0.445$) (48).

The validity of the ImPACT assessment has also been examined. The developers of ImPACT have shown that athletes with more severe concussions defined by duration of on-field markers of concussion performed significantly worse than less severely injured athletes on the memory component of the ImPACT assessment ($F=5.5$, $p<0.024$) among a sample of 64 concussed high school athletes, and that, larger decreases from baseline scores are correlated with concussion severity based on initial on-field symptoms (48,73). These results support the construct validity of the ImPACT assessment.

The concurrent validity of the ImPACT assessment has been demonstrated through correlational studies. The Symbol Digit Modalities Test, used to measure scanning and tracking aspects of attention and speed processing, has been shown to be strongly significantly correlated with ImPACT Processing Speed and Reaction Time Indices ($r=0.70$, $p<0.01$) (35). The divergent validity of the ImPACT assessment was demonstrated by an analysis of the relationship between different ImPACT test components which showed non-significant correlations (73).

The psychometric properties of the ImPACT assessment have only recently begun to be explored by its developers. A 2006 study involving 72 concussed and 66 non-concussed high school athletes demonstrated that the ImPACT assessment had a sensitivity and specificity of approximately 82% and 89% respectively (73).

3.5.3 CogSport

Developed in South Africa for use among athletes, the CogSport assessment requires a pre- and post-injury assessment. Developers of the CogSport assessment have shown that the test has good test-retest reliability. A study involving 60 volunteers aged 18-40 years, demonstrated high to very high intra-class correlation coefficients at test-retest intervals of 1 hour and 1 week (0.69-0.90) (97). This indicates that the 'true' variance in scores accounts for most of the variance between testing times.

Among elite athletes, the concurrent validity of the CogSport test battery was examined by comparing the CogSport assessment with the Digit Symbol Substitution Test (used to assess psychomotor speed, visual short-term memory, attention and concentration) and Trail-Making Test (used to assess visual scanning, complex attention, mental flexibility and visual-motor speed) (21,97). High correlations were found with the Digit Symbol Substitution Test for working memory and decision-making speed (r=0.86 and 0.72 respectively), but low correlations were found with the Trail-Making Test for all speed measures (r=0.44, 0.34, 0.33 and 0.23 for psychomotor speed, decision-making speed, working memory speed, and learning speed respectively) (97).

3.5.4 HeadMinder Concussion Resolution Index

Developed in the United States, the Concussion Resolution Index (CRI) is a Web-based instrument that is designed to be administered both at baseline and post-injury. During the initial test development phase, the developers of the Concussion Resolution Index demonstrated that the assessment scores well for test-retest reliability among a sample of 414 athletes in high school, college, and club settings (98). For athletes in college or adult club teams, 2-week test-retest reliabilities for the CRI Indices were 0.90 for the Processing Speed Index, 0.73 for the Simple

Reaction Time Index, and 0.72 for the Complex Reaction Time Index. For high school students, 2-week test-retest reliabilities were 0.79, 0.72 and 0.65 for the same Indices as above (74).

The concurrent validity of the CRI assessment was also examined during the test development phase. Moderate correlations of the CRI indices were found with various traditional neurocognitive tests (98). The CRI Processing Speed Index has been demonstrated to be correlated with other measures of processing speed including the Symbol Digit Modality Test (r=0.66), the Grooved Pegboard Test (used to measure motor coordination and psychomotor speed) (r=0.60), and the Wechsler Adult Intelligence Scale-III Symbol Search subtest (r=0.57) (21,98). The CRI Simple Reaction Time Index correlated with Grooved Pegboard performance at 0.46 and 0.60 (dominant and nondominant hands respectively) and with the Trail-Making Test at 0.56. The CRI Complex Reaction Time Index correlated with Grooved Pegboard performance at 0.59 and 0.70 (dominant and nondominant hands respectively) (74).

In 2001, the developers reported that the CRI assessment demonstrated an 88% sensitivity score in identifying post-concussion symptoms in athletes (74). These data were collected and reported as part of ongoing field trials among a sample of 834 athletes, 26 of whom sustained a concussion. Post-concussion symptoms were detected in 23 of the 26 concussed individuals (88%) (74).

3.6 Summary Neurocognitive Assessments Chapter

The recent development of computerized diagnostic tools reflects the growing interest in the application of sophisticated technology to provide better and more accurate injury diagnoses. While the ongoing process of validation of computerized models for concussion assessment is an encouraging sign for the eventual widespread implementation of standardized computer tools, existing instruments are deficient in several ways that make them less than ideal for the initial diagnosis of concussion and for monitoring recovery. The Automated Neuropsychological Assessment Metrics, the Immediate Post-Concussion Assessment and Cognitive Testing, CogSport, and the HeadMinder Concussion Resolution Index have essentially the same tasks as a paper and pencil-based neurocognitive test battery. Users are thus extremely aware that they are being tested on various aspects of mental ability. The cognitive evaluation is thus easily effected by participants' motivation and perhaps to some extent, their test-taking abilities. Moreover, these tests are only capable of measuring cognitive abilities as discreet domains rather than as systems operating simultaneously, thus providing a poor reflection of daily functioning. Interactive computer assessments, such as the CCAT, address these deficiencies. They have the potential to be the next step in the evolution of concussion diagnostic and assessment tools.

Chapter 4
Study Design and Methodology

This pilot study was a prospective observational clinical study. Its purpose was to assess a new diagnostic tool for the evaluation of concussion.

4.1 Study Objectives

4.1.1 Primary Study Objective

To explore, on a pilot basis, among head injured patients presenting to the KGH Emergency Department, the *construct validity by extreme groups* of the CCAT when examining persons who have and have not been diagnosed with a concussion using conventional clinical criteria.

4.1.2 Secondary Objective I

To examine the *criterion-related concurrent validity* of the CCAT using correlational analyses between head-injured patients' scores on the CCAT related to their scores on traditional measures of neurocognitive impairment (criterion measures). These criterion measures include memory and attention.

4.1.3 Secondary Objective II

To inform planning for a more definitive study by providing information relating to the feasibility and execution of the study in the emergency department setting and by investigating the diagnostic test properties of sensitivity and specificity of the instrument.

4.2 Study Populations

This pilot project involved patients presenting to the emergency department at Kingston General Hospital (KGH) and Hotel Dieu Hospital (HDH) with recent head injury. Patients were triaged as usual by the attendant nursing staff in the emergency department. Research staff then reviewed the recorded patient history to determine eligibility. Among all those enrolled, patients were further categorized into two different groups according to the presence or absence of concussive injury. A second control group of normal healthy volunteers recruited from the Kingston community during the development phase of the CCAT was also included in study.

4.2.1 Normal Volunteers

Prior to this pilot study, during the development phase of the CCAT, healthy volunteers between the ages of 16 and 30 from the Kingston community were recruited by the developers of the CCAT. Volunteers were recruited using Facebook, an online social networking program. An advertisement for participants was posted on the website such that it could be viewed by users who were members of the "Kingston community."

Through an iterative process of testing and modification in groups of 25 participants, an appropriate level of difficulty on the computer assessment was established among a sample of 68 healthy volunteers. These data were used as the comparison group for selected analyses with the Concussed Patients group.

4.2.2 Patient Identification and Recruitment

Patient identification and recruitment, was performed by research nurses working in the emergency departments at KGH and HDH. Research nurses were available from 0800h to 2200h daily through the months of June to August 2008 to screen for eligible patients. Prior to June 2008, research nurses were available 0800h to 1600h daily, excluding weekends. Patients were identified and recruited by emergency department research nurses during working hours only.

Patients were identified using the Patient Care System (PCS). This database program permits researchers working within the emergency department to identify patients' demographic characteristics and their presenting complaints. This information is available as soon as the patient is registered by the triage nurse. Patients between the ages of 16 to 40 with "head injury" as their presenting complaint were approached by the research nurse to assess his or her eligibility when the research nurse was available. Subject to the patient fulfilling all eligibility criteria, eligible patients were invited to participate in the study.

In most cases data collection was carried out in the emergency department. In some cases however, where patients were reluctant to complete the study at the time of their hospital visit, patients were given the option to return within 72 hours from the time of injury to Hotel Dieu Hospital to participate in the study.

4.2.3 Head-injured Non-concussed Patients

Patients with recent head injury (i.e. any superficial head and/or face wounds and bruises) but without having been diagnosed with concussion were included in the study as a control group.

4.2.4 Head-injured Concussed Patients

Patients were classified as concussed if they:

1) Had any of the following (observed or self-reported): loss of consciousness, any period of altered consciousness, and/or amnesia, and;

2) Had a confirmed discharge diagnosis of concussion by a physician in the Emergency Department.

4.3 Eligibility Criteria

The following eligibility criteria were applied to all patients and assessed by reviewing the Background Questionnaire, the patient's emergency record, and/or at the discretion of the research personnel where applicable.

4.3.1 Inclusion Criteria

Subjects were invited to participate in the study if they met the following inclusion criteria: 1) aged 16 to 40 years old; and 2) able to see clearly and have the full functional use of both hands.

4.3.2 Exclusion Criteria

Subjects were excluded if: 1) they had pre-existing mental and/or psychological impairment through any of the following: diagnosed mental condition, substance abuse or apparent mental retardation; 2) they were receiving sedating medications to treat his or her injury (e.g. opioid pain medication); 3) they had a head injury occurring greater than 72 hours prior to the emergency room assessment (this was to ensure that performance on the CCAT was not biased by the healing process); and 4) they required neurosurgical interventions to treat their head injury.

4.3.3 Enhanced Case Identification

We experienced difficulty identifying and enrolling patients throughout the study. This became clear part way into the data collection period. In an attempt to improve enrolment, a surveillance system link to the KGH and HDH emergency departments was developed and implemented for the duration of this pilot project whereby email alerts were sent directly to a Blackberry data account within 15 minutes of an eligible patient presenting to either KGH or HDH. This eliminated the need for constant observation on PCS and gave researchers time to arrange a suitable testing environment in the emergency department in which to complete the study.

4.4 Data Collection

This pilot project involved primary data collection out of the Emergency Departments at Kingston General Hospital and Hotel Dieu Hospital in Kingston, Ontario between August 2007 and July 2008.

4.4.1 Administration of the Neurocognitive Test Battery

The sequence of tests included in the test battery was determined according to the importance of each test to the neuropsychological evaluation, as well as the timing of the various tests (e.g. several tests required repeat administration with specific periods of time between them). A brief description of the tests is provided in **Appendix A** and the test sequence and the times required to administer each test are provided in **Appendix B**.

4.4.2 The Background Questionnaire

All participants were required to complete a background questionnaire at the beginning of the study. The purpose of the questionnaire was to collect information on variables that may be related to performance on the CCAT. In addition to providing personal demographic information such as age, gender and highest level of education, individuals were asked specifically about their driving experience, their frequency of video game use and to describe any previous head injuries they may have had. Patients were additionally asked to report symptoms related to their head injury. The Background Questionnaire is provided in **Appendix C**.

4.4.3 Administration of the Computerized Concussion Assessment Tool

The CCAT was designed to require minimal administration. The instructions for the tasks on the computer assessment are programmed into its introduction; every user must complete the introduction, including a practice round, before beginning the assessment. However, because this pilot study is looking at the efficacy of the game itself, each participant was led through the instructions and practice round by the researcher and was encouraged to ask for clarifications. This was to ensure that participants clearly understood the tasks of the computer assessment.

4.4.4 Testing Conditions

Testing was performed in many locations in the ED including the waiting room, treatment rooms, an adjacent office, and at the ED research desk. This variability among patients' testing situations was unavoidable within the emergency department setting where it was important that the research study not interfere with or interrupt the medical examination.

4.4.5 Ethical Considerations

All study participants underwent a medical examination for their injuries consistent with the usual standard of care in the hospital emergency department. Participation in this study was voluntary and patients were free to withdraw from the study at any time. The consent form (**Appendix D**) and the information sheet for participants (**Appendix E**) are appended.

Study identification numbers were assigned to patients sequentially as they were enrolled into the study, thereby assuring anonymity. Data were kept in locked cabinets in the Clinical Research Center of Kingston General Hospital. Computer files will be stored on a password-protected computer in a locked office in KGH.

The study protocol and all amendments received approved from the Queen's Research Ethics Board.

4.5 Data Management and Statistical Methods

Patients were given consecutive identification numbers upon enrolment in the study. After the patient's discharge diagnosis had been confirmed, patients were entered into either the Head-injured Concussed Patients group or the Head-injured Non-concussed Patients group, as appropriate.

4.5.1 Sample Size

During the planning stage, a sample size of 50 patients was chosen as a feasible number of patients to recruit over the study period and appropriate for a pilot study of this new diagnostic tool. Because this was a pilot study, no information was available on which to base sample size calculations. However, it was anticipated that the Concussed Patients group would perform considerably worse than the Non-concussed Patients comparison group and the Normal Volunteers comparison group.

4.5.2 Descriptive Statistics

The three study populations (Head-injured Concussed Patients, Head-injured Non-concussed Patients and Normal Volunteers) were described by demographic, clinical, and injury-related characteristics where applicable, and factors considered as potential confounders such as past video game and driving experience were examined using descriptive statistics. This involved examining the distribution of the data, the means and standard deviations and the medians and interquartile ranges, and percentages. Differences between groups were compared using t-tests, chi-square tests, analysis of variance or Wilcoxon rank sum tests.

4.5.3 Group Differences in Performance on the CCAT

The primary analysis involved comparisons of CCAT Scores for Selective Attention, Divided Attention, Memory, and Effort between the Concussed Patients group and the Non-concussed Patients group, and between the Concussed Patients group and the Normal Volunteers group using Wilcoxon rank-sum tests and chi-square statistics.

A secondary analysis adjusting for covariates was also performed using multiple linear regression. The outcomes (i.e. CCAT Scores for Memory, Selective Attention and Divided Attention) were log-transformed as their distributions were non-normal. Logistic regression was used to model the outcome of Effort Score as this is a dichotomous variable. All regression models were fitted with the covariates of age, gender, education level and effort. These covariates were chosen based on the observed differences between participant groups that were found in the initial descriptive analysis investigating the population characteristics.

In addition, functions evaluated by the computer assessment were compared between groups in order to explore the underlying performance parameters on which the CCAT Scores are based. For this exploratory analysis, data were included only for participants who completed the driving portion of the computer assessment at fixed speed (i.e. the accelerate and brake options were turned off). Divided Attention Score (DAS) is one of 3 primary scores generated by the computer. The calculation is based on the user's ability to keep the car at the centre of the road while simultaneously performing the various tasks of attention and memory that the game requires:

DAS = [(Time on Road – Time on Wall)/(Time on Road)
*100%]

Selective Attention Score (SAS) is another one of 3 primary scores generated by the computer. The calculation is based on the user's ability to correctly identify target pylons and to ignore distracter pylons:

SAS = [(% Target Pylons Reacted To) – (% Distracter Pylons Reacted To)]

Memory Score (MS) is the third of 3 primary scores generated by the computer. The calculation is based on users' performance on a memory test following each round of driving. During the driving portion of the computer assessment, 7 Billboard images (stimuli peripheral to the roadside) and 7 Road Sign images (stimuli near to the roadside) are displayed per Round. These 14 images are presented to the user alongside unfamiliar images at the end of the driving portion; the user is asked to identify which of two images he or she remembers having seen:

MS = [(# Correct Road Signs identified + # Correct Billboards identified)/14 *100%]

4.5.4 Correlational Analysis

CCAT Scores for Selective Attention, Divided Attention, Memory, and Effort were correlated with various scores on traditional neurocognitive tests. This was done using Spearman's rank correlation coefficients.

4.5.5 Diagnostic Test Properties

Sensitivity, specificity, positive, and negative predictive values were calculated by comparing the reference standard diagnosis (i.e. observed or self-reported symptoms and the emergency department physician's diagnosis) with concussion/non-concussion classifications suggested by CCAT cut-off values.

Chapter 5
Results

5.1 Patient Groups

Forty head-injured patients were recruited over the period beginning August 2007 and ending July 2008 during visits to the emergency departments at Kingston General Hospital (KGH), and at Hotel Dieu Hospital (HDH) in Kingston, Ontario. All patients completed the computer game assessment and the neurocognitive test battery in the emergency department. Of this patient sample, 22 patients were diagnosed with concussion and 18 patients had a non-concussive head injury. Head injuries in this latter group included lacerations, bruises or other trauma to any area on the head.

5.2 Normal Volunteers

Sixty-eight healthy volunteers were recruited during the development phase over the period beginning May 2007 and ending August 2007 through Facebook, a social networking website. This Normal Volunteers group were used as a comparison group for selected analyses.

5.2.1 Results from the Development Phase

The CCAT was developed through an iterative process of testing and modification in order to establish an appropriate level of difficulty among a large sample of healthy volunteers between the ages of 16 and 30. Seventy five participants were recruited in groups of 25 through

Facebook, an online social networking web program (99). Following each round of testing, minor modifications were made to the program. Each of the 75 participants completed the video game twice (with a duration of one week between assessments). This was done in order to observe if the assessment was subject to practice effects as would be indicated where there are large changes in test performance between test and retest (89). A comparative analysis of game performance between initial testing (time 1) and testing one week later (time 2) indicated that there was a difference between time 1 and time 2. At time 2, users spend less time on the "wall" (i.e. on the sides of the track) ($p=0.02$), and show a better response on the task of identifying pylons along the roadside ($p=0.006$). These data have implications for the clinical use of this type of assessment. If a learning effect persists in subsequent versions of the CCAT, the video game format may not be appropriate for monitoring recovery.

5.3 Descriptive Analysis

5.3.1 The Study Population

Differences between the Patients groups and the Normal Volunteers group were found to be significant for several of the demographic characteristics and game-related factors assessed by the background questionnaire (**Table 1**). A higher percentage of men than women participated in the study for all participant groups. This was particularly true among the Patients groups where 64% of all Concussed Patients and 89% of all Non-concussed Patients were male. In contrast, 53% of the Normal Volunteers group were male.

There was no significant difference in the mean age of each participant group. The average age of the overall population was 22.5 years. No significant differences were found between groups by possession of a valid driver's license nor by the amount of time spent playing video games. There was also no difference between patient groups in their driving frequency.

There was a significant difference between participant groups by education level, although at least 50% of each participant group had attended or were attending college or university. Due to differences in recruitment strategies for the Normal Volunteer group and the Patients groups, the higher proportion of participants educated at the college/university level in the Normal Volunteers group was expected.

The North American Adult Reading Test was administered to the patient sample only, and provided an additional estimate of intellectual ability. No difference was observed between the two patient samples.

Table 1 Descriptive statistics for the three participant groups

	Head-injured Concussed Patients n = 22	Head-injured Non-concussed Patients n = 18	Normal Volunteers n = 68	χ^2/t/F	p value
Gender				7.81	0.02
Women	8 (36%)	2 (11%)	32 (47%)		
Men	14 (64%)	16 (89%)	36 (53%)		
Age (years)	23.3 (6.2)	23.1 (5.5)	21.2 (2.7)	2.99	0.05
Possess valid Ontario driver's license	17 (77%)	16 (89%)	56 (82%)	0.92	0.63
Driving frequency				2.24	0.33
≥ Weekly	14 (88%)	11 (79%)	--		
Monthly	1 (6%)	0	--		
< Once a month	1 (6%)	3 (21%)	--		
Previous head injury				9.74	0.05
Past year	2 (10%)	0	0		
Lifetime	8 (38%)	8 (44%)	21 (31%)		
No previous head injury	11 (52%)	10 (56%)	46 (69%)		
Current video game use (hours/week)				5.05	0.75
Never	6 (27%)	4 (22%)	25 (37%)		
< 5	13 (59%)	8 (44%)	27 (40%)		
5-10	2 (9%)	4 (22%)	11 (16%)		
> 11	1 (5%)	2 (11%)	5 (7%)		
Highest level of education				31.95	<0.0001
High school	8 (36%)	5 (28%)	3 (4%)		
College/University	10 (45%)	10 (56%)	64 (94%)		
Post-graduate	1 (5%)	0	1 (1%)		
Full-Scale IQ from the NAART Mean (SD); Median (IQR)	103.9 (7.4); 101.7 (99.7, 108.7)	99.9 (7.2); 101.3 (104.4, 94.3)	--	1.65	0.11

5.3.2 Effort

Among the entire patient population (n=40), three patients failed the Medical Symptom Validity Test. Exclusion of these patients from the overall analysis did not significantly affect the results; hence these patients were included in all analyses.

There was no significant difference in the percentage of the group who passed the Medical Symptom Validity Test between the Concussed Patients group and the Non-concussed Patients group. On the CCAT Effort Score, the Patients groups scored significantly worse than the Normal Volunteers group at a significance level of $p<0.05$ (**Table 2**).

5.3.3 Concussive Symptoms by Self-Report

Patients being seen in the emergency department were asked to provide information about their head injury. Specifically, they were asked whether they had lost consciousness, experienced dizziness or blurred or double vision as a result of their injury, and whether they were able to clearly remember events leading up to and following their head injury. The frequency of positive responses to these questions is shown in **Table 3**. Interestingly, several non-concussed patients reported having experienced symptoms commonly associated with concussion.

Table 2 Effort performance for the three participant groups

	Head-injured Concussed Patients n = 22	Head-injured Non-concussed Patients n = 18	Normal Volunteers n = 68	χ^2	p values
	n (% of subjects who passed)	n (% of subjects who passed)	n (% of subjects who passed)		
Computerized Concussion Assessment Tool Effort Score	10 (45)	8 (44)	47 (69)	6.12	<0.05
Medical Symptom Validity Test[2]	17 (89)	13 (93)	--	0.11	0.74

Table 3 Self-reported symptoms related to patients head injuries

	Head-injured Concussed Patients	Head-injured Non-concussed Patients
Loss of consciousness	7	2
Dizziness	19	9
Blurred or double vision	10	6
Unable to remember events clearly before and following the head injury	8	1

[2] Proportion of adults with severe traumatic brain injury or neurological disease who passed the MSVT was reported to be 98% (n = 26) (92).

5.3.4 The CCAT Assessment[3]

As the computer assessment consists of 3 rounds of driving and 3 memory tests, differences between Rounds 1, 2, and 3 were examined according to performance parameters and test Scores. No statistically significant difference between rounds was found for any of these measurements (**Appendix G**). This suggests that it is not necessary to have 3 testing segments. Anecdotally, during the administration of the computer assessment, several participants seemed not to have a clear understanding of the tasks of the game and the instructions involving the game controller throughout their first round of driving and the first memory test. Because there was some uncertainty about users' proper execution of the computer assessment, Round 1 data were eliminated and the average of Rounds 2 and 3 was calculated for each individual and used in all subsequent analyses.

All performance parameters and computer game test Scores were assessed for normality. All measures displayed a non-normal distribution except for the 2 neurocognitive assessments of memory (Wechsler Memory-III subtests of Logical Memory and Family Pictures which assess verbal and visual memory respectively). In order to simplify both the analysis interpretation and the results display, all analyses have been calculated based on ranks of scores and associated non-parametric statistics.

The distribution of scores on the computer assessment corresponding to selective attention, divided attention and memory were all heavily skewed to the right, indicating that patients generally performed well on these measures (data not shown).

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[3] See **Appendix F** for a Glossary of CCAT Terms

5.4 Construct Validity of the CCAT by Extreme Groups Comparison

The primary Scores generated by the computer assessment were compared between the 3 participant groups (**Table 4**). No statistically significant differences were observed for any of the measures between the 2 Patients groups. This is reflected by the similarity in the median Scores for Selective Attention, Divided Attention and Memory in the Concussed Patients group and the Non-concussed Patients group.

In contrast, statistically significant differences were found for all CCAT Scores between the Concussed Patients group and the Normal Volunteers group.

Table 4 The CCAT Scores: medians, interquartile ranges and tests for statistical significance between the three participant groups

	A	B	C	p values[4]	
	Head-injured Concussed Patients n = 22	Head-injured Non-concussed Patients n = 18	Normal Volunteers n = 68	A vs. B	A vs. C
Computerized Concussion Assessment Tool Scores	Median (IQR)	Median (IQR)	Median (IQR)		
Selective Attention Score	90.8 (81.7, 96.7)	91.7 (83.3, 96.7)	96.7 (91.7, 100.0)	0.80	0.01
Divided Attention Score	98.0 (96.7, 98.4)	98.1 (96.7, 98.7)	99.1 (97.8, 99.7)	0.67	0.001
Memory Score	77.5 (60.0, 80.0)	65.0 (60.0, 80.0)	85.0 (75.0, 90.0)	0.78	0.01
Effort Score n (% who achieved 100%)	10 (45)	8 (44)	47 (69)	0.95	0.05
Overall score	86.0 (81.1, 91.7)	86.0 (82.2, 90.8)	93.2 (89.2, 96.6)	0.97	0.002

[4] From chi-square statistics (categorical data) and Wilcoxon rank-sum test (non-parametric).

5.4.1 Comparison of Performance Parameters at Fixed Speed

All subjects in the patient groups completed the computer assessment at fixed speed. Thirty-seven Normal Volunteers completed the CCAT assessment at fixed speed (**Table 5**).

Performance parameters relating to the calculation of DAS indicate that there was no significant difference between groups in the amount of time spent on the Wall, or in the Total Drive Time. When the overall analysis looking at differences between groups on CCAT Scores was repeated using only data collected from computer assessments set to fixed speed, the difference between the Concussed Patients group and the Normal Volunteers group became non-significant (**Table 6**).

Performance parameters relating to the calculation of SAS indicate no significant difference between participant groups. However there was a difference found between the Concussed Patients group and the Normal Volunteers group for the Target Pylons Average Response Time. Median response times for the three groups indicated a trend for slower response times as injury severity would suggest.

Performance parameters relating to the calculation of MS show significant differences between participant groups for identification of Road Signs ($p=0.04$) but not for Billboards ($p=0.11$). There appears to be a trend in performance based on injury severity, however the difference appears to be between the patient sample as a whole and the Normal Volunteers group rather than between the Concussed Patients group and all participants without concussion.

Table 5 Performance parameters on the CCAT for the three participant groups

	A	B	C		
	Head-injured Concussed Patients n = 22	Head-injured Non-concussed Patients n = 18	Normal Volunteers n = 37	p values	Post-hoc[5]
	Median (IQR)	Median (IQR)	Median (IQR)		
Total Drive Time (seconds)	125.45 (123.77, 128.41)	124.70 (123.18, 126.93)	126.06 (124.28, 128.99)	0.24	
Time on Wall (seconds)	2.47 (1.92, 4.36)	2.42 (1.64, 4.18)	2.68 (1.61, 3.38)	0.94	
Percent Time on Wall (%)	1.96 (1.56, 3.30)	1.95 (1.33, 3.32)	2.12 (1.23, 2.63)	0.99	
# Target Pylons Reacted To (out of 15) n (%)				0.49	
<13	5 (23)	4 (22)	4 (11)		
13-<15	10 (45)	11 (61)	20 (54)		
15	7 (32)	3 (17)	13 (35)		
Target Pylons Average Response Time	1.12 (0.97, 1.23)	1.05 (0.95, 1.23)	0.91 (0.83, 1.01)	0.03	A-B B-C A-C*
# Distracter Pylons Reacted To (out of 30) n (%)				0.60	
0	10 (45)	9 (50)	19 (51)		
1	9 (41)	8 (44)	17 (46)		
2	3 (14)	1 (6)	1 (3)		
Distracter Pylons Average Response Time	0.08 (0, 0.43)	0.05 (0, 0.55)	0 (0, 0.35)	0.32	
# Billboards Correct (out of 5)				0.11	

[5] Asterix indicates difference between groups at the 0.05 significance level.

n (%)				
0	1 (5)	0	0	
1-3	10 (45)	12 (67)	13 (35)	
4-5	11 (50)	6 (33)	24 (65)	
# Road Signs Correct (out of 5) n (%)				0.04
0	1 (5)	0	0	
1-3	12 (55)	8 (44)	8 (22)	
4-5	9 (41)	10 (56)	29 (78)	

Table 6 The CCAT Scores for all assessments performed at fixed speed

	A	B	C	p values[6]	
	Head-injured Concussed Patients n = 22	Head-injured Non-concussed Patients n = 18	Normal Volunteers n = 37	A vs. B	A vs. C
Computerized Concussion Assessment Tool Scores	Median (IQR)	Median (IQR)	Median (IQR)		
Selective Attention Score	90.8 (81.7, 96.7)	91.7 (83.3, 96.7)	95.0 (91.7, 100.0)	0.80	0.09
Divided Attention Score	98.0 (96.7, 98.4)	98.1 (96.7, 98.7)	97.9 (97.4, 98.8)	0.67	0.38
Memory Score	77.5 (60.0, 80.0)	65.0 (60.0, 80.0)	80.0 (75.0, 90.0)	0.78	0.03
Effort Score n (% who achieved 100%)	10 (45)	8 (44)		0.95	
Overall score	86.0 (81.1, 91.7)	86.0 (82.2, 90.8)	93.2 (89.2, 96.6)	0.97	0.02

[6] From chi-square statistics (categorical data) and Wilcoxon rank-sum test (non-parametric).

5.4.2 Subgroup Analysis by Injury Severity (as inferred by CT scanning)

One possibility for the observed homogeneity between patient groups' Scores is misclassification of injury. Given that concussion severity occurs along a continuum and, as a "gold standard" for the diagnosis of concussion does not exist, it is possible that some patients with concussion were entered into the Non-concussed Patients group. Similarly, it is possible that some patients were misdiagnosed with concussion and therefore classified incorrectly in the Concussed Patients group. To address the potential for misclassification of injury, a subgroup analysis was performed among the 22 Concussed Patients whereby patients were grouped according to whether they had had computed tomography (CT) scans to assess their head injury. Doctors generally request CT scans in the case where they are concerned about a more serious head injury based on the severity of symptoms or the mechanism of injury, or a combination of both.

Eight patients diagnosed with concussion underwent CT scans for their head injuries. The CCAT Scores of this subgroup were compared with the CCAT Scores for the Concussed Patients who did not undergo CT scans (n=14) and with the Head-injured Non-concussed Patients group (n=18). There were no significant differences between groups for any of the CCAT Scores (**Table 7**).

5.4.3 Adjustment for Covariates

In an attempt to further explore the observed similarity in performance on the CCAT between Patients groups and the difference between the patient sample and the Normal Volunteers group, multiple linear regression was applied to the data including covariates of age, gender, education and effort in the model (**Table 8**). Statistically significant differences were found between groups for gender, education and effort in the initial descriptive analysis.

The results indicate that after adjusting for age, gender, education and effort, the differences in performance on CCAT Scores for memory, divided and selective attention between the Concussed Patients group and the Normal Volunteers group become non-significant. However a statistically significant difference between groups remained on the CCAT Overall Score.

Table 7 The CCAT Scores: subgroup analysis for Concussed Patients with CT scan

	A	B	C	p values[7]	
	Head-injured Concussed Patients with CT Scan n = 8	Head-injured Concussed Patients without CT Scan n = 14	Head-injured Non-concussed Patients n = 18	A vs. B	A vs. C
Computerized Concussion Assessment Tool Scores	Median (IQR)	Median (IQR)	Median (IQR)		
Selective Attention Score	92.5 (84.2, 98.3)	90.0 (80.0, 96.7)	91.7 (83.3, 96.7)	0.61	0.93
Divided Attention Score	98.3 (97.8, 98.4)	97.7 (95.3, 98.5)	98.1 (96.7, 98.7)	0.32	0.89
Memory Score	60.0 (47.5, 87.5)	80.0 (70.0, 80.0)	65.0 (60.0, 80.0)	0.39	0.47
Overall score	86.0 (81.1, 91.7)	86.0 (82.2, 90.8)	93.2 (89.2, 96.6)	0.66	0.76

Table 8 The CCAT Scores: adjustment for covariates

	A	B	C	p values[8]	
	Head-injured Concussed Patients n = 22	Head-injured Non-concussed Patients n = 18	Normal Volunteers n = 68	A vs. B	A vs. C
Computerized Concussion Assessment Tool Scores	Median (IQR)	Median (IQR)	Median (IQR)		
Selective Attention Score	90.8 (81.7, 96.7)	91.7 (83.3, 96.7)	96.7 (91.7, 100.0)	0.61	0.18
Divided Attention Score	98.0 (96.7, 98.4)	98.1 (96.7, 98.7)	99.1 (97.8, 99.7)	0.38	0.08
Memory Score	77.5 (60.0, 80.0)	65.0 (60.0, 80.0)	85.0 (75.0, 90.0)	0.48	0.13
Effort Score n (% who achieved 100%)	10 (45)	8 (44)	47 (69)	0.44	0.27
Overall score	86.0 (81.1, 91.7)	86.0 (82.2, 90.8)	93.2 (89.2, 96.6)	0.99	0.005

7 From chi-square statistics (categorical data) and Wilcoxon rank-sum test (non-parametric).
8 Adjusted for age, gender, effort and education status using multiple linear or logistic regression, as appropriate.

5.5 Neurocognitive Tests

Performance on neurocognitive tests for memory, divided and selective attention was compared between the Head-injured Concussed Patients group and the Head-injured Non-concussed Patients group. None of these neurocognitive tests was able to discriminate between the Concussed Patients group and the Non-concussed Patients group at a significance level of p=0.05 (**Table 9**). However, the Concussed Patients group had lower mean and median scores than the Non-concussed Patients for all aspects of memory and for selective attention, indicating a trend in neurocognitive deficit as injury classification would suggest.

Table 9 Patients' performance on neurocognitive tests

	Head-injured Concussed Patients n = 22		Head-injured Non-concussed Patients n = 18		p values
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
Memory					
WMS-III Logical Memory subtest: Recall I[1] (verbal memory)	7.3 (3.0)	7 (6, 9)	8.3 (2.5)	9 (6, 11)	0.17
WMS-III Logical Memory subtest: Recall II[1] (verbal memory)	3.5 (2.3)	3 (2, 5)	4.6 (2.2)	5 (3, 6)	0.09
WMS-III Family Pictures I[9] (visual memory)	7.9 (3.0)	8 (6, 9)	9.1 (3.2)	9 (7, 11)	0.24
WMS-III Family Pictures II[10] (visual memory)	8.2 (2.9)	8 (6, 10)	8.9 (3.4)	9 (6, 11)	0.49
Divided Attention					
D-KEFS Trails subtest[11]	9.5 (3.5)	11 (8, 12)	9.5 (2.4)	9 (8, 11.5)	0.65
D-KEFS Stroop subtest[12]	10.2 (2.5)	10 (9, 12)	9.8 (3.3)	11 (7.5, 12)	1.0
Selective Attention					
Trails subtest: Visual Scanning[2]	10.6 (3.0)	11 (9, 13)	11.8 (1.8)	12 (10.5, 13)	0.20

[9] For healthy individuals, Mean (SD) is 10 (3) (91).
[10] For healthy individuals, Mean (SD) is 10 (3) (91).
[11] For healthy individuals, Mean (SD) is 10 (3) (90).
[12] For healthy individuals, Mean (SD) is 10 (3) (90).

5.6 Criterion-Related Concurrent Validity of the CCAT

Among all patients, CCAT Scores were compared with several neurocognitive tests through correlational analyses. Spearman's correlation coefficients were employed as most of the distributions of test scores were skewed.

The CCAT Memory Score showed moderate correlations with the WMS-III Logical Memory neurocognitive test (designed to measure immediate and short-term verbal memory) and with the WMS-III Family Pictures neurocognitive test (designed to measure immediate and short-term visual memory) (**Table 10**).

The CCAT Divided Attention Score was not significantly correlated with either of the two neurocognitive tests used to assess divided attention (**Table 11**).

The CCAT Selective Attention Score showed moderate correlation with the Visual Scanning neurocognitive subtest used to measure selective attention (**Table 12**).

Table 13 shows the correlation between the CCAT Overall Score and other computer assessment Scores. The CCAT Overall Score is a composite calculation derived from the 3 primary Scores (Memory, Selective Attention and Divided Attention) and should thus show high correlations with the component CCAT Scores:

$$\text{Overall Score} = [(SAS + DAS + MS)/3]$$

The Overall Score is highly correlated with the Memory Score and the Selective Attention Score. The Overall Score is weakly correlated with the Divided Attention Score. These correlations indicate which of the component Scores are contributing most to the composite Overall Score. By this reasoning, the Divided Attention Score is not a useful measure.

Education Status and FSIQ were weakly correlated with the computer assessment Scores.

Table 10 Correlational Analysis: Memory

	Computerized Concussion Assessment Tool Memory Score
Logical Memory subtest: Recall I (verbal memory)	0.26 (0.12)
Logical Memory subtest: Recall II (verbal memory)	0.18 (0.30)
Family Pictures I (visual memory)	0.32 (0.04)
Family Pictures II (visual memory)	0.40 (0.02)

Table 11 Correlational Analysis: Divided Attention

	Computerized Concussion Assessment Tool Divided Attention Score
Trails subtest (divided attention)	0.07 (0.69)
Stroop subtest (divided attention)	0

Table 12 Correlational Analysis: Selective Attention

	Computerized Concussion Assessment Tool Selective Attention Score
Trails subtest: Visual Scanning (selective attention)	0.31 (0.07)

Table 13 Correlational Analysis: Overall Score

	Computerized Concussion Assessment Tool Overall Score
CCAT Memory Score	0.91 (<0.05)
CCAT Divided Attention Score	-0.08 (0.62)
CCAT Selective Attention Score	0.62 (<0.05)

5.7 Diagnostic Test Properties

Diagnostic test properties of the computer assessment Scores are summarized in **Table 16**. Cut-off values were determined based on the distribution of data for each of the CCAT Scores. All Scores at their various cut-off values show poor sensitivities and the specificities.

Table 14 Diagnostic test properties of the CCAT

CCAT Cut-off (%)	Head-injured Concussed Patients n = 22	Normal Volunteers n = 68	Sensitivity (LI, UI)	Specificity (LI, UI)	Positive Predictive Value (LI, UI)	Negative Predictive Value (LI, UI)
Selective attention Score (SAS)						
<90	10	11	45 (25, 66)	84 (77, 91)	48 (28, 68)	17 (10, 25)
<80	2	5	9 (0, 21)	93 (88, 98)	29 (10, 47)	24 (16, 32)
<70	2	4	9 (0, 21)	94 (90, 99)	33 (14, 53)	24 (16, 32)
<60	2	3	9 (0, 21)	96 (92, 99)	40 (20, 60)	24 (16, 32)
Divided attention Score (DAS)						
<99	21	33	95 (87, 100)	51 (42, 61)	39 (19, 59)	3 (0, 6)
<95	1	3	5 (0, 13)	96 (92, 99)	25 (7, 43)	24 (16, 33)
<90	0	2	0	97 (94, 100)	0	25 (17, 33)
Memory Score (MS)						
<90	18	41	82 (66, 98)	40 (30, 49)	31 (11, 50)	13 (7, 19)
<80	11	19	50 (29, 71)	72 (64, 81)	37 (17, 57)	18 (11, 26)
<70	8	9	36 (16, 56)	87 (80, 93)	47 (26, 68)	19 (12, 27)
<60	5	3	23 (5, 40)	96 (92, 99)	63 (42, 83)	21 (13, 28)
Overall Score						
<145	20	55	91 (79, 100)	19 (12, 27)	27 (8, 45)	13 (7, 20)
<140	17	39	77 (60, 95)	43 (33, 52)	30 (11, 50)	15 (8, 21)
<135	15	20	68 (49, 88)	71 (62, 79)	43 (22, 64)	13 (6, 19)
<130	13	12	59 (39, 80)	82 (75, 90)	52 (31, 73)	14 (7, 20)

Chapter 6
Discussion

6.1 Study Rationale

The purpose of this study was to inform the planning and execution of a larger validation study for the Computerized Concussion Assessment Tool, and to provide preliminary estimates of the discriminative ability of this novel diagnostic instrument in the evaluation of concussion. This pilot project represents the first time that the CCAT has been tested among concussed patients. The three key cognitive functions that this new instrument was designed to measure were selective attention, divided attention and memory. The ability of the instrument to discriminate between injury groups and the implications for the refinement of the CCAT and in planning a larger validation study will be the focus of this discussion.

6.2 Key Findings

Statistically significant differences between the patient sample and the Normal Volunteers group were identified for demographic characteristics, game-related factors and performance on the CCAT. This suggested that a crude comparative analysis might mask important imbalances between the three groups. After adjusting for age, gender, education and effort, CCAT Scores corresponding to memory, selective attention and divided attention were not significantly different between the three groups. A subgroup analysis comparing CCAT Scores from concussed patients with and without referral for computed tomography, and Head-injured Non-concussed Patients, also failed to find differences between groups. In addition, the point estimates (i.e. medians) of the Scores between the three groups for the crude and adjusted analyses did not suggest a trend according to injury severity.

Moderate correlations were observed between both the CCAT Memory Score and Selective Attention Score and their respective neurocognitive tests. There was no evidence of a correlation between Divided Attention and the neurocognitive test designed to assess divided attention.

The diagnostic test properties of the CCAT indicate that this pilot version of the instrument is not yet ready to be used as a stand-alone diagnostic tool.

6.3 Discrimination Between Groups

The primary study objective was to explore the construct validity of the CCAT by comparing performance on the CCAT between the three participant groups (extreme groups comparison).

There are several possible explanations for the failure of the CCAT Scores to discriminate between the Concussed Patients group and all non-concussed participants. One explanation may be that the assessments of cognitive function measured by the Scores are not measuring what they purport to measure. It is also possible that the measurements are not sensitive enough to detect subtle cognitive deficits that result from concussive injury.

Another possibility is that the reference standard of the ED physician's diagnosis of concussion in addition to self-reported or observed symptoms related to the injury is creating too much "noise" between patient groups. That is, the reference standard may not be correctly discriminating between concussed and non-concussed patients with recent head injury. Many patients not actually diagnosed with concussion reported symptoms related to concussive injury.

This reflects the fact that the diagnosis of concussion by the physician is associated with some subjectivity and demonstrates the potential for the misclassification of concussion (63).

Finally, the small sample size of this pilot study resulted in a situation where differences between groups must be large in order to be detected. It is possible that statistically significant differences in CCAT performance may be detected among a larger study population, though these differences may be smaller than originally expected.

6.4 The CCAT Scores and Performance Parameters

The first secondary study objective was to examine the criterion-related concurrent validity of the CCAT using correlational analyses to compare CCAT Scores with traditional neurocognitive assessments.

6.4.1 Selective Attention Score

While there were no statistically significant differences between groups for the Selective Attention Score, moderate correlations were observed between the Selective Attention Score and the neurocognitive test assessing selective attention (D-KEFS Trails subtest: Visual Scanning). This suggests that the Selective Attention Score may represent a valid measurement of selective attention. In addition, the performance parameter of response time was found to be significantly worse for the Concussed Patients group than for all non-concussed patients. Response time has been discussed as a potentially useful indicator of brain injury and as a possible index measurement for concussion severity. This performance parameter should thus be considered in the development of subsequent versions of the CCAT as a potential marker of concussion severity.

6.4.2 Divided Attention Score

Within the entire study population, the Divided Attention Score showed very little variation and was not correlated with the divided attention neurocognitive tests (D-KEFS Stroop and Trails subtests). Thus, the Divided Attention Score is likely not a true assessment of divided attention. Similarly, the performance parameter from which the CCAT Divided Attention Score is generated (i.e. Time on Wall), is not effective at discriminating between injury groups and thus appears unlikely a useful marker of concussive injury.

6.4.3 Memory Score

Point estimates (i.e. medians) of the Memory Score in the subgroup analysis for Concussed Patients with CT scan suggest that the Memory Score has some ability to discriminate between injury groups. The performance parameters from which the Memory Score is derived reflect this observation. Moderate correlations were observed between the Memory Score and neurocognitive tests that assess memory. These observations taken together suggest that the Memory Score generated from the computer assessment may be a valid assessment of memory.

6.4.4 Overall Score

The Overall Score is an un-weighted average of the 3 component Scores (Memory, Selective Attention and Divided Attention). It is intended to provide clinicians, athletic trainers and other administrators of the CCAT assessment with a simple and easy interpretation of injury severity.

High correlations observed between the Overall Score with the Memory Score and the Selective Attention Score indicate that these component Scores contribute most to the Overall Score.

6.4.5 Effort Score

The difference in Effort Score between groups may be interpreted in two ways: if it is assumed that the Effort Score is an accurate measure of effort, it is possible that patients were exaggerating their symptoms; perhaps because they felt it was expected of them, or because they were in pain or uncomfortable and lacked motivation to perform their best under the circumstances. Symptom exaggeration and/or lack of motivation as measured by the Effort Score would therefore imply that performance on other aspects of the computer assessment may have been affected by poor effort among patients. However, it is also possible that the Effort Score is not measuring what it was intended to measure. The Effort Score is generated in the same way as the Memory Score (i.e. using images from the driving portion of the computer assessment), albeit with images that are intended to be obviously unfamiliar to the user. As the Memory Score is perhaps the most sensitive indicator of concussion, the Effort Score (essentially an easy memory test) may actually be a marker of concussive brain injury. As an indication of this, a relatively high correlation between the Effort Score and the Memory Score was observed ($r=0.53$, $p<0.05$).

6.5 Considerations for the Future Development of the CCAT

The second secondary objective was to inform and direct the planning of a larger validation study for the CCAT.

6.5.1 Neurocognitive Test Battery

Although no statistical significant differences were found between injury groups on the neurocognitive tests, the point estimates (i.e. means and medians) of the memory and selective attention neurocognitive tests suggest that there are clinically relevant and meaningful trends according to injury severity. There are many possibilities that may explain the failure of the neurocognitive test battery to discriminate between injury groups including the small sample size of the study, potential misclassification of injury and/or cognitive deficits as a result of concussion that are too subtle to detect using these tests.

As recovery from concussion is poorly understood and deficits in cognitive function as a result of the injury are often difficult to detect, the acute care setting offers the opportunity to identify and recruit concussed patients with very recent brain injury. However neurocognitive test batteries are rarely employed by researchers in the acute care setting as they are time-consuming and difficult to administer in this environment. While one study exists where researchers administered a neurocognitive test battery (consisting of seven tests) exclusively to concussed patients in the emergency department of a university teaching hospital, no previous research has employed neurocognitive tests to diagnose concussion in the acute care setting (100).

Validation studies for concussion diagnostic tools that have been performed among athletes in field settings make use of longer test batteries than the one designed for this study (101). In addition, these studies are generally conducted among individuals with more severe concussions; post-injury testing is generally completed within one week or longer from the time of injury among concussed athletes who remain symptomatic (97). Furthermore, the test batteries are administered for the primary purpose of demonstrating correlation between the neurocognitive test (i.e. criterion-related validity) and the diagnostic tool in question, rather than as a method of diagnosing concussion (17,21,35,97).

6.5.2 Memory

Relative to the other tests, the point estimates for the neurocognitive memory tests (WMS-III Logical Memory and Family Pictures subtests) are particularly able to discriminate between the two Patients groups. This is important for the future development of concussion assessments, suggesting that, among the three key cognitive functions assessed in this study, memory may be the most sensitive indicator of concussive injury.

6.5.3 Selective Attention

The point estimates for the neurocognitive test that measured selective attention (D-KEFS Trails: Visual Scanning subtest) also showed a trend for worse performance among the Concussed Patients group relative to the Non-concussed Patients group.

6.5.4 Divided Attention

Neurocognitive tests for divided attention (D-KEFS Stroop and Trails subtests) failed to show any difference between injury groups. Moreover, the point estimates did not indicate a trend based on injury status. This result may have occurred because of the small sample size of the study or other factor related to the study design, or it may represent a true finding. Deficits in divided attention as a result of concussive injury may be less common than are deficits in selective attention and/or memory function.

6.5.5 Application of Cognitive Assessments to Concussion Evaluation

At present, no single cognitive assessment has demonstrated greater sensitivity than others with respect to the detection of subtle deficits in cognitive functioning as a result of concussive injury (39,71). Similarly, there is no consensus among researchers and clinicians as to the most accurate neurocognitive test for the assessing concussion (40,71). As the signs of concussion are often difficult to detect, various, and non-specific, most diagnostic criteria for the evaluation of concussion as well as guidelines for return to play decisions in the athlete population emphasize that cognitive deficits observed for any *one* function is indicative of concussion (21,41,64,101,102).

Existing research that investigates deficits in memory, attention and concentration as a result of concussion, shows conflicting evidence as to which function may be the most sensitive indicator of concussion. For example, in a recent study by Collie et al. (2006) the authors suggest that the best marker of concussion may be divided attention (39). In contrast, other researchers have suggested that memory is the most robust indicator of concussion (17,48). In another paper presented by Grindel et al. (2001) it was reported that tests designed to evaluate speed of information processing, verbal learning, and memory were the most sensitive concussion markers (21). In the present study, the observed trends in neurocognitive performance according to injury status can only be considered as exploratory.

6.5.6 Intellectual Ability

In order to be effective at assessing concussion among a wide range of individuals and in situations where minimal administration is required such as in the emergency department or on the sideline of athletic events, the CCAT should not be affected by baseline intellectual ability. In this respect, the CCAT Scores are very poorly correlated with both level of education and full scale IQ according to the NAART, thus demonstrating the potential for its wide scale application among diverse patient groups.

6.5.7 Test Battery Modifications

The neurocognitive test battery administered as part of this pilot project required 75 minutes. This is not longer than what it takes to assess a head injury in the Emergency Department setting; however, in several cases during this pilot study, patients were unable or unwilling to complete the full test battery within these time limits. This was due to interruptions due to their medical examination (e.g. memory tests requiring a specific time lapse between repeat administrations were disrupted) and/or due to patient discomfort as a result of their head injury. As well, in many cases where patients' medical examinations took less time than the 90 minutes required to participate in the study, patients were unwilling to spend additional time in the emergency department to complete the study after they had been discharged by the physician. Therefore, the neurocognitive test battery should be shortened. This can be accomplished in two ways: (1) by condensing some of the tests that are included in the existing battery, specifically the WMS-III Logical Memory subtest has a recognition component that may be removed, and the NAART, of which a shorter version has been developed and shows similarly good test properties (103); and, (2) by eliminating tests that are unnecessary, specifically one of the two tests assessing divided attention.

The time constraints of the memory tests may be considered an inherent limitation of the test battery. This problem may be addressed through greater communication between research and medical personnel within the emergency department setting.

6.6 Sensitivity of the CCAT

The primary settings for which the CCAT was initially intended are the acute care setting and on the sideline of athletic competitions for use as an initial screening mechanism in the evaluation of concussion. As the consequences of premature return to usual activity or premature return to athletic competition may be devastating, the CCAT should be able to detect the effects of very mild concussion (i.e. have good sensitivity). At this early stage in the CCAT's development, the sensitivity and specificity of the instrument based on the CCAT Scores indicate that the assessment is not a useful stand-alone tool for the evaluation of concussion.

6.7 Methodological Considerations

6.7.1 Population

The study population was a convenience sample of head-injured patients recruited from the emergency departments at Kingston General Hospital and Hotel Dieu Hospital. Patients were only recruited during day and night shifts when the research nurse was available.

In addition, a group of normal, healthy volunteers was recruited from the Kingston community through a social networking website during the development phase of the CCAT. The majority of individuals in this group were university students. Thus there was very little variation within this group with respect to demographic and game-related characteristics. In contrast, the emergency department patient population was particularly diverse with respect to these characteristics and therefore not an ideal comparison group.

6.7.2 Sample Size

Forty injured patients participated in this pilot study including 22 Concussed Patients and 18 Non-concussed Patients. Although some trends were observed, no differences were found between injury groups. It is likely that statistically significant differences between groups may have been detected among a larger population. While subject accrual was lower than anticipated, the main purpose of this pilot study was to inform the planning and administration of the larger validation study, and it was not powered to find important clinical differences.

6.7.3 Misclassification of Injury

There is no "gold standard" for the diagnosis of concussion. To evaluate the validity of the CCAT, the expert clinical judgment of the physician was used to classify patients into a Concussed Patients group or a Non-concussed Patients group. In addition to a discharge diagnosis of concussion, the patient had to have reported or exhibited at least one symptom associated with concussion to be included in the Concussed Patients group. While this reference standard represents an attempt at more accurate injury classification, it is possible that there was some misclassification of concussion between the two Head-injured Patients groups. This would lead to smaller group differences on the CCAT Scores and neurocognitive tests observed in the study, and hence a failure to identify true differences.

6.8 Recommendations

(1) *The emergency department setting*. The emergency department is an appropriate setting for this study despite the challenges related to patient recruitment and data collection, as it would be difficult to organize and conduct standardized testing in the field setting. Communication among research and medical personnel should be emphasized in the planning of the larger validation study.

(2) *Patient recruitment*. In addition to a greater awareness of the study within the emergency department in order to facilitate the process of identifying eligible patients, *early* case identification is important in order for the research nurse to arrange a suitable testing environment

within the emergency department and then to complete the study in less time than is required for the medical examination. The Blackberry surveillance system that was implemented midway into the data collection period of this pilot study provides an opportunity to do this. Using this system, the research nurse is notified within 15 minutes of a potentially eligible patient registering with the triage nurse.

(3) *Comparison groups*. Patients that present to hospital emergency departments are extremely diverse. Appropriate comparison groups for a Concussed Patients group recruited from emergency departments should thus be recruited from within the emergency department setting. A larger validation study for the CCAT should consider recruiting Normal Volunteers from the emergency department waiting room. In addition, a different patient group from that which was used in the present study should be considered. A similar study done in the emergency department setting used a patient comparison group composed of ED patients with orthopaedic, non-cranial injuries (68). Patients in this group all had injuries requiring similar procedures and similar amounts of time to complete the medical examination, and were unrelated to possible concussive injury.

(4) *Modifications to the CCAT*. The CCAT would be most useful as a stand-alone instrument involving minimal administration. A more comprehensive introduction to the tasks of the game and detailed instructions should be included at the beginning of the computer assessment. This should include an instructive and interactive practice round.

Anecdotally, although several participants remarked that they found the CCAT to be a relatively easy video game compared with those that are commercially available, all participants appeared to be interested and engaged in the computer assessment and the vast majority of users commented that they found the computer assessment to be fun and novel. While it is important to consider and improve upon aspects of the video game that may make the assessment appear more game-like, it is equally important that the CCAT function first and foremost as a diagnostic instrument.

Based on the data analysed in this pilot study, there is some evidence that the CCAT Memory Score and CCAT Selective Attention Score are providing accurate measurements of their respective cognitive functions. However there is no evidence to suggest they are able to detect subtle cognitive deficits as a result of concussion. The CCAT Divided Attention Score is not a useful measurement and the calculations and performance parameters from which this Score is generated should thus be revisited by the developers of the CCAT before proceeding with a larger validation study. Similarly, the CCAT Effort Score may not be measuring what it purports to measure. Finally, the data suggest that users' response time to Target Pylons may be a potentially useful marker of concussion. Developers should consider incorporating Average Target Pylon Response Time as a fourth primary score generated by the computer assessment.

6.9 Conclusion

The objectives of this pilot study were to explore the validity of a novel diagnostic instrument, the Computerized Concussion Assessment Tool, using two methods. This was achieved by comparing performance on the CCAT between concussed and non-concussed patients recruited from hospital emergency departments as well as a normal, healthy volunteer sample recruited prior to the start of this study. In addition, CCAT Scores and performance parameters were compared against results from neurocognitive tests among the patient population through correlational analyses.

The CCAT was unable to discriminate between concussed patients and non-concussed individuals. However, moderate correlations observed between the CCAT Scores for Memory and Selective Attention and their respective neurocognitive tests support a view that there should be optimism for the future development of the CCAT.

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Appendix A

Summary of Neurocognitive Tests

Test	Time to administer	Measurement	Primary Task Description
Wechsler Memory Test			
Logical Memory subtest	5-10 minutes; followed 25-35 minutes later by second iteration	• ***Auditory*** memory • ***Immediate memory*** • Delayed memory • Recognition delayed memory	Examinee listens to two different stories read by the examiner, and immediately after hearing each story is asked to retell it from memory. After 25-35 minutes, examinee is asked to retell both stories and answer questions about the stories.
Family Pictures subtest	5-10 minutes; followed 25-35 minutes later by second iteration	• ***Visual*** memory • ***Immediate memory*** • Delayed memory • Recognition delayed memory	Examinee is shown four different scenes with four family members and then asked to remember as much as he or she can about each scene.

			After 25-35 minutes, examinee is asked again to remember as much as he or she can about each scene.
Delis-Kaplan Executive Functioning System			

Stroop subtest	5-10 minutes	• ***Divided*** attention
		  • Naming speed
		  • Reading speed
		  • Verbal inhibition
		  • Cognitive flexibility
			Condition 3: Inhibition/Switching
			Examinee must inhibit reading words in order to name dissonant ink colours in which those words are printed.

Trails subtest	10-15 minutes	• Visual scanning • ***Attention***	Condition 1: Visual Scanning Examinee must sequence letters within the format of a visual-motor task.

		• Executive functioning
		  • Multitasking
		  • Simultaneous processing
		  • ***Divided attention***
			Condition 4: Number-Letter Switching
			Examinee is required to switch back and forth between connecting numbers and letters in sequence.

Word Memory Test	5 minutes; followed 10 minutes later by second iteration	• ***Effort***	Examinee must remember a list of 10 word pairs, each representing a single common object (e.g. French-fries).
North American Adult Reading Test	10 minutes	• ***Premorbid intelligence***	Examinee is presented with a list of words and is asked to read the words, guessing at the pronunciation if they are unfamiliar with a word.

Appendix B

Test Battery Timeline

Tests to be done in the ER waiting room:

Timeline		
5 min		Background questionnaire and patient consent: To provide demographic information and to assess for potential covariates.
		Tests to be administered by the researcher:
20 min *(25 min)*	1.	Memory tests from the Wechsler Memory Test-III: To assess short- and long-term visual and auditory memory. The test requires two rounds of testing each lasting 20 minutes spaced 20-35 minutes apart.
15 min *(40 min)*	2.	***Computerized Concussion Assessment Tool*** (CCAT): A novel video game computer assessment of concussion.
5 min *(45 min)*	3.	Medical Symptom Validity Test (MSVT): To assess effort. The test requires two rounds of testing each lasting approximately 5 minutes spaced 10 minutes apart.
20 min *(65 min)*	4.	Wechsler Memory Test-III (repeat)
5 min *(70 min)*	5.	MSVT (repeat)
15 min *(85 min)*	6.	Delis-Kaplan Executive Functioning System Stroop and Trails subtests: To assess divided attention and inhibition.
5 min	7.	North American Adult Reading Test (NAART): To assess and control for intellectual ability, this test is a measure of verbal fluency that correlates highly with IQ.
Total:*90 min*		

Appendix C
Background Questionnaire

Date ____/____/_______ *Participant ID Number:* _______________

DD MM YYYY

BACKGROUND INFORMATION

1. Age __________ years

2. Gender: ☐ Male ☐ Female

3. Do you have a valid driver's license? ☐ No ☐ Yes

   If yes, for how long have you been driving? __________ ☐ Months or ☐ Years

   How often do you drive: Daily Weekly Monthly Less than once a month

4. Have you ever had a concussion or head injury? ☐ No ☐ Yes

   If yes, or if you are uncertain, please describe: ___________________________________

   ____

   ____

   And if yes, how long ago: __________ ☐ Months or

   (if multiple, how long since the most recent) ☐ Years

5. What is your field of study/work (if applicable)? ______________________________

6. How much time do you spend playing video games? (in a typical week)

- ☐ Never
- ☐ < 5 hours
- ☐ 5 – 10 hours
- ☐ 11– 15 hours
- ☐ > 15 hours per week

7. Are you left- or right-handed? ☐ Left ☐ Right

8. Please answer the following questions:

	Yes	No
I lost consciousness after my head injury.	☐	☐
If Yes, for how long? ____________		
After my head injury, I felt dizzy.	☐	☐
After my head injury, I had blurred or double vision.	☐	☐
I can remember clearly before and after my head injury.	☐	☐

If No, please describe: ____

____

9. Have you been drinking in the past 12 hours? ☐ No ☐ Yes

If yes, how much? ____________

Have you been drinking in the past 24 hours? ☐ No ☐ Yes

If yes, how much? ____________

Appendix D

Patient Consent Form

Patient Information Sheet
A Pilot Study of a Computerized
Concussion Assessment Tool (CCAT)

Site Investigator: **Dr. Rob Brison**
Department of Emergency Medicine
Queen's University

Student Researcher: **Jennifer Skinner, MSc Candidate**
Department of Community Health and Epidemiology
Queen's University

Introduction

A concussion assessment tool has been developed by researchers at Queen's University. The instrument is similar to a video game; using a standard game controller, the participant navigates around the racetrack while appropriately responding to, remembering, and ignoring specific stimuli. The instructions for the game are presented on the computer screen before the game begins.

This is a pilot project being conducted by an Emergency Room physician to determine whether this concussion assessment tool is able to accurately diagnosis concussion. The results of this study will also be used by a Master's student for her thesis project.

Purpose

The consistency of this instrument has been established by a group of healthy volunteers. The purpose of this pilot study is to determine how well patients with head injury perform on the assessment and to compare patients' performance against other measurements of concussion severity.

You are being seen in the Emergency Department and are invited to participate in this research study.

Procedures

If you agree to participate, you will be asked to complete a short Background Questionnaire while you wait to be seen by the doctor. Your decision to participate in the study will not have any impact on your wait-time (i.e. when the doctor is ready to see you, you will see the doctor at that time, regardless of how much of the questionnaire(s) you have completed).

A member of the research team will then administer a memory test, the video game, and 2 other tests to assess attention and response time. In total, the testing should take less than two hours. Testing may be completed as you wait for the doctor or diagnostic test results and/or after you have been discharged from the hospital. You may choose to withdraw from the study at any time.

A member of the research team will collect information related to your head injury and your medical history from your medical record. This information will be entered on a data form. This form will record a study number for you and neither your name nor any personal information that could identify you will be entered on the form.

Potential Benefits

There will be no personal benefit gained from participating in this study. Ultimately, this computerized concussion assessment tool may better inform the diagnosis and management of future concussion patients.

Potential Risks

There are no anticipated risks associated with participating in this study.

Confidentiality

All information obtained for this study will be kept strictly confidential and your anonymity will be protected at all times. Your name will not be identified in any discussion or publication of the research report. Data collected for this study will be kept in locked files in the Clinical Research Unit located within Kingston General Hospital and will be available to the investigation team only.

Reimbursement

No payment will be made to you for participating in this study.

Voluntary Participation

You are free to refuse to participate or withdraw from this research study at any time and your present or future care will not be affected in any way.

In Case of Negative Side Effect

If you suffer any negative side effect as a result of your participation, medical care will be provided to you in the same manner as you would ordinarily receive. By signing this consent form, you do not waive your legal rights nor release the investigator from his legal or professional responsibilities.

Further Information

Please contact any of the individuals identified below if you have any questions or concerns:

Dr. Rob Brison, Site Investigator, Department of Emergency Medicine, 613-548-2389
Dr. Gord Jones, Department Head, Emergency Medicine, 613-548-2368
Dr. Albert Clark, Chair, Queen’s University Ethics Review Board 613-533-6081
If you agree to participate, you will receive copies of the signed information and consent forms.

Appendix E
Patient Information Sheet

<u>Patient Information Sheet</u>

<u>A Pilot Study of a Computerized</u>

<u>Concussion Assessment Tool (CCAT)</u>

Site Investigator: **Dr. Rob Brison**
Department of Emergency Medicine
Queen's University

Student Researcher: **Jennifer Skinner, MSc Candidate**
Department of Community Health and Epidemiology
Queen's University

<u>Introduction</u>

A concussion assessment tool has been developed by researchers at Queen's University. The instrument is similar to a video game; using a standard game controller, the participant navigates around the racetrack while appropriately responding to, remembering, and ignoring specific stimuli. The instructions for the game are presented on the computer screen before the game begins.

This is a pilot project being conducted by an Emergency Room physician to determine whether this concussion assessment tool is able to accurately diagnosis concussion. The results of this study will also be used by a Master's student for her thesis project.

<u>Purpose</u>

The consistency of this instrument has been established by a group of healthy volunteers. The purpose of this pilot study is to determine how well patients with head injury perform on the assessment and to compare patients' performance against other measurements of concussion severity.

You are being seen in the Emergency Department and are invited to participate in this research study.

Procedures

If you agree to participate, you will be asked to complete a short Background Questionnaire while you wait to be seen by the doctor. Your decision to participate in the study will not have any impact on your wait-time (i.e. when the doctor is ready to see you, you will see the doctor at that time, regardless of how much of the questionnaire(s) you have completed).

A member of the research team will then administer a memory test, the video game, and 2 other tests to assess attention and response time. In total, the testing should take less than two hours. Testing may be completed as you wait for the doctor or diagnostic test results and/or after you have been discharged from the hospital. You may choose to withdraw from the study at any time.

A member of the research team will collect information related to your head injury and your medical history from your medical record. This information will be entered on a data form. This form will record a study number for you and neither your name nor any personal information that could identify you will be entered on the form.

Potential Benefits

There will be no personal benefit gained from participating in this study. Ultimately, this computerized concussion assessment tool may better inform the diagnosis and management of future concussion patients.

Potential Risks

There are no anticipated risks associated with participating in this study.

Confidentiality

All information obtained for this study will be kept strictly confidential and your anonymity will be protected at all times. Your name will not be identified in any discussion or publication of the research report. Data collected for this study will be kept in locked files in the Clinical Research Unit located within Kingston General Hospital and will be available to the investigation team only.

Reimbursement

No payment will be made to you for participating in this study.

Voluntary Participation

You are free to refuse to participate or withdraw from this research study at any time and your present or future care will not be affected in any way.

In Case of Negative Side Effect

If you suffer any negative side effect as a result of your participation, medical care will be provided to you in the same manner as you would ordinarily receive. By signing this consent form, you do not waive your legal rights nor release the investigator from his legal or professional responsibilities.

Further Information

Please contact any of the individuals identified below if you have any questions or concerns:

Dr. Rob Brison, Site Investigator, Department of Emergency Medicine, 613-548-2389
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Dr. Albert Clark, Chair, Queen's University Ethics Review Board 613-533-6081
If you agree to participate, you will receive copies of the signed information and consent forms.

Appendix F
Glossary of CCAT Terms

Billboard = An image located far from the roadside appearing during the driving portion of the assessment. There are 5 billboards presented per round.

Distracter Pylon = Blue, triangular images *or* orange, square images that appear at the roadside during the driving portion of the assessment. The user is instructed to ignore the distracter pylons as they appear.

Divided Attention Score (DAS) = One of 3 primary scores generated by the computer and based on the user's performance on the assessment.

= [(Total Drive time – Time on Wall)/(Total Drive time) *100%]

= [(2.283min – time_on_track)/(2.283min) *100%] (3min=best time)

Effort Score = A computer-generated score based on the user's ability to correctly identify unfamiliar billboard and road sign images (i.e. those that were not presented during the driving portion of the assessment).

= [4 – (# of correct billboards/road signs identified)/4]

Memory Score = One of 3 primary scores generated by the computer and based on the user's performance on the assessment.

= [(# Correct Road Signs identified + # Correct Billboards identified)/14 *100%]

Overall Score = A composite calculation derived from the 3 primary CCAT Scores (Memory, Selective Attention and Divided Attention).

= [(SAS + DAS + MS)/3]

Road Sign = An image located near to the roadside appearing during the driving portion of the assessment. There are 5 road signs presented per round.

Round = One lap of driving on the CCAT. There are 3 rounds, followed each time by a memory test, per testing session.

Selective Attention Score (SAS) = One of 3 primary scores generated by the computer and based on the user's performance on the assessment.

= [(% Target pylons responded to) – (% Distracter pylons responded to)]

Target Pylon = Orange, triangular images that periodically appear at the roadside during the driving portion of the assessment. The user is instructed to "press the Green 'A' on his or her control" when the target pylons appear. There are 5 target pylons presented per round.

Time on Wall = a performance parameter on the CCAT indicating the amount of time that the user spends touching the perimeter of the roadside.

Total Drive Time = a performance parameter on the CCAT indicating the amount of time (seconds) per round that the user spends completing the driving portion of the assessment. Maximum Drive Time is equal to 283.3 seconds.

Appendix G

CCAT Scores and Performance by Driving Round

Head-injured concussed patients: Scores and performance for first, second and third rounds within one testing session

				Interquartile Range		
		n	Median	25th Quartile	75th Quartile	p
Selective Attention Score	1	22	86.7	83.3	96.7	
	2	22	93.3	93.3	100.0	
	3	22	88.4	76.7	100.0	
	Total	66	93.3	86.7	100.0	0.29
Memory Score	1	22	50.0	30.0	80.0	
	2	22	70.0	60.0	90.0	
	3	22	80.0	60.0	90.0	
	Total	66	70.0	50.0	90.0	0.07
Divided Attention Score	1	22	97.9	97.2	98.2	
	2	22	98.2	96.4	98.8	
	3	22	97.6	96.3	98.3	
	Total	66	98.0	96.9	98.4	0.27
Time on Wall	1	22	2.6	2.3	3.6	
	2	22	2.5	1.5	4.6	
	3	22	2.9	2.2	4.8	
	Total	66	2.5	2.0	4.1	0.29
Drive Time	1	22	125.2	123.8	127.8	
	2	22	124.1	123.9	129.4	
	3	22	126.3	124.3	128.3	
	Total	66	125.5	123.7	128.3	0.63

Head-injured non-concussed patients: Scores and performance for first, second and third rounds within one testing session

				Interquartile Range		
		n	Median	25^{th} Quartile	75^{th} Quartile	p
Selective Attention Score	1	18	91.7	83.3	93.3	
	2	18	90.0	86.7	93.3	
	3	18	93.3	86.7	100.0	
	Total	54	91.7	86.7	96.7	0.59
Memory Score	1	18	70.0	60.0	80.0	
	2	18	65.0	50.0	80.0	
	3	18	80.0	60.0	90.0	
	Total	54	70.0	50.0	90.0	0.53
Divided Attention Score	1	18	97.7	96.8	98.4	
	2	18	98.3	96.8	99.1	
	3	18	97.8	97.1	98.4	
	Total	54	97.8	96.8	98.5	0.62
Time on Wall	1	18	2.9	2.0	3.9	
	2	18	2.2	1.2	4.1	
	3	18	2.7	2.1	3.6	
	Total	54	2.7	1.8	4.0	0.63
Drive Time	1	18	124.5	123.5	126.6	
	2	18	125.1	122.6	128.1	
	3	18	124.4	123.9	125.8	
	Total	54	124.4	123.0	126.6	0.99