THE ONSET AND EFFECT OF COGNITIVE FATIGUE ON SIMULATED SPORT PERFORMANCE

By

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This document is dedicated to everyone who has helped me become who I am today, I am forever grateful.

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The sport of ice hockey requires refined anticipation, reaction, strategy, speed, and decision-making skills within situations that are constantly changing. Competitive athletic environments characterized by prolonged task exposure, high task difficulty, and multiple task demands, like that of ice hockey, impose significant information processing demands on the athlete. Such increases in mental workload can consume as well as deplete the cognitive system's resources available for task completion, and promote the development of fatigue.

Fatigue is characterized by a reduction in available resources and a decreased ability to continue task performance at one's highest potential as a result of engagement in either mental or physical tasks for a period of time without adequate rest. Specifically, fatigue has been proposed to mediate attentional allocation, information processing, and task performance under conditions of elevated and prolonged workload, situations characteristic of sport competitions. Therefore, the purpose of the current investigation was to determine the effects of varying levels of cognitive fatigue on ice hockey decision-making effectiveness and efficiency. More specifically, the aim was to explore individual decision time and accuracy as a function of time-on-task. A secondary purpose was to determine if performance changes are related to variations in attentional focus, as indicated by visual search patterns, and/or to fluctuations in arousal, as indexed by heart rate and skin conductivity.

Eighteen male athletes (mean age = 20.6, *SD* = 2.57) with advanced ice hockey experience participated in the experiment. The testing period consisted of 120 video sequences, with each scenario being followed by a question concerning a tactical decision with four multiple-choice responses. Participants were asked to select the *most* appropriate response as quickly and as accurately as possible. Heart rate, skin conductivity, gaze behavior, and subjective ratings of performance states were assessed.

Data supported the notion that time-on-task promotes the development of cognitive fatigue and fluctuations in performance, as well as arousal. Specifically, fatigue was related to faster response times and elevated arousal. However, response accuracy and visual fixation duration were not significantly related to time-on-task. In sum, the results suggest that cognitive fatigue is distinctly manifested physiologically, subjectively, and behaviorally in athletes. Yet, continued research is necessary to gain a more complex and accurate understanding of cognitive fatigue within sport. Strengths, limitations, future directions, and applied implications are addressed.

CHAPTER 1
INTRODUCTION

The ability to accurately and effectively allocate attention is a critical factor in determining performance outcome. Specifically within athletics, the importance of appropriately directing and sustaining attention during a sporting competition has been anecdotally confirmed by athletes for years; "concentration" and "focus" are emphasized as critical factors in determining sport success. However, the task of appropriately attending in the sport environment can be as challenging and taxing as the physical exertion associated with performance. Yet, sport scientists have only recently begun to explore how attentional fluctuations relate to sport performance.

As the field of sport psychology has progressed, greater consideration has been directed to understanding the relationship between cognitive processes and athletic performance. While numerous factors (i.e., strength, cardiovascular endurance, experience) can contribute to performance fluctuations, recent sport psychology research has placed an emphasis on understanding how internal factors (i.e., cognitions, emotions) can influence performance. At present, however, minimal research has progressed to examine cognitive fatigue as a potential performance mediator. The relationship between mental fatigue and performance has not been adequately examined in athletics and therefore fatigue's influence on attention and performance remains unclear. Anecdotal evidence, however, would support the notion that fatigue does influence performance. It is a frequent occurrence to hear athletes, coaches, and commentators attribute poor performance to being mentally taxed/fatigued. For example, following a challenging semifinal match at the Tennis Masters Cup, both, tennis star Andy Roddick and reporters attributed the atypical challenge to a combination of mental and physical fatigue. However, in order to gain a more complete understanding of sport performance, sport psychology researchers must explore how cognitive fatigue develops in sporting competitions, and how the resulting fatigue influences performance.

Attention

The scientific study of attention has a strong foundation in the general psychology literature. Over a century ago, William James (1890) markedly defined attention as the "the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others" (p. 403-404). It has been well noted that successful sport performance is reliant upon an athlete's ability to appropriately select features of the environment or him/herself to attend to, and then sustain attention on the relevant information for an appropriate duration (Cox, 1994). For athletes, the ability to sustain attention and concentrate on selected task related features are often the most important components of successful performance (Nideffer, 1993). However, attention can become dispersed or compromised as a result of features of the environment and/or internal states.

Attentional Distractors

Attending to mass amounts of environmental stimuli can prove to be detrimental to performance; too much attention is given to irrelevant information and too little attention is given to significant cues, resulting in a performance decrement. Maintaining appropriate focus can be a daunting task since nearly anything can serve as a distractor.

Certain conditions (i.e., high emotionality, depleted cognitive resources) increase the tendency to redirect attentional focus away from the central task and onto irrelevant and potentially distracting stimuli (Wegner, 1994). Under conditions of depleted resources (i.e., anxiety, fatigue), distractors compete with relevant cues for already diminished assets, resulting in the allocation of fewer resources for task performance (Moran, 1996). The elements that interfere with or redirect attention away from relevant cues can occur as either external (i.e., crowd noise, temperature) or internal distractors (i.e., one's own thoughts, subjective feelings of fatigue) (Moran, 1996).

Visual Attention

Within the laboratory, shifts in attentional direction to external distracting cues or irrelevant information can be monitored in a variety of ways. One popular means of assessing allocation of visual attention is through the use of eye tracking systems. The location of a visual gaze is typically assumed to index the focus of attention (Duchowski, 2002). When an area of the environment is fixated upon, the observer is gathering the most detailed and highest quality information, while gathering relatively less detailed information from surrounding peripheral areas. In addition to visual fixation locations, the search pattern employed will also dictate the efficiency by which information is extracted for task completion (Williams, 2000). Efficient and successful performance is often characterized by visual search patterns that involve fewer fixations of longer duration (Williams, Davids, & Williams, 1999). This approach allows for more information to be extracted with a single fixation, rather than requiring several saccadic movements, during which visual acuity is decreased. The exploration of attention and attentional lapses has been furthered by the ability to track eye movements and visual attention.

Visual gaze patterns provide an index of attentional focus and how search patterns and attention can fluctuate under various conditions (i.e., fatigue, anxiety, high workload). Within a sport performance, attentional focus is often required to be rapidly redirected, increasing the demands that are placed on the cognitive system and the overall level of mental workload (Matthews, Davies, Westerman, & Stammers, 2000). Specifically, competitive environments characterized by prolonged task exposure, high task difficulty, and multiple task demands evoke an overall greater level of information processing. Such increases in mental workload monopolize and deplete the cognitive system's resources available for task completion, thereby initializing the development of fatigue. Fatigue has been proposed to mediate attentional allocation, information processing, and task performance under conditions of elevated and prolonged workload (Matthews & Desmond, 2002).

Fatigue

Generally, fatigue can arise from engagement in both physical and mental activities of various intensities and duration. The negative results or unpleasant experiences of prolonged or intense behavior, regardless if the activity is fun or tedious, has been defined as *fatigue* (Craig & Cooper, 1992). Unfortunately, Craig and Cooper's broad conceptualization does not effectively capture the essence or breadth of fatigue. Indeed, vague conceptualizations of fatigue, like the one above, have plagued the extant literature on fatigue, regardless of the discipline from which the definitions have emanated.

Recently, Job and Dalziel (2001) proposed a comprehensive definition of fatigue as "the state of an organism's muscles, viscera, or central nervous system, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or systemwide energy to maintain the original levels of activity and/or processing by using normal resources" (p. 469). In other words, fatigue is characterized by a reduction in available resources and a decreased ability to continue task performance at one's highest potential as a result of engagement in either mental or physical tasks for a period of time without adequate rest. Additionally, this definition effectively differentiates fatigue from other related constructs, namely habituation and boredom. In contrast to fatigue, *habituation* will ensue regardless of rest and is independent of available energy/resources (Reber, 1995). Similarly, *boredom* will persist after rest unlike fatigue and is mediated by subjective disinterest, rather than by resource availability. Although there are variable formal definitions of fatigue, Job and Dalziel's conceptualization most clearly defines fatigue and will therefore be used in this investigation to operationalize fatigue.

Many investigations have sought to better understand fatigue's influence on human performance by examining various components of task effectiveness and efficiency. The fatigue research is diverse and is comprised of studies investigating the effects of both physical and mental fatigue on the performance of both cognitive and manual tasks. Although the absence of sufficient capacity or energy to execute a task intuitively suggests that output/performance would be negatively influenced by a fatigue state, the empirical findings are somewhat equivocal. The following synopsis highlights selected findings related to physical and mental fatigue with respect to cognitive performance.

Physical Fatigue

Physical fatigue has been assumed to result in decreased cognitive functioning. To evaluate this assumption, Davey (1973) examined cognitive task performance following an exercise bout. Specifically, after cycling for various durations, short-term memory functioning was assessed through performance on a numeric-sequence identification task.

Results indicated an inverted-U pattern of performance with task performance being increased after moderate amounts of exercise but hindered after prolonged exercise.

Similarly, Reilly and Smith (1984) investigated the effect of exercise intensity on cognitive task performance. To induce physical fatigue, active male university students pedaled on a cycle ergometer at 25, 40, 55, 70, and 85% VO_2max. During the exercise, participants completed two mental arithmetic tasks for 60 seconds during each loading interval. Although the tasks were completed while exercising, rather than post-exercise, the results were similar to those obtained by Davey (1973); performance was better following some physical activity than when at rest, yet performance deteriorated at the extreme levels of exercise.

Using a similar procedure, Salmela and Ndoye (1986) examined cognitive processing fluctuations during progressive exercise. They found that participants reacted significantly faster to central stimuli than to stimuli in the extremes of the visual field as exercise intensity and duration increased. The authors proposed that as exercise increased in intensity, attentional focus narrowed, as was indicated by slower responses to stimuli presented in the visual periphery.

Collectively, researchers have often assumed that endurance and/or high intensity exercise will promote a fatigue state. Under this assumption, these studies (Davey, 1973; Salmela & Ndoye, 1986; Reilly & Smith, 1984; Reilly & Smith, 1986; Davey, Thorpe, & Williams, 2002) suggest that when the body physically fatigues, cognitive processes will be influenced by the physiological reaction to exercise. But, as highlighted earlier, fatigue can develop as a result of cognitive involvement (Bartley & Chute, 1947). Therefore, how is mental task performance influenced when an individual is cognitively fatigued?

Cognitive Fatigue: A Self-Report Perspective

In contrast to physical fatigue, cognitive fatigue refers to the diminished mental capacity and resources resulting from the demands placed on the cognitive system through various types of mental work (i.e., decision making and concentration). Initial interest and much of the contemporary research on cognitive fatigue has been stimulated by a desire to understand military and ergonomic issues, while improving working conditions.

Bartlett's (1943) seminal research was designed to better understand how individuals perform after continuous, prolonged task exposure. Using an aircraft simulator, behavioral and performance changes were monitored among pilots as time-on-task progressed. Bartlett found that the longer the pilots were involved in the task, the greater the decrease in timing accuracy. Likewise, fewer instruments in the display were attended to. Such variations in performance have direct implications for safety and efficiency. Specifically, by recognizing that prolonged periods of flying can promote the development of fatigue and the resulting fatigue can impair performance, pilots and others involved in related fields can develop schedules that minimize prolonged task exposure and include periods of sufficient periods of rest.

Bartlett acknowledged that pilots are subjected to prolonged conditions of sustained attention and constant information processing, conditions that promote fluctuations in performance. Recognizing the inherent, cognitively demanding characteristics of flying, and the often erratic rest patterns of both commercial and military pilots, Morris and Miller (1996) tested sleep deprived pilots using a flight simulator task. Results indicated a positive correlation between subjective reports of fatigue and performance errors. Again, the negative influence of fatigue on performance was apparent.

Based on previous research and the potentially severe consequences of decreased performance (i.e., fatal accidents), there has been a recent surge in fatigue research in the transportation industry. For example, Matthews and Desmond (2002) recently examined the influence of task-induced fatigue on simulated driving performance. Specifically, participants were asked to follow another vehicle through a simulated course that was comprised of both curved and straight roadways for six minutes (control condition). In the fatigue condition, participants completed the task for 24 minutes, while also engaging in a signal detection task. Prior to and following each driving session, participants completed self-report assessments of their levels of fatigue symptoms, emotions, motivation, effort, and cognition. A post-task comparison of the control and fatigue groups' self-report and performance scores revealed that those who engaged in the 24-minute task (fatigue group) indicated that they expended greater effort, yet exhibited decreased performance. These findings further support the connection between cognitive fatigue and impaired task completion.

Cognitive Fatigue: A Physiological Perspective

Cognitive fatigue is catalyzed through cognitive processes and often associated with fluctuations in attention that can be physiologically assessed. In particular, tasks requiring vigilance or sustained attention, or those that are monotonous have often been associated with distinct patterns of physiological arousal. Heart rate (HR) and skin resistance/conductivity are measures of particular interest among studies investigating the physiological changes associated with cognitive fatigue.

In their 1972 investigation, Dureman and Bodén assessed the effects of four hours of continuous simulated driving on general performance, subjective ratings of fatigue, and physiology (pulse, respiration, skin resistance, and muscular tension in the neck).

The primary finding was that as time-on-task increased, subjective fatigue and skin resistance increased, while pulse rate and performance decreased. Similarly, Lal and Craig (2002) recently examined the physiological changes that occurred in relation to a fatiguing, two hour driving simulation (subjective assessment of fatigue was used to ensure fatigue induction). An analysis of pre and post-driving HR indicated a decrease in HR at the completion of the drive.

Other extant research (Dureman & Bodén, 1972; Lal & Craig, 2002; Moolenaar, Desmond, Mascord, Starmer, Tattam, & Volkerts, 1999; Macchi, Boulos, Ranney, Simmons, & Campbell, 2002) strongly implicates a triangular relationship between arousal, fatigue, and performance, with suppressed physiological arousal believed to be one of the primary factors associated with fatigue and decreased performance. Specifically, elevated levels of workload arise from prolonged task exposure, high task complexity/ difficulty, multiple task completion or a combination of the three (all are scenarios relevant to athletic competition). The elevated workload and cognitive demands prompt the development of fatigue (Matthews & Desmond, 2002). Therefore, fewer resources are available for task completion because of the task characteristics themselves and reduced levels of general arousal associated with fatigue states. In turn, due to reduced resources and lower levels of arousal, attentional allocation and information processing capabilities become "sub-optimal," unless resources are sacrificed from other processes. However, a circular relationship often results; when fatigue develops resources are compromised and arousal levels are reduced. As such, one must work "harder" to maintain performance levels. In turn, more resources are needed, thereby further escalating the development and consequences of fatigue. Because only a general framework regarding this pattern of events exists, future research is warranted to better understand the physiological changes associated with cognitive fatigue, and to determine whether those physiological variations have a direct influence on information processing, attentional allocation to environmental cues, and eventual performance.

Limitations of Previous Research

As highlighted previously, physiological fluctuations can often redirect attention, resulting in performance fluctuations. Fatigue (physical and cognitive) has also been shown to influence physiological states, yet relatively minimal work has examined the triangular relationship between fatigue, attention, and performance in sport from a physiological perspective.

The illusive nature of cognitive fatigue is apparent in the wide variety of operational definitions of the concept and the overall lack of sport specific literature addressing the topic. Generally speaking, ambiguous and erroneous definitions are provided when speaking about fatigue; defining it in terms of its consequences, rather than its origins (e.g., Brown, 1994). Theoretical inconsistencies have resulted in an inability to clearly define a state as being fatigue.

An additional shortcoming of previous research is the assumption (e.g., Bartlett, 1943; Davey, 1973; Reilly & Smith, 1984) that fatigue has been induced when not explicitly monitored (i.e., prolonged exercise, time-on-task). Additionally, in 1947, Bartley and Chute emphasized that it was inappropriate and inaccurate to assess fatigue solely through performance indices. However, researchers continue to infer cognitive fatigue solely through performance scores (Davies, Shackleton, & Parasuraman, 1983).

Contemporary investigations of cognitive fatigue have primarily focused on fatigue in ergonomic settings, highlighting transportation due to the grave numbers of fatalities and accidents believed to be the result of fatigued drivers (e.g., Matthews & Desmond, 2002; Lal & Craig, 2002). Within much of the literature, fatigue is referenced as resulting from a wide variety of factors (i.e., sleepiness, general nighttime impairments, time-on-task) and is often recognized by fluctuations in performance. However, the assumption that each type of "fatigue" is equivalent, and that performance scores can indicate the presence or absence of fatigue, is erroneous. Moreover, boredom and habituation are two psychological states that arise from similar, yet distinct conditions as fatigue. However, having similar origins and effects as cognitive fatigue, the confusion between habituation, boredom, and fatigue exasperates the inherent limitations associated with fatigue research.

Although there have been numerous investigations that have explored how muscular fatigue influences both physical and cognitive sport performance, and how cognitive fatigue and its symptoms are associated with impaired performance in ergonomic settings, there remains in significant gap within the literature. Specifically, how cognitive fatigue influences sport related mental tasks has been ignored.

It is apparent that the ability to appropriately and adequately process information is critical to successful performance. Most sports (e.g., hockey, baseball, football, tennis) require that participants are able to quickly and continuously use the environment and prior knowledge to make performance decisions. Other sports impose different time constraints and are more self-paced (e.g., golf, bowling, dart throwing), yet the cognitive demands remain intense. The demands on attention and information processing that are inherent in sport have the potential to induce cognitive fatigue states, yet have been overlooked in competition scenarios. Therefore, the present investigation was designed to evaluate the effect of fatigue on attention and performance in a dynamic sport simulation.

Statement of the Problem

The sport of ice hockey encompasses anticipation, reaction, strategy, speed, and decision-making. With the average player moving at speeds approaching 12mph and attending to objects moving at speeds exceeding 90mph in a confined area (approximately 190 by 90 feet), the ice hockey player must be ready to respond to rapidly presented cues and situations that are constantly changing. Such physical and mental demands can promote the development of fatigue, a state characterized by reduced resources and ability. Despite fatigue's likely influence on performance and how athletes perform, train, and react, sport scientists have relatively ignored cognitive fatigue. Indeed, the current sport science literature has not addressed how the cognitive demands of sport influence the cognitions, behaviors, and physiology of athletes.

Statement of Purpose

The purpose of this investigation was to determine the effects of varying levels of cognitive fatigue on ice hockey decision-making effectiveness and efficiency. More specifically, the aim was to explore individual decision time and accuracy as a function of time-on-task. A secondary purpose was to determine if performance changes were related to variations in attentional focus, as indicated by visual search patterns, and/or to fluctuations in arousal, as indexed by heart rate and skin conductivity.

Hypotheses

The following hypotheses were based on previous theory and research findings from the fields of general psychology, human factors, and the sport sciences. The hypotheses were designed to address the issues concerning cognitive fatigue onset in sport and resulting performance effects, as well as the physiological and behavioral correlates of time-on-task.

Subjective-Reports

1. Visual analog ratings of fatigue will increase significantly as time-on-task increases. Specifically, *final subjective ratings* of fatigue will be significantly *greater* than *initial fatigue ratings* (Dureman & Bodén, 1972).

2. Visual analog reports of *motivation will not increase* as time-on-task increases, since the task rewards and demands will be maintained across trial blocks (McMorris & Graydon, 1996).

3. Visual analog reports of *boredom will not increase* as time-on-task increases, due to dynamic and engaging task demands (McMorris & Graydon, 1996).

Task Performance

4. Mean response time will significantly increase over the duration of the task. Therefore, as *time-on-task increases*, *response time will increase*, indicating a positive relationship between task length and performance (Macchi et al., 2002).

5. It is hypothesized that as *subjective reports of fatigue increase* (as reported on the visual analog scale) and independent of time-on-task, *response time will increase* (Macchi et al., 2002).

6. *Response accuracy will decrease* significantly across participants as *time-on-task increases*, indicating a negative relationship between task duration and performance accuracy (Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2000).

7. As *subjective reports of fatigue increase* (independent of time-on-task), *response accuracy* is hypothesized to *decrease* (Lorist, Klein, Nieuwenhuis, De Jong, Mulder, & Meijman, 2000).

Behavioral Indices

8. As *subjective reports of fatigue increase*, *mean fixation duration will decrease*. As fatigue ratings increase, visual search patterns will become more inefficient, with decreased fixation duration (Williams et al., 1999; Williams, 2000).

9. As *time-on-task increases*, the *mean fixation duration will decrease* (Williams et al., 1999; Williams, 2000). Specifically, the mean fixation duration for the second viewing of scenarios (TB 13-24) will be significantly shorter than first (TB 1-12).

10. As visual analog *subjective reports of fatigue increase*, the *number of visual fixations will increase*. As subjective ratings of fatigue increase, more fixations

will be required to extract sufficient information from the visual scene (Williams et al., 1999; Williams, 2000).

11. As *time-on-task increase*s, *the number of visual fixations will increase* (Williams et al., 1999; Williams, 2000). Specifically, the number of visual fixations for the second viewing of scenarios (TB 13-24) will be significantly greater than first (TB 1-12).

Physiological Reactions

12. *Heart rate will decrease* significantly as subjective reports of *fatigue increase*. Therefore, as participants become more fatigued their arousal levels will decrease (Dureman & Bodén, 1972; Lal & Craig, 2002).

13. As *time-on-task increases*, *heart rate will decrease* (Dureman & Bodén, 1972; Lal & Craig, 2002).

14. *Skin conductivity will decrease* significantly as *subjective reports of fatigue increase*. It is hypothesized that as participants become more fatigued their arousal levels will also decrease. (Dureman & Bodén, 1972).

15. As *time-on-task increase*s, *skin conductivity will decrease* (Dureman & Bodén, 1972).

Significance

Cognitive fatigue is a concern within many performance domains, however, at present, the cognitive fatigue research is both disjointed and removed from the sport sciences. The general fatigue literature continues to be burdened with numerous incomplete and inaccurate definitions of fatigue, and lacks a formal methodological framework. Additionally, the influence of cognitive fatigue on performance has been overlooked in the sport psychology literature. Yet within environments such as athletics that emphasize performance quality and quantity, it is important to understand the factors that mediate performance output, so that the occurrence of negative consequences (i.e., decreased performance quality) may be reduced.

Within sport, participants are often required to complete several tasks simultaneously, including attending to relevant internal and external cues effectively.

Over a period of time, this responsibility can be fatiguing (Lal & Craig, 2002). It is evident that athletes endure demanding physical conditions, while also being presented with cognitively demanding tasks such as directing and allocating attention, anticipating upcoming movement sequences, and making decisions. At the present, there is no evidence to indicate how prolonged decision-making and resulting cognitive fatigue is manifested physiologically, subjectively, or behaviorally in sport. Therefore, the specific aim of the current study was to assess changes in athletes' performance, subjective reports of performance states, and physiology in relation to time-on-task within a simulated, dynamic, ice hockey scenario.

To achieve this aim, the current investigation implemented a multi-method approach of assessment, combining the use of both subjective (i.e., visual analog self report of current states) and objective (i.e., heart rate and response time) measurements. Within this assessment paradigm, fatigue and performance were examined as separate yet potentially interacting constructs, with each being assessed independently, a feature of the design that has been often overlooked in previous investigations. Additionally, this investigation focused solely on fatigue resulting from prolonged work exposure, a methodological oversight in previous fatigue research (Holding, 1983). To further illuminate the onset and influence of fatigue, the two related psychological concepts of motivation and boredom were also be assessed throughout the duration of the task. With attention being given to the several methodological and conceptual shortcomings of previous research, the current study attempted to present a multidimensional, sport-specific perspective of cognitive fatigue.

The unification of the literature from several related, yet often isolated disciplines form the foundation on which the current investigation is established. This body of literature and resulting investigation represents a movement towards the greater comprehension of the prevalence and influence of cognitive fatigue in sport. Through greater knowledge of the characteristics and mechanisms of cognitive fatigue, especially attention, athletes can increase self-awareness about cognitions, behaviors, and physiology during performance and fatigue states. Self-awareness is a primary factor in the development of self-control and the moderation of potentially negative consequences (e.g., fatigue and anxiety) (Ravizza, 1993). By recognizing attention related performance difficulties, athletes can actively engage in strategies to control attention and in turn minimize the negative influence of fatigue on performance (Gopher, 1992).

CHAPTER 2
REVIEW OF LITERATURE

This chapter presents a review of literature associated with fatigue. Within the review, a survey of the theoretical and empirical literature associated with attention, fatigue, and their interactions and associations with performance will be presented. A concise review of the dominant perspectives of attention and the relevance of attention to human performance will be presented first, followed by an introduction to the concept of fatigue. The fatigue-performance relationship will then be addressed in two sections: one highlighting physical fatigue, and the second focusing on cognitive fatigue, with an exploration of the measurement techniques frequently used and the common limitations of the research. The chapter will conclude with a synthesis of the presented material, with future directions and practical applications being highlighted.

Attention

The term "attention" is used frequently in daily conversation and is a topic of research in many disciplines. In particular, researchers concerned with understanding human performance have attempted to identify the function(s) of attention and how attention is directed, allocated, and maintained.

The ability to allocate and sustain attention to relevant information is crucial to the successful completion of both cognitive and motor tasks (Abernethy, 2001). Having such a profound influence on human behavior, the concept of attention has been a topic of research and theoretical debate in both psychology and motor behavior, with the first psychological endeavors beginning in the later half of the 19th century. Continuing from this point, the study of attention has proceeded through a series of paradigm shifts, each resulting in the development of several theories, some of which will be discussed below.

James (1890) described attention as “the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. It implies withdrawal from some things in order to deal effectively with others” (p. 403-404). In other words, attention can be viewed as the concentration of mental activity through the allocation of cognitive resources to select processes so as not to be interrupted or influenced by irrelevant stimuli (external or internal) (Schmid & Peper, 1993). According to this definition, as well as more contemporary approaches, attention has been viewed as selective in nature and limited in capacity (Cherry, 1953; Kahneman, 1973). Specifically, attention enables individuals to focus on a particular stimulus, task, or sensation, and disregard other incoming information. However, the amount of information attended to at a time is limited. As the study of attention progressed and the above concepts expanded on, attention was no longer viewed solely as consciousness, as purported by James (1890), but through a variety of metaphors (Fernandez-Duque & Johnson, 1999; Abernethy, 2001).

Attention Metaphors

Contemporary attention research has been primarily driven by the use of metaphors, with two dominant perspectives, including notions of attention as a filter and as a resource (Fernandez-Duque & Johnson, 1999). Broadbent (1958) initially advanced the concept of attention as a filter through his single-channel theory. Broadbent assumed that individuals have the ability to allocate attention to a specific task, while filtering irrelevant and extraneous information from processing. Specifically, when two or more stimuli occur simultaneously, all enter the sensory buffer (a process which does not require attention), but only one stimulus can pass through the filter to be processed (an attention demanding process). According to filter theories, attention is a single resource that utilizes a filter in the early stages of information processing to prevent irrelevant information from overloading the system's capacity and reaching long-term memory. Broadbent's general concept of a filter has been retained by subsequent researchers (e.g., Treisman, 1960) who acknowledge that irrelevant incoming information is blocked from reaching further stages of information processing and memory by a filter, however the point at which the filtering of information takes place varies among theorists.

Rather than attention being mediated by a filter, "resource" theorists view attention as being controlled by its limited-capacity, either as a single resource or a combination of several resources (Kahneman, 1973; Navon & Gopher, 1979). Kahneman (1973) proposed that attention is a single, but flexible "resource pool" from which several tasks may draw simultaneously, until the capacity of the pool is exhausted. Once the task demands exceed the resources available, performance begins to decline. Using a similar rationale, but proposing multiple "resource pools," Navon and Gopher (1979) attempted to explain the successful performance of several tasks simultaneously. In many situations, several tasks may be performed simultaneously without a noticeable performance decrement as long as the tasks are drawing resources from different pools, with the task demands dictating from which pools the resources will be drawn. The collective premise of this family of theories is that individuals possess limited resources for attentional processing and when these resources cannot meet the demands of the task(s) at hand, a decrease in performance is seen, either in efficiency, output, or a combination of the two (Kahneman, 1973; Desmond & Matthews, 1997). Additionally, individuals have a specified amount of processing space or capacity that may be divided among several simultaneous tasks. In other words, there is a limit on the quantity or amount of attention that can be applied to a single task or several tasks at a time. In summary, attention is limited in information processing capability, either by lack of resources, space, or capacity (Abernethy, 2001).

Regardless if one uses a filter or a resource metaphor to describe attention, the ability to orient attention is undeniably crucial to human performance. While performance psychology is grounded in theories of cognition, attention, and information processing, cognitive processes cannot directly be observed in naturalistic or research settings (Matthews et al., 2000). However, performance variables such as response accuracy and reaction time can be used to describe unobservable cognitive processes (Matthews et al., 2000). Monitoring performance fluctuations in various environmental contexts provides insight into the cognitive processes responsible for such modifications and is important for understanding and modifying human performance. Through investigations into human performance, awareness is gained into what factors and conditions promote successful performance, as well as those that lessen the probability of accurate and effective task performance as a result of disruptions in attention (e.g., distractors) and limitations in information processing and cognitive abilities (e.g., fatigue and low arousal) (Matthews et al., 2000).

Attentional Distractors

In performance scenarios, not only is it imperative for participants to attend to appropriate cues, but also to maintain that focus for a sufficient duration (Moran, 1996). However, distracting elements of the environment often compromise attentional focus, redirecting attention away from relevant information.

Distractors are factors that prompt shifts in attentional focus, and often will promote a performance decrement (Moran, 1996). Although an infinite number of sources can serve as a distractor and are continuously present internally and in the environment, there is an increased likelihood that they will be attended to in situations when the cognitive system is already compromised. For example, in conditions of high emotionality (e.g., high pressure situations) or depleted cognitive resources (e.g., fatigue states), individuals express a greater tendency to redirect attention away from the central task and to irrelevant and potentially detrimental stimuli (Wegner, 1994). In these situations, distractors compete with relevant information for already diminished resources, resulting in the allocation of even fewer resources to the central task (Moran, 1996).

Often in athletics when distractors cause breaks in attention and subsequent performance deteriorates, the result is described as “choking.” Common external distractors in sport are noise, behaviors and tactics of opponents, in addition to other various environmental and playing conditions (Moran, 1996). Similarly, physical sensations (e.g., sweaty palms, tense muscles) may function as internal attentional distractors for athletes (Nideffer, 1993). Specifically, when such feelings and sensations are attended to and interpreted negatively, there is an increased probability for a decrease in performance (Lazarus, 2000).

It is widely assumed that arousal and anxiety have a direct influence on attention (Abernethy, 2001). Commonly, the responses of anxiety and arousal, coupled with various physical symptoms redirect attention inward, away from the task relevant cues. Specifically, anxiety has been empirically illustrated to influence primary task performance by promoting shifts in attentional allocation and direction (Janelle, Singer, & Williams, 1999). In a recent investigation, Janelle and colleagues (1999) utilized a simulated driving task under varying levels of anxiety and task demands to empirically validate the above assumption. Using a dual-task paradigm, with a central driving task and a peripheral light detection task, distraction and attentional shifts were assessed through visual search patterns. Results indicated that in an effort to compensate for a reduced attentional field resulting from elevated levels of anxiety, individuals redirected foveal fixations to the periphery to identify cues located beyond the central focal area. During this period of redirection, however information located in the primary focal and essential to successful primary task performance were disregarded. The findings of Janelle and colleagues' driving simulation study indicate that anxiety modulates visual search strategies and patterns, with the resulting modifications negatively impacting central task performance.

Whereas anxiety and arousal's influence on attention has been explored in some depth, a related concept, fatigue, has been relatively ignored in both the general and sport psychology literatures. To gain more insight into the influence of fatigue on cognitive processes and performance, visual search patterns can be monitored to index attentional focus, as has been done already in reference to various internal states and external environments (e.g., Janelle et al., 1999).

Visual Attention

Fluctuations in visual attention have customarily been monitored through changes in overt performance or through self-report (retrospective and concurrent) measures. However, less subjective measures, such as more sophisticated eye tracking systems have been developed to indicate where visual attention is being allocated. The basis of the approach is that when the eye moves, a specific area of the visual display is brought into finer detail in the fovea, a small, yet sensitive area of the eye. When visual stimuli are fixated on (i.e., in the fovea), the information extracted is of highest quality and greatest detail (Duchowski, 2002). Specifically, foveal fixations, areas of interest/point of regard, and eye movement data can be acquired using a light reflection off the cornea, in conjunction with a video image of the eye (Duchowski, 2002; Williams et al., 1999). The ability to track eye movements has provided an additional avenue for the exploration of attention, and specifically visual attention.

It is assumed that by tracking eye movements (i.e., fixation location, fixation duration, and search rate), an individual's path of attentional allocation can also be followed, and the cognitive process of visual attention can be assessed (Duchowski, 2002). Specifically, fixation locations can be used to discern where an individual is visually attending and what environmental cues are significant in the decision-making process, without reliance upon subjective interpretation of where the individual reports attending. Moreover, the duration and number of fixations made provides an index of the cognitive demands (i.e., information-processing demands) of the task; the length of visual fixations, as well as the total number of fixations highlight the importance, as well as the complexity of each area of information extraction (Williams et al., 1999).

Although it is possible to direct attention to the visual periphery without a change in visual fixation, it is the definite movements and foveal fixations that indicate the direction of blatant visual attention and more detailed inspection by the viewer. This is not to discredit the importance of information presented in the periphery; instead it is often the material in the periphery that directs subsequent foveal fixations and focus of attention. The use of concurrent verbal reports, in conjunction with eye movement data, illustrates the success of and similarity between the two methods in identifying the locus of visual attention (Williams & Davids, 1997). However, the association can be moderated by both task characteristics and the performer's level of expertise. Specifically, among experts examining 3 versus 3 soccer scenarios, there was a discrepancy in the focus of attention between self-report and eye movement data, an inconsistency attributed to the expert's tendency and ability to use peripheral vision to extract relevant information from areas other than the fixation location. In sum, a general association exists between self-report accounts of visual attention and eye movement data, yet it is possible for skilled performers to maintain a fixation while extracting important information from the periphery.

It is important, however, to highlight that cognitive processes and information processing are key determinants, in addition to the visual display, in the orienting of attention. Because of the involvement of higher-level cognitive processing in directing attention, it is possible for individuals to voluntarily disconnect their attention from their foveal fixation (i.e., not "seeing" what one is looking at). Although this limitation associated with eye tracking is recognized, it is assumed that attention is directed at the point of fixation. However, it is understood that it is possible for the point of gaze and direction of attention to be detached. In conclusion, the addition of eye tracking methodologies to the study of attention has provided a fresh perspective on how attention can be monitored *during* task performance with relatively minimal disruption to "normal" performance.

Visual Attention in Sport

Eye movements in sport

During sport performance, athletes primarily implement two styles of eye movements, pursuit tracking and saccades, to bring information detected in the visual periphery into the fovea (Williams et al., 1999). Pursuit tracking is a relatively slow and smooth tracking style often associated with full head movement. Pursuit tracking is typically utilized when a slow object is being followed through an environment (i.e., the object is followed continuously from point A to B). Because of the obvious time requirement to obtain a stable retinal image, the utility and frequency of pursuit tracking in fast paced sports is minimal and is typically used in slower self-paced tasks. In contrast, saccades are rapid eye movements that are used to shift the eyes from one position in the visual space to another (i.e., the fixation "jumps" from point A to B *without* attending to all points in-between). During the saccadic movement itself (i.e., the actual movement from point A to B) there is a decreased sensitivity to the visual environment, prohibiting the extraction of visual information. Therefore, the fixation is more important for information processing than the movement. Ballistic sport scenarios, such as an ice hockey game, in which the visual environment is dynamic and under rapid flux, require frequent saccadic eye movements and fixations for adequate information extraction.

In addition to implementing the appropriate eye movements to shift from points in the display, it is essential that athletes acquire the information from the environment in the most practical and efficient manner to ensure a rapid and accurate response. The expert-novice athlete distinction is commonly used to demonstrate the differences between effective/efficient search patterns and less effective/efficient approaches.

Effectiveness and efficiency in visual search patterns

The ability of an athlete to orient attention appropriately and to efficiently carry out a movement is directly related to sport performance and outcome (Nideffer, 1993). The search strategy employed by athletes will dictate the efficiency by which performance will be carried out (Williams et al., 1999). For example, skilled performers generally use fewer fixations of a longer duration on highly informative areas of a display in an attempt to anticipate future actions. This process employed by experts is highly efficient since it maximizes the utility of the display and the time available (Williams, 2000). Additionally, elite athletes "expect the unexpected" in the most challenging and difficult sport specific circumstances, typically orienting attention automatically to the most important aspects of the visual display. Knowing where to and when to look is a crucial aspect of successful sport performance. It is therefore imperative that players are able to recognize the central and most information rich areas of the display and direct their attention swiftly and appropriately (Williams et al., 1999).

The concept and measurement of visual attention has diverse utility and application. Within the current investigation, visual gaze patterns and points of fixation will be used as markers of attentional focus. The purpose of monitoring changes in visual attention through eye tracking is to observe the potential fluctuations in search efficiency (i.e., number of fixations and fixation duration) through the stages of development of cognitive fatigue, a temporary state associated with problems in maintaining task-related attention and effort during an on-going performance (Brown, 1994). The availability of attentional resources and ample attentional capacity are central to successful human performance, however, fluctuations in attention and information processing do occur.

Specifically, fatigue states are associated with reduced attentional capability and increased distractibility (Moran, 1996; Desmond & Hancock, 2001).

Attention: A Summary

In summary, how attention is directed, allocated, and maintained is of primary interest to researchers and practioners concerned with understanding human performance. Various theories and metaphors have been developed to better conceptualize *what* attention is and *how* it influences performances. Yet, regardless of the specific approach taken (i.e., filter or resource), it is agreed that the amount of information that can be attended to is limited (Fernandez-Duque & Johnson, 1999). In addition to its limited nature, attention is also subject to negative disruptions caused by both internal and external distractors (Moran, 1996). The probability that task irrelevant information will cause a break in attention is amplified by states of high emotionality and already reduced resources. Such fluctuations in attentional direction that result from environmental changes, distractors, or reduced resources can be monitored physiologically through eye tracking methodology. Specifically, gaze patterns and visual fixations provide objective information about where an individual is "looking," while providing a reasonable estimate of what they are "seeing." Therefore, by monitoring eye movements ("looking"), it can be inferred what an individual is attending to ("seeing") (Duchowski, 2002). By understanding the purpose of attention, the characteristics of attention, and how attention can be measured, mediators of sport performance can be explored.

Fatigue

Conceptualizing Fatigue

Fatigue is a term commonly used to describe a negative result or unpleasant experience of a wide range of behaviors such as long distance running, lifting weights, prolonged driving, monitoring a visual display, or solving logic problems. Sustaining these activities, either positive or negative, for a few seconds to several weeks, can result in the development of fatigue (Craig & Cooper, 1992). Specifically, during the performance of cognitive and motor tasks, attentional demands are placed on the human system, creating an amount of cognitive workload (Matthews et al., 2000). The information processing required to successfully execute such tasks necessitates cognitive "energy"/ "resources," yet after periods of prolonged task exposure, high task difficulty, or multitasking, it is likely that such resources may become insufficient for optimal performance. That is, the cognitive resources have been already consumed by other task requirements and environmental demands. The minimization of available resources prompts the development of a fatigue state that continues to reduce the overall working capacity of the system, making the system (both the physical and cognitive components) more susceptible to stress (Schönpflug, 1983). Therefore, in conditions of elevated or prolonged workload, fatigue becomes a mediator between information processing and task performance (Matthews & Desmond, 2002). In environments, such as sport, that require attention and alertness to successfully execute multiple tasks, understanding how performers respond to the numerous attentional demands under stable and variable conditions is essential for reducing the occurrence of negative performance consequences (Lal & Craig, 2002).

To better understand what fatigue is and how it influences performance, a working/operational definition of fatigue will be provided. Currently, numerous common definitions of fatigue exist and a few of the most relevant and frequently referenced examples will be briefly introduced because the current number of definitions is extensive. Next, the "essential features" of fatigue will be described and contrasted with the characteristics of related constructs. Finally, a contemporary view of the state of empirical knowledge concerning fatigue will be provided. The discussion will highlight the influence of physical fatigue on performance, while also focusing on cognitive fatigue and its influence on performance as indicated by subjective reports, physiology, and other output measures.

Fatigue Defined

Within the common vocabulary fatigue has a broad connotation, with individuals using the term to refer to feelings of being tired, overworked, and unmotivated. Having such a broad range of reference in everyday language has the potential to create confusion in the scientific literature. It is therefore essential to operationally conceptualize and define fatigue. Regrettably, a universally accepted definition of fatigue is lacking and the ambiguous and complex nature of fatigue is perpetuated by the lack of a formal definition. As a result, a standard measurement of fatigue and fatigue states is lacking (Fairclough, 2001). With the discrepancies pertaining to the conceptualization and definition of fatigue, some researchers, even as early as the 1920s, proposed the abandonment of such a concept of fatigue (Muscio, 1921). Muscio (1921) argued that no test would validly be able to assess fatigue since there is not a definite observable criterion except for that provided by the test itself. However, advancements have been made in the conceptualization of fatigue so that abandonment of the concept is unwarranted.

Fatigue may be generated through two primary modes of exertion, either physical or mental, each resulting in subjective feelings of tiredness, with perhaps unique influences on performance (Matthews et al., 2000). Additionally, fatigue can be either active or passive in nature (Desmond & Hancock, 2001). During active fatigue, a constant, inescapable demand is placed on attention. When fatigue develops during situations of continuous demand, available attentional resources and the frequency by which external sources are sampled is reduced. In contrast, passive fatigue is the result of chronic understimulation (Desmond & Hancock, 2001). Although fatigue can be further reduced and categorized from the general to the specific, it is essential that an overarching definition of fatigue be presented.

Although all definitions of fatigue attempt to operationalize and clarify the same construct, disparity among and omissions within many of the definitions of fatigue remain. Craig and Cooper (1992) broadly define fatigue as "the weariness that accrues from applying oneself to a task over a period of time" (p. 289), regardless of the setting or the task. Recognizing the broad scope of this definition, the authors proceeded to limit fatigue as a result of "the effects that stem from the continued exercise of an activity" (p. 290-291), thereby distinguishing fatigue from the tiredness encountered from eating, drinking, or lack of sleeping. However, Craig and Cooper's definition lacks sufficient specificity and depth by failing to address how rest influences fatigue and what constitutes "weariness" and therefore cannot be considered an adequate depiction of the concept of fatigue.

Similar to Craig and Cooper, Brown (1994) failed to make reference to the cause or nature of fatigue, defining psychological fatigue as a "subjectively experienced disinclination to continue the task" (p. 298). As a result of this lack of causal specificity, such a definition could be interpreted as a lack of motivation, rather than fatigue (Job & Dalziel, 2001). Conversely, Hancock and Verwey (1997) significantly narrowed the scope of fatigue, defining it as an "individual's multi-dimensional physiological-cognitive state associated with stimulus repetition which results in prolonged residence beyond a zone of performance comfort" (p.497). By only highlighting stimulus repetition as a cause of fatigue, other potential fatiguing agents such as constant attentional demands, decision-making demands, or behavior repetition are disregarded. Although the above definitions describe the same construct, a definite lack of consistency exists among them; some definitions fail to recognize the two types of fatigue (physical [peripheral] and mental [central]), while others fail to capture the essence of the concept of fatigue, often being either too vague or too specific. The limitations that are inherent in the presented definitions reflect a common problem within the fatigue literature that has plagued the empirical investigation of fatigue.

In an attempt to clarify the ambiguity that has characterized the term "fatigue," Job and Dalziel (2001) have recently set forth a series of "essential features" that all definitions of fatigue should include. First, fatigue must be viewed as a hypothetical construct; it is a state of the individual, not a feature of his/her behavior or a performance outcome. In other words, reduced performance effectiveness or efficiency is not fatigue; however, fatigue may lead to such results. An adequate definition should also identify the cause, not solely the result of the state. Similarly, fatigue should include a description of the conditions that arise in either the muscles or central nervous system that contribute to the onset of fatigue. Next, definitions of fatigue should avoid extremely technical language, so that the description fits within the general population's logical conception of fatigue. Finally, the definition should be adequate so that fatigue can be distinguished from other related phenomenon. Job and Dalziel (2001) integrated each of the critical features and consequently defined fatigue as "the state of an organism's muscles, viscera, or central nervous system, in which prior physical activity and/or mental processing, in the absence of sufficient rest, results in insufficient cellular capacity or systemwide energy to maintain the original levels of activity and/or processing by using normal resources" (p. 469). Figure 2-1 presents a graphical conceptualization of fatigue, based on the definition provided by Job and Dalziel (2001). The figure emphasizes the significance of previous work and insufficient rest in the promotion of fatigue, which results in a diminished ability to perform at previous standards and a reduction in available resources, with a probable decrement in overt performance.

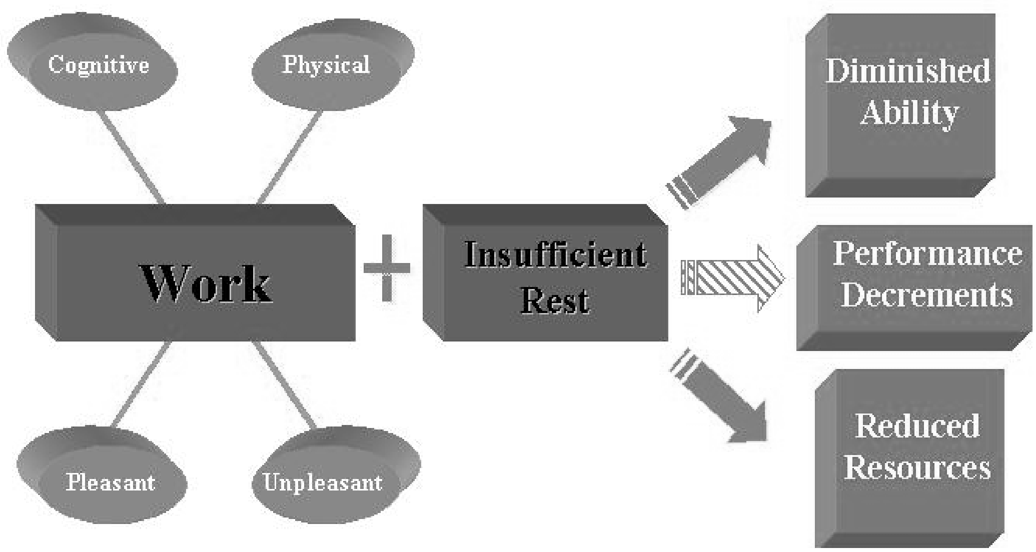

Figure 2-1. Graphical conceptualization of fatigue.

Although it is difficult to assert the precise influence of fatigue on performance considering the prevalence of variable definitions and related constructs (e.g., habituation, motivation, boredom), it is assumed that information processing efficiency and effectiveness may be compromised by fatigue (Matthews et al., 2000). In summary, fatigue is the result of previous activity without sufficient rest that leads to inadequate levels of energy or available resources to continue the activity with original levels of effort. Additionally, the resulting fatigue state has the potential to increase the probability for distractors to disrupt task-focused attention (Moran, 1996), redirect attention to the subjective symptoms of the state (Matthews et al., 2000), and hinder other factors related to successful task performance.

Mental fatigue and related cognitive states

While Job and Dalziel (2001) conceptualized fatigue in a coherent and comprehensive manner, how can fatigue be differentiated from related constructs? To recapitulate, fatigue is a state (either physical or mental) that is the result of activity without adequate rest, resulting in insufficient means to continue performing using typical resources.

Habituation

In comparison to fatigue, habituation is a form of learning that results from repeated exposure (either successive or intermittent) to a stimulus and is characterized by a decreased reaction to the particular stimulus (Job & Dalziel, 2001). Therefore, the states of fatigue and habituation can be discriminated according to two primary characteristics. First, fatigue results not only from repeated stimulus contact, but also from a reduction in energy or capacity to perform. Second, habituation to a stimulus will continue after sufficient rest, whereas fatigue will dissipate after an adequate rest period. Therefore, habituation can be distinguished from fatigue based on its cause and persistence.

Motivation

Motivation is the drive that initiates, directs, and sustains behavior and is based on a plethora of factors, ranging from rewards and punishment to perceived ability (Petri, 1991; Job & Dalziel, 2001). Although fatigue influences behavior patterns and persistence, it is solely based on performance capacity, previous activity, and rest, rather than on a range of internal and external motivators.

Boredom

Boredom is an individual's emotional reaction to an event, stimulus, or environment that is perceived to be repetitive, unvaried, predictable, or monotonous (Davies et al., 1983). Both boredom and fatigue may arise from the presence of a repetitive behavior or stimulus. However, boredom is influenced by previous exposure to a behavior or stimulus, independent of a rest period, whereas a rest period will modulate fatigue. Simply defined, boredom is a subjective feeling of disinterest, independent of time on task, energy, and rest (Job & Dalziel, 2001).

Although habituation, motivation, boredom, and fatigue are similar in origin and influence, and are often used interchangeably, it is necessary to stress the distinctions between them. Additionally it is important to highlight the unique combination of characteristics that result in the individual state of fatigue.

Fatigue and Human Performance

Fatigue is a common, yet complex phenomenon that puzzles researchers and can impede human performance. In many performance scenarios, particularly sport, the human body is physically taxed. How this exertion influences the performance of cognitive and motor tasks will be briefly reviewed with a focus on physical fatigue's influence on psychological variables (i.e., information processing and cognition). Although physical fatigue influences muscular exertion and performance (see Bompa, 1999 for a review), it also impacts cognitive functioning, an aspect of its influence that is often overlooked in sport. The following section will provide a brief review of the relevant literature related to exercise-induced (physical) fatigue and cognitive performance. Additionally, because performance demands extend to include cognitively demanding tasks, such as maintaining attention and decision-making, the review will also focus on how cognitive fatigue is related to performance, subjective, and physiological variables.

Exercise-Induced Fatigue and Performance

> In sports, fatigue is public enemy number one! Those athletes who cannot effectively cope with fatigue have a high probability of performing poorly and loosing the game, race, or match. Fatigue also affects the ability to stay focused, resulting in technical and tactical mistakes and throwing or shooting inaccuracies. This explains why, toward the end of a game or match, more mistakes are visible. (Bompa, 2000, p.149)

Bompa (2000) both emphatically and clearly portrays the prevalence and influence of fatigue in sport. In athletics, a decline in task performance is often attributed to the onset of fatigue; individuals can no longer perform at the same level due to a perceived reduction in ability, resources, or capacity because of previous performance. However, human performance researchers and sport scientists are both concerned with the validity of such statements and interested in the mechanisms that may promote such a performance decrement. Therefore, empirical investigations have examined the influence of physical fatigue/exertion on the performance of cognitive and motor tasks.

Physical exertion and cognitive processes are not independent; exercise can modulate arousal. Specifically, when engaging in any type of physical activity, arousal levels (e.g., heart rate) increase. The resulting alterations in arousal levels can either facilitate or hinder cognitive functioning and performance (Zaichkowsky & Baltzell, 2001). Selected studies that have examined the exercise induced arousal/fatigue-performance relationship will be reviewed.

Under the assumption that individuals make incorrect decisions when physically fatigued, Davey (1973) examined cognitive functioning following exercise. A post-activity protocol was used to assess the short-term memory functioning of participants following cycling bouts of consistent resistance, but of variable duration. Performance on a numeric-sequence identification task was the dependent measure. An analysis of pre- and post-exercise mental task performance scores revealed an inverted-U pattern of performance. The inverted-U hypothesis (Yerkes & Dodson, 1908) has frequently been used to frame both the positive and negative effects of arousal on performance. Within the inverted-U paradigm, performance is predicted to increase as physical arousal increases until an optimal arousal threshold is reached. If arousal proceeds to increase beyond this upper limit, a reduction in performance will result. Specifically within this investigation, the inverted-U pattern emerged, with exercise improving task performance after 30 second and after two-minute bouts of cycling. However, performance was hampered after 10 minutes of exercise (the threshold within the hypothesis). The resulting performance pattern supports the contention that physical exertion/fatigue has a similar effect on cognitive performance as general arousal, enhancing performance to a degree, but also hindering performance if the optimal level of exercise/exertion is surpassed.

To replicate and extend the exercise-induced fatigue research, Reilly and Smith conducted a pair of studies to investigate the effect of exercise intensity on both cognitive (1984) and psychomotor (1986) task performance. In both protocols, active male university students pedaled on a cycle ergometer at 25, 40, 55, 70, and 85% VO_2max. During the exercise, participants completed two mental arithmetic (1984) or pursuit rotor

(1986) tasks for 60 seconds during each loading interval. Although the tasks were completed while exercising, rather than post-exercise, the results were similar to those obtained by Davey (1973); performance was better at 25% VO_2max than at rest, and performance deteriorated at 70 and 85% VO_2max. In the two experiments, moderate physical work (44% and 38% VO_2max respectively) was associated with peak performance, a pattern indicative of the inverted-U. In summary, Reilly and Smith illustrated that both cognitive and psychomotor task performance are affected similarly by physical activity and fatigue.

Using a similar procedure as the preceding studies, Salmela and Ndoye (1986) examined cognitive alterations during progressive exercise. The authors hypothesized that as exercise increased in intensity, attentional focus would narrow, as indicated by a slower response to stimuli presented beyond the central visual field (i.e., located in the periphery). To test this hypothesis, participants cycled at increasingly difficult levels of resistance and responded verbally to five lights presented in various areas of their visual field. Salmela and Ndoye found support for their hypothesis; reactions to central stimuli were significantly faster than to stimuli in the extremes of the visual field as exercise progressed. Additionally, the inverted-U pattern of performance was once again apparent, with performance being initially enhanced by activity, but as the level and intensity of exercise increased beyond an “optimal” level, the activity hampered task performance.

In summary, the above investigations are representative of the majority of the literature examining the exercise-cognition association. Within the literature, as in the selected sample, various forms of activity and exertion are used to induce what are described to be fatigue states (although fatigue is not explicitly measured). Results indicate that prolonged/intense exercise and the resulting fatigue negatively influence performance on a variety of cognitive and motor tasks. Although the results support the inverted-U hypothesis in describing the relationship between exercise and cognitive performance, caution must be exercised not to blindly accept this unidimensional, simplistic explanation. Further research is necessary to produce a more complex and accurate depiction of the influence of exercise and ensuing fatigue on performance, specifically assessing the development of fatigue, taking into account task characteristics (both physical and mental), the fitness level of the population involved, the point at which assessment is done (post versus during exertion), and the subjective appraisal of the situation and activity by the participant. Clearly, the study of the effects of exercise on cognition and human performance is central to understanding human behavior and performance, however, the body is not the only resource taxed during performance.

Cognitive Fatigue and Performance

As alluded to, performance demands are not limited to physical stress and strain; attention and information processing exert similar demands and can stimulate the development of *cognitive* fatigue. Early research into the effects of cognitive fatigue approached the relationship between mental activity and performance as though mental and physical activity had a similar origin and influence on performance, attempting to find straightforward decrements in cognitive performance (Craig & Cooper, 1992). Unfortunately, little support was found for reduced mental output (e.g., decreases in performance quality) after repeated exposure to a task (Craig & Cooper, 1992).

The measurement of mental activity and subsequent cognitive alterations is unique, in that a majority of the processes are not directly observable (Matthews et al., 2000).

This potential limitation however, has not prevented exploration into cognitive fatigue's influence on human performance, but has encouraged the use of multiple modes of assessment. This section will begin with an exploration into what cognitive fatigue is, followed by an overview of contemporary research. Within the overview, methods for assessing cognitive fatigue, namely, self-report and physiological indices will be highlighted. The section will conclude with a synopsis of where the current literature stands and what questions remain unanswered.

Fatigue is a term that is used to refer to a variety of sensations and effects encountered in the laboratory, everyday life, work, and sport. Fatigue resulting from prolonged mental activity has two distinct categories: task specific and generalized fatigue (Holding, 1983). *Task specific mental fatigue* results when an individual is tired of performing a specific task, and changing activities will alleviate the fatigue. In contrast, *generalized fatigue* is a broad state of tiredness that is not related to one specific task; therefore the switching of tasks will not alleviate generalized fatigue. With fatigue having such broad foundation and implications, this section will be limited to a discussion of task specific cognitive fatigue and its relationship with performance.

Early investigations (1943-1972)

Seminal research conducted by Bartlett (1943) began the investigation into the fatigue-performance association. Bartlett used the Cambridge Cockpit, a simplistic aircraft simulation, to assess changes in behavior and overall performance as time-on-task increased. Pilots were asked to respond to information presented on several displays, a task with little physical involvement. As time-on-task progressed, a decrease in timing accuracy was found, although responses were otherwise appropriate. Additionally, a reduction in the number of instruments attended to by the pilots was noted; the pilots attended to the most important aspects of the display while ignoring other relevant information, an indicator of a reduced attentional field as a result of prolonged activity. Although, Bartlett's work was conducted a half a century ago, it set the stage for more recent research, drawing attention to the relative breakdown in coordination of behavior as time-on-task/fatigue increases; as fatigue develops, overt performance may not decrease, although the efficiency of task completion may be compromised (Bartlett, 1943).

Rather than manipulating fatigue induction solely through time-on-task, Hockey (1970) used sleep deprivation in conjunction with a prolonged task to fatigue participants. In the 1970 experiment, both sleep deprived and rested participants completed the dual-task of tracking a target and responding to light signals. During the initial phases of the experiment, both groups responded more quickly to centrally presented signals than to those presented in the periphery. However, as time-on-task increased, already fatigued (sleep deprived) participants began to respond more slowly to centrally presented signals, minimizing the difference in response time between signals presented in the periphery and those in the central visual field. Rested participants did not duplicate the response pattern of their fatigued counterparts, but rather maintained a faster response time to centrally presented stimuli as compared to peripheral stimuli. The decreased sensitivity to centrally presented stimuli by fatigued participants indicates that the cognitive processes of either response selection or attentional selectivity are hampered by fatigue.

The practical application of fatigue research was further advance by Dureman and Bodén (1972). In their 1972 investigation, Dureman and Bodén combined the realism of a driving simulator with physiological data collection to depict a more complete picture of what occurs subjectively, overtly, and physiologically as a result of four hours of continuous driving. Results indicated that the drive successfully induced progressive feelings of fatigue that paralleled overt performance errors. In conjunction with performance errors, a decrease in arousal was noted, with lower heart rate and increased skin resistance as time-on-task increased. This pattern of performance and arousal was markedly different when arousal and motivation were stimulated through an electric shock when a steering error was made, a change that highlights the importance of optimal arousal for successful performance and how fatigue may compromise the maintenance of an optimal level of arousal.

Contemporary investigations (1996-2002)

Contemporary investigations of cognitive fatigue have primarily focused on fatigue in ergonomic settings, highlighting transportation due to the grave number of fatalities and accidents believed to be the result of fatigued drivers/pilots (e.g., Desmond & Matthews, 1997; Matthews & Desmond, 2002; Lal & Craig, 2002). Within this literature, fatigue is examined as a general construct resulting from factors such as sleepiness, general nighttime impairments, and time-on-task. The present review will however focus on the influence of time-on-task, with an ergonomic orientation.

The link between fatigue and performance decrements is not a new concept. However, within the last decade there has been a surge in the investigation of fatigue within the transportation industry. Similar to Bartlett's (1943) early investigation, Morris and Miller (1996) utilized a simulated flight paradigm to examine the relationship between time-on-task and performance, while incorporating the measurement of physiological reactivity. Ten partially sleep deprived Air Force pilots flew eight, two-segment legs in a flight simulator. During the flight, performance and physiology were monitored and altitude, velocity, and speed error scores were calculated to measure performance over time. Electrooculographic (EOG) data was used to monitor blink characteristics (i.e., amplitude, rate, duration, and closure rate) and saccade information (i.e., velocity and rate). In conjunction with physiological and performance indices, subjective ratings of fatigue, workload, and sleepiness were also collected using a three-scale survey consisting of the Crew Status Check Card, the Sleep Survey Form developed by the USAF School of Aerospace Medicine (SAM Form 202 and SAM Form 154) and the Stanford Sleepiness Scale (SSS; Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) to assess fatigue and workload, sleep habits from the previous evening, and current sensations of "sleepiness," respectively. Results indicated a positive correlation between subjective reports of fatigue and error. Additionally, blink amplitude was found to be the best predictor of changes in error; smaller blink amplitude corresponded with increases in error. It was also found, through manual inspection, that saccade rate apparently decreased across epochs as indicated through the pilot's crosscheck of instruments. Morris and Miller's investigation revealed that measurable, negative performance changes occur in fatigued pilots. Additionally, these fatigue symptoms and performance correlates can be measured physiologically.

To better understand and subsequently manage fatigue in the transportation field, Lal and Craig (2002) monitored the physiological changes that occurred during a driving simulation. Thirty-five nonprofessional drivers, who were self-described to be sleep deprived, performed a driving simulation task until physical signs of fatigue were apparent (approximately two hours). Heart rate was recorded prior to and following the "drive." Additionally, during the drive, video was used to capture the driver's face and overt physical signs of fatigue. The video was used in conjunction with EOG and an electroencephalogram (EEG). To assess self-report assessment of fatigue, the “fatigue state question” scale was created (and validated) to measure fatigue levels before and after the task. The most relevant finding to the current investigation is the decrease in heart rate post-race, as compared to pre-race. It is this decreased physiological arousal that is believed to be one of the contributing factors to performance decrements in a variety of settings, however future research is warranted to better understand the physiological changes associated with fatigue.

To extend earlier findings pertaining to the physiological correlates of fatigue and how fatigue effects may be moderated, Moolenaar and colleagues (1999) examined the influence of the stimulant ephedrine and a placebo on driving performance and physiological reactivity to a four hour, 3-way divided attention task (pursuit tracking, peripheral target detection, and random visual signal detection) designed to mimic the demands of driving. Subjective reports indicated that the participants who received the placebo did become fatigued as time-on-task increased, in comparison to the experimental group. Additionally, the control group experienced a progressive deceleration in heart rate over the four-hour drive. Although subjective and physiological differences were noted between the groups, performance was only significantly different for pursuit tracking; as time-on-task increased, control subject’s tracking performance decreased, as indicated by an increase in tracking delay. In contrast, the experimental group’s performance increased on the tracking task as time-on-task increased. Surprisingly, and counter to related research (e.g., Hockey, 1970), the control (fatigue) group did not express a decreased sensitivity to peripheral targets. In summary, the direct relationship between subjective fatigue and lower arousal was supported, whereas performance was not necessarily hindered by fatigue or lower arousal.

In a similar investigation, Macchi and colleagues (2002) conducted a direct comparison between fatigued (no nap) and rested (nap) professional long-haul drivers. The purpose of the study was to assess the effects of an afternoon nap on perceptions of fatigue, performance, and arousal. After a three-hour nap and a two-hour “night-driving” session in a simulator, the participants who were rested were significantly less sleepy and fatigued, had faster reaction times, exhibited less performance variability, and had higher levels of arousal than prior to the rest. It appears that the nap provided a “sufficient” period of rest, and was able to minimize fatigue and its negative effects/consequences.

In another recent transportation investigation, Matthews and Desmond (2002) examined the influence of task-induced fatigue on simulated driving performance. In a two-part investigation, fatigue effects were hypothesized to be the result of reduced attentional resources and ineffective effort regulation. Two tasks (control and fatigue inducing [FI]) were used in a repeated measures design to contrast fatigued and non-fatigued driving performance. In both conditions, participants were instructed to follow a lead car on a stimulated track at a constant speed of 30mph. For the control task, this was the participant’s only objective for six minutes while on both curved (higher workload) and straight (lower workload) roadways. In contrast, for the 24-minute, FI task, participants were required to complete a secondary signal detection task in addition to the central driving task on both curved and straight roadways. Fatigue symptoms, emotions, motivation, effort, and cognitions were subjectively assessed before and after each drive. Analysis of the subjective reports revealed differences between the two groups, including higher effort ratings during the FI task. Although there was an elevated level of perceived effort exerted during the FI task, results indicated a decrease in performance as fatigue developed. Specifically, there was an increase in heading error (difference between front of car and roadway) and a decrease in signal detection on straight-aways, compared with curved road segments as fatigue levels increased. According to the performance data, in situations perceived to require low effort (straight-aways), fatigued individuals ineffectively regulated effort, rather than had insufficient resources available for task performance. This finding emphasizes the importance of understanding the task demands when predicting and understanding fatigue's effect on performance. In summary, the data confirms that task-directed effort or lack thereof is responsible for driving performance while fatigued. Additionally, the authors suggest increasing motivation prior to and during task execution, rather than attempting to minimize attentional demands, is more effective for decreasing the negative influence of fatigue on performance.

The implications for fatigue research to improve performance have been well recognized by the transportation industry, yet has been relatively ignored within sport and exercise sciences. It is apparent through the reviewed research that cognitive fatigue influences and is influenced by human output, both directly and indirectly. Specifically, it is cognitive effort (e.g., allocating attention, decision-making) that has the potential to deplete resources to prompt a fatigue state. However, once a fatigue state develops it is often paired with lowered arousal, decreased environmental sensitivity, slowed reaction time, and overall impaired performance. Understanding how this procedure develops and is expressed in a sporting context could provide useful information pertaining to individual cognitive involvement in training and gaming situations.

Limitations in the Literature

This chapter has presented a survey of relevant literature and theory associated with the performance-fatigue relationship, however, insufficient definitions, theories, and methodologies continue to plague the literature, leaving many unanswered questions. In much of the reviewed literature (e.g., Bartlett, 1943; Dureman & Bodén, 1972), the word fatigue is used in the title of the article or the abstract, but is not specifically revisited in the content of the article. This common oversight within the literature makes the assumption that all tasks can and will create a fatigue state for individuals at the same rate, an incorrect assumption; it is incorrect for researchers (e.g., Bartlett, 1943; Davey, 1973; Reilly & Smith, 1984) to assume that a fatigue state has developed as the result of prolonged exercise or time-on-task when it has not been specifically assessed. Additionally, this oversight perpetuates the confusion associated with the term fatigue. Although the term fatigue was used in the title or briefly in the introduction, it was used oftentimes interchangeably with vigilance, drowsiness, boredom, and other related but independent constructs. Such ambiguity among researchers emphasizes the importance of the implementation of an effective operational definition.

However, caution must be exercised when defining fatigue. Although there have been numerous attempts to conceptualize fatigue, one common misconception is that fatigue is defined in terms of its consequences and is not recognized as a state of being (Brown, 1994). Research that has taken this approach is circular in nature and does not adequately address the concept of fatigue. Although this conceptual inconsistency has plagued the literature, Job and Dalziel (2001) have provided a solid example of what future definitions of fatigue should incorporate to accurately depict the state.

Conceptual and methodological limitations discussed above have minimized the applicability and generalizations of many of the fatigue research's findings. However, recognition of such limitations will promote more valid investigations. The more knowledge gained about fatigue, the better it and its negative consequences can be managed.

Management of Fatigue

Matthews and Desmond's (2002) results point to the notion that individuals have the ability to offset/minimize some of the deficits in information-processing that occur as a result of fatigue by simply modifying effort or strategy. As reviewed above, the effects of cognitive fatigue on performance are linked to changes in effort and/or resource availability (Dureman & Bodén, 1972; Matthews & Desmond, 2002). Not only do recent empirical investigations indicate the potential for individuals to override fatigue effects, but also this phenomenon is well noted anecdotally. "Fatigue can be quickly forgotten in a state of emergency or an excess of enthusiasm" (Holding, 1983, p.145). Through alterations in strategy and/or effort, performance may be maintained. However, Brown (1994) cautions that although a decrease in performance or task effectiveness is not guaranteed if work continues after the onset of a fatigue state, task efficiency *will* be compromised.

Although ambiguity remains regarding how output is influenced as fatigue sets in, some certainty exists that as fatigue increases, response variability increases and performance efficiency decreases (Bartlett, 1943; Craig & Cooper, 1992; Brown, 1994). In summary, the influence of fatigue on performance efficiency and effectiveness has the potential to be moderated by an individual's motivation and/or ability to exert additional effort required for task maintenance, as well as through effective attentional allocation. The ability for athletes to effectively manage their attention and effort is central not only performance, but also to the minimization of injury and the prevention of burnout. However, the benefits of fatigue management cannot be obtained unless more sport-specific cognitive fatigue research is conducted.

Conclusion

Attention is a vital component of human performance. Additionally, the appropriate allocation of attentional resources and cognitive effort is indicative of successful and even elite performance. Unfortunately, there are many internal and external factors that can compromise the efficiency and effectiveness of attentional allocation. One such variable is fatigue, either physical or cognitive. Within sport, cognitive fatigue is often the result of athletes concentrating maximally on the task at hand and constantly having to make quick and accurate decisions based on environmental stimuli (Bompa, 1999).

Anecdotally, coaches and athletes have linked losses in concentration, impaired decision making, lack of focus, and other mental breakdowns to fatigue. The sources of fatigue in sport are numerous and inherent given the physical and mental demands placed on the athlete. In most sporting contexts, players are required to search a complex and dynamic visual display, to attend to relevant cues while ignoring irrelevant information, and then make the most appropriate decision based upon the newly acquired and stored information. The process hopefully culminates in an efficient and effective series of movements (McMorris & Graydon, 1996). However, performing such activities over an extended period of time with minimal rest can result in fatigue. One objective of the present investigation is to reduce some of the ambiguity associated with cognitive fatigue, specifically cognitive fatigue in sport. Through the use of subjective reports of fatigue, physiological patterning, visual search patterns, and performance indices, insight will be gained regarding the onset, symptoms, and influence of cognitive fatigue in sport, while making advancements in the knowledge base of sport science and the general human performance literature.

CHAPTER 3
METHODS

Herein the methodology employed to empirically investigate the onset and effects of cognitive fatigue during a sporting simulation is described. An hour-long hockey decision-making task was used to induce fatigue and monitor performance changes in simulation situations (Reilly, 1996). Through the assessment of fatigue, boredom, motivation, performance, and physiological reactivity, a more detailed depiction of cognitive fatigue's development and influence in sport has been gained. Specific variables of interest and importance are reviewed below.

Participants

To determine an adequate sample size, the power table for single group repeated measures designs (Barcikowski & Robey, 1985) was referenced. The desired power was determined to be 0.80 with a medium effect size and alpha level set at the 0.05 level. Based on these requirements, a sample size of 14 was determined to be adequate.

Eighteen male athletes (mean age = 20.6, *SD* = 2.57) with advanced ice hockey experience (high school level or beyond) and an average of 10.03 (*SD* = 4.41) of playing years of hockey involvement participated in the experiment. Participation was limited to males because the simulation was only available with male players. Prior to participation, participants were asked to restrict caffeine and food intake for the four hours prior to testing and to avoid alcohol for 24 hours prior to their scheduled session due to the potential interaction between food and beverage consumption and fatigue (Lal & Craig, 2002) (see Appendix A).

Task

Video clips demonstrating actual on-ice play extracted from EA Sports NHL 2001 (Electronic Arts, Redwood, CA*)* for Sony PlayStation 2 (Sony Computer Entertainment America, San Mateo, CA) using the Pinnacle Video Editing Suite (Pinnacle Systems, Inc., Mountain View, CA) were used in the simulation. Scenarios were created using the replay function of the simulation and altering the angle so that an "on-ice" perspective was created. Attention was given to creating scenarios that were different enough to minimize boredom, yet similar in the level of complexity. The teams used in the simulation footage were numbered players dressed in Team USA home and away jerseys. The level of play was set to "pro" and the speed of the simulation was "moderate" in an attempt to create scenarios that are most similar to the actual playing intensity and skill level of the participants. Scenarios include defensively and offensively oriented perspectives that players from either position are qualified and able to "read."

To establish the validity of the scenarios, as well as the most appropriate response to each question, a CD-Rom of the simulation was provided to 7 hockey coaches. The coaches were provided with each question and four possible responses and asked to identify the most appropriate response. If the coach felt that none of the responses were applicable, they were asked to supply what they believed to be the most appropriate response. Coach response concordance demonstrated reliability (R = .87). A total of 60 clips, lasting 6.3 to 14.4 seconds in duration were selected for inclusion in the simulation.

A Sharp Notevision LCD Projector (Model XG-NV2U, Tokyo, Japan) projected the resulting hockey footage from a Falcon Northwest Mach V XP 2800 computer (Falcon Northwest Computer Systems, Ashland, Oregon). The testing period consisted of 12 trial blocks (TB) presented twice, once in the first half and once in the second half, for a total of 24 trial blocks. Blocks consist of five video sequences, with each video clip being followed by a question concerning a scenario-relevant decision with four multiple-choice responses. Participants were asked to select the *most* appropriate response as quickly and as accurately as possible. Each trial block was approximately 2.5 minutes in duration, however the actual block lengths varied based on individual response times due to individual differences in the time required by participants to respond to each question. Trial blocks were presented randomly across participants, as was the order of the clips within each block. A program written in LabVIEW (6.0, National Instruments, Austin, TX) will control the timing and presentation of information.

Prior to the beginning of each trial bock and following TB 24, three separate visual analog scales (VAS) were presented to monitor changes in fatigue, motivation, and boredom over the duration of the experiment. Although this assessment interrupted the central task, this pause is not a period of sufficient rest, and therefore did not decrease or eliminate a fatigue state (Job & Dalziel, 2001). Throughout the testing period both visual search patterns and arousal were monitored to index the onset and effect of cognitive fatigue.

Although the methodology is grounded in the assumption that time-on-task promotes the development of fatigue, it is inappropriate and inaccurate to presume as time-on-task increases, fatigue increases proportionally (Sirevaag & Stern, 2000; Holding, 1983). Therefore, time-on-task was used to induce fatigue, yet fatigue development was also monitored through successive reports of the subjective experience of fatigue and fluctuations in physiology.

Measurement Devices and Dependent Variables

Gaze Behavior Measurement and Data Reduction

Eye movements were monitored and recorded using the Applied Science Laboratories 5000 Series Model 504 Eye Movement System with Eyehead Integration (ASL, Bedford, MA) in conjunction with a Dell Optiplex GX250 2.53 GHz computer (Dell Inc., Austin, TX). The Model 504 is a complete video eye tracking system with a remote optics eye camera that allows for a moderate amount of head movement (approximately one square foot), and therefore does not limit a seated individual's normal range of head movement. The Model 504 uses pupil-corneal reflection to measure point of gaze related to the scenarios recorded by a scene camera. A head mounted magnetic sensor and transmitter was used to monitor the head's location in space. The participant's visual gaze patterns are displayed on the image acquired from the remote scene camera as a set of cross hairs. The intersection of the cross hairs represents the coordinates of the pupil position and corneal reflex of the "dominant" eye.

The system's accuracy is to 0.5° visual angle with a visual range of 50° horizontally and 40° vertically. Point of gaze coordinates are sampled at 60Hz. Calibration of the system through a nine-point reference grid prior to testing ensured that the points of gaze correspond to the appropriate elements of the visual display. The numbers in the calibration grid were arranged in a three by three matrix, with the upper left corner labeled point 1, the middle point 5, and the lower right point 9. During the calibration process the coordinates of the visual fixation were recorded as the participant progresses through the nine points.

For this investigation, fixation duration and total number of fixations per scenario were of primary interest. A fixation occurs when the eye remains stationary on any point in the display for a period of 100ms of longer. Eyenal software (ASL, Bedford, MA) was used offline to identify eye fixation and scan patterns per segment (i.e., clip) of data. The total number of fixations per trial block and the mean fixation duration of each trial block was used to represent gaze behavior for each trial block.

Arousal Measurement and Data Reduction

In conjunction with the ASL Model 504 eye tracking system and Dell Optiplex GX250 2.53GHz computer, AcqKnowledge (3.7.3, Biopac Systems Inc., Santa Barbara, CA) was used to manage the data collection through integration with a program written in LabVIEW. Specifically, the LabVIEW software triggered the collection of heart rate and skin conductivity through a Biopac MP150 system (Biopac Systems, Inc., Santa Barbara, CA) and signaled video clip onset and offset, as well as indicated trial block durations. Additionally, the LabVIEW software synchronized response time and eye movement data with arousal levels for each video clip scenario. Data was reduced offline using the AcqKnowledge software. Specifically, the software calculated the mean, standard deviation, and maximum values of heart rate (beats per minute (BPM)) and skin conductance levels (micromho (μmho)).

Heart rate

Heart rate was measured using pre-gelled disposable snap electrodes placed on the interior of both the left and right forearms, with a ground electrode on the participant's non-dominant forearm. The arms were prepared using rubbing alcohol. The Biopac amplifier bandpass filter was set to 1 - 35 Hz with a Gain of 5000 Hz.

Skin conductivity

Skin conductivity was measured using nonpolarized silver-silver chloride (Ag-Ag Cl) electrodes placed on the medial edge of the non-dominant hand. The hand and electrodes were prepared using Omni-prep with distilled water and ECI electrode paste, respectively. A Biopac Electrodermal activity amplifier (GSR100B) provided a continuous 0.5 V through the electrodes. The amplifier was set to detect a range of 0-50 μmhos, with a bandpass filter set from DC to 1.0 Hz. The signal was amplified 500 times by the Biopac amplifier.

Task Performance: Response Time

The time taken from question onset until response submission constituted the total response time (RT) in milliseconds (ms) for each scenario (trial). The LabVIEW program running on a Falcon Northwest Mach V XP 2800 computer both triggered the timing mechanism and stored the response times after each trial.

Task Performance: Response Accuracy

To obtain a measure of decision-making effectiveness, the LabVIEW program running on a Falcon Northwest Mach V XP 2800 computer was used to record participant responses and score the responses according to the master list of responses. The numbers of correct responses per trial block constituted the response accuracy (RA) score, with maximum score per block being five and minimum score being zero.

Subjective States: Visual Analog Scales

To monitor fluctuations in subjective states related to performance, three visual analog scales were used. Visual analog scales are brief, simple scales that place minimal cognitive demands on the respondent and minimally disrupt the completion of other tasks (a primary rational for selection in this study). The scales are 100 unit horizontal lines without unit markers and that contain anchor words/phrases at each end to identify the maximal and minimal levels of the mood/state being assessed (Brown, 1994). Descriptive anchors were selected to accurately capture how the participants were feeling at a given instance and have been used in other fatigue/performance related studies successfully (Brunier & Graydon, 1996). Brown (1994) cites that using a bipolar analog scale is a "sophisticated" method for assessing the subjective symptoms of fatigue that is not influenced by a potentially diminished ability or tendency to report such symptoms when fatigued, as noted through the use of other self-report assessments. Additionally, a pre-assessment training session on how to use the VAS increases the reliability and validity of the measure (Gift, 1989). Because the primary task was computer based, a program written in LabVIEW modified the VAS so it could be administered electronically. Scores on the scale range from zero to 100, with the scores increasing in value from left to right along the scale. The score/value that corresponded to where the participant placed the cursor was the subjective state score (boredom, motivation, or fatigue) that the participant received for that trial block. The LabVIEW program recorded subscale scores.

Procedure

Upon entering the laboratory, participants were informed that during the session they would be answering questions related to their ice hockey background and their experiences in the experimental session. Additionally, participants were told that they would be viewing ice hockey scenarios, which would be followed by tactical decisions related to the previously viewed video clip. Participants were informed that their response time and accuracy would be calculated after the session to determine how they performed in comparison to other ice hockey players, and that they would be notified about their performance at a later date. It was then explained that eye movements and physiological responses would be monitored during the task through several non-invasive sensors. Following explanation of the tasks and their involvement, participants completed an informed consent document (see Appendix B) approved by the Institutional Review Board (see Appendix C) and the sport history demographic questionnaire.

After the completion of the informational material, participants were fitted with heart rate and skin conductivity sensors in the preparation area and then seated in the testing area 1.5m away from a 1.5 m x 2 m projection screen. The laboratory was darkened to enhance the image of the pupil obtained from the eye tracking system and to enhance the quality of the video projection. Once seated comfortably, the eye tracking system was calibrated.

Following successful calibration of the eye tracking system, the participants was reminded that their goal was to respond as quickly and as accurately as possible to the presented questions, because their final score would be based on both measures and would determine their ranking in the "competition" (McMorris & Graydon, 1996). The competition incentive was provided to increase motivation and the probability that the participants would exert more effort than if no incentives were provided. Feedback was not provided in an effort to minimize the habituation effects associated with repeated/prolonged testing. In addition, the location of the relevant cues varied among the clips in order to enhance involvement in the task and minimize boredom, an approach similar to that taken by McMorris & Graydon (1996).

Following verbal explanation of the task, participants were guided through a practice session. During the demonstration, task guidelines and directions were provided (see Appendix E for complete instructions). Specifically, participants were shown, and given the opportunity to familiarize themselves with the interactive components they would encounter during the testing session. The first feature participants were exposed to were the three Visual Analog Scales (VAS) that were used to measure subjective experiences of fatigue, motivation, and boredom (Appendix F). Participants were provided with a training session on how to use the VAS and were specifically instructed how to select, change, and submit responses when presented with the scales, as well as provided with explicit operational definitions for the anchors. The experimenter demonstrated how to use the provided computer mouse to indicate how they feel *at that moment* by placing a mark in the box the appropriate distance from the corresponding descriptor. Following the brief explanation and demonstration, participants had the opportunity to practice selecting and submitting VAS responses.

Once participants demonstrated competency using the VAS, the next component of the experiment was presented. Specifically, a sample hockey scenario followed by four response selections were shown. Participants were informed that this video-question sequence would comprise the majority of the testing session and their objective was to select *the most appropriate* response as quickly and accurately as possible. Only one selection per question could be submitted, but responses could be changed an unlimited number of times prior to clicking the continue button. Participants had a maximum of one minute to submit a final response. Once again, the participants were provided with the opportunity to practice selecting, changing, and submitting responses. At the completion of the practice period lasting approximately five minutes, the actual testing session began.

Following completion of the twenty-fourth trial block and subsequent VAS, the experimental session ended and the experimenter returned to the laboratory to remove the sensors and to explain the purpose of the investigation to the participant (see Appendix G for debriefing script). The duration of the testing sessions was approximately 60 minutes, a period comparable to an ice hockey competition.

Design and Analysis

The design was a repeated measures time series, with all participants engaging in all 24 trial blocks, a design typical of fatigue research that examines output (Campbell & Stanley, 1969). A common limitation associated with time series designs is that alternative explanations, other than the factor under investigation, could be responsible for the observed changes. The current investigation however minimized the potential influence of extraneous variables by simultaneously assessing factors, in addition to fatigue, which may be related to performance fluctuations (i.e., response time, boredom, motivation, visual search patterns, and arousal).

Data were examined for outliers, defined to deviate from the mean by at least three standard deviations, an area which comprises 99.74% of the distribution (Herzberg, 1989). Data that exceeded this criterion were considered to be missing data, variables with considerable missing data (at least one-third of the data set) were not considered for further analysis. A Kolmogorov-Smirnov test was conducted to assess the distribution of the data, and determine if the assumption of normality was met. A Pearson-product-moment correlation was used to determine the magnitude and direction of the relationship between subjective reports of fatigue and performance indices (i.e., response time, response accuracy), gaze behavior (i.e., fixation duration), and arousal (i.e., heart rate, skin conductance levels). A repeated measures multivariate analysis of variance (MANOVA) was used to evaluate changes in subjective ratings (i.e., fatigue, motivation, boredom), performance (i.e., response time, response accuracy), gaze behavior (i.e., fixation duration), and arousal (i.e., heart rate, skin conductance levels) over the 24 trial blocks, across participants. Univariate analyses of variance (ANOVA) were used to evaluate simple effects and significant simple effects were followed with Tukey's Honestly Significant Difference (HSD) follow-up analyses for planned comparisons, controlling for Type I Error violations possible when conducting multiple comparisons.

CHAPTER 4
RESULTS

Results for this investigation are presented in the following chapter. The first section will present the correlations between subjective cognitive fatigue and performance, gaze behavior, and arousal. The second section will assess the influence of time-on-task on subjective reports of fatigue, boredom, and motivation, as well as time-on-task with the objective measures of performance, behavioral indices, and physiology.

Across dependent measures, data that exceeded three standard deviations from the mean were deemed outliers and were scored as missing data. A total of six response time values, nine mean fixations values, and one heart rate value were deemed outliers and thus discarded from further analysis. Additionally, the dependent measure of visual fixations was discarded from further analysis due to excessive lost data within and between participants. Kolmogorov-Smirnov tests confirmed that the data within blocks of the remaining dependent measures did not deviate significantly from the normal distribution (p-values ranged from 0.11 to 1.00), therefore raw data was considered appropriate for use in subsequent analyses.

Correlates of Subjective-Reports of Fatigue

Pearson product-moment correlation coefficients were computed to assess the magnitude and direction of the relationship between subjective reports of fatigue and performance indices, gaze behavior, and arousal.

Task Performance

A significant negative correlation was found between fatigue and mean response time ($r = -.39$, $p < .001$), indicating that as participants reported higher levels of subjective fatigue they also responded faster to the tactical decision-making task. The significant association is displayed in Figure 4-1. No relationship was found between fatigue and response accuracy ($r = -.06$, $p = 0.22$).

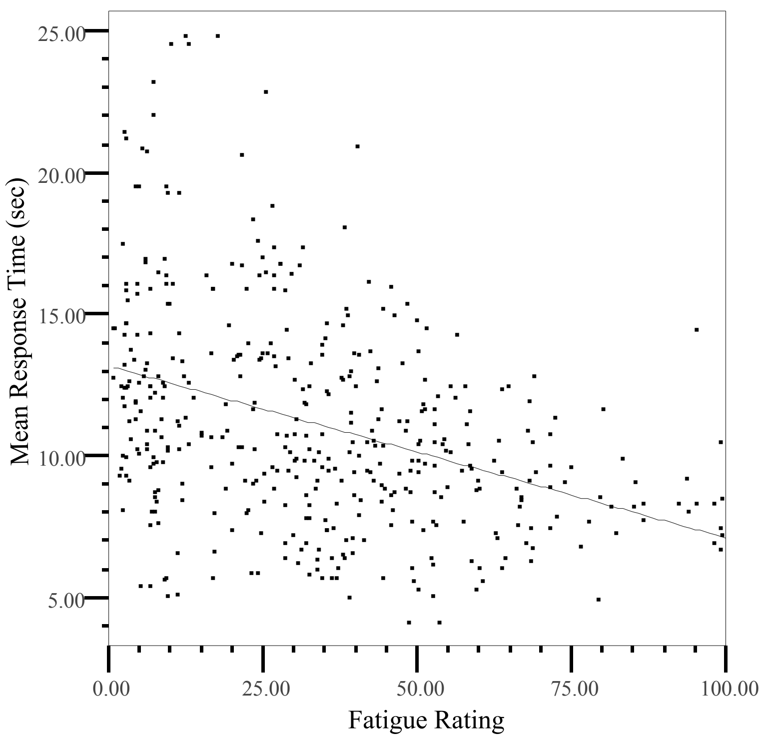

Figure 4-1. Subjective fatigue by mean response time.

Gaze Behavior

Fatigue and mean fixation duration ($r = .01$, $p = .89$) were not significantly related.

Arousal

A significant positive correlation was found between fatigue and heart rate ($r = .30$, $p < .001$), indicating that higher levels of subjective fatigue were associated with elevated heart rate. Additionally, a significant positive correlation was found between fatigue and skin conductance levels ($r = .40$, $p < .001$), indicating that higher ratings of fatigue were associated with greater skin conductivity. The associations are displayed in Figures 4-2 and 4-3 respectively.

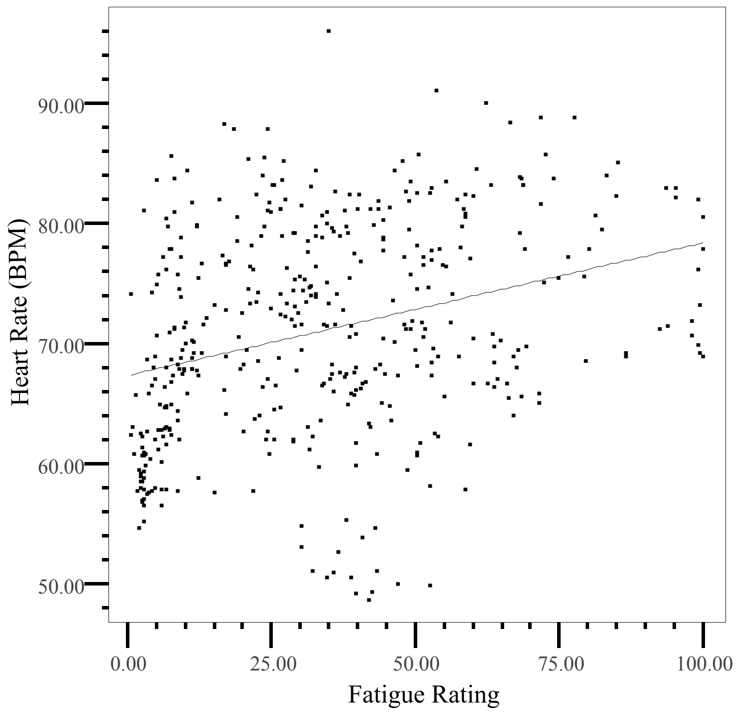

Figure 4-2. Subjective fatigue by heart rate.

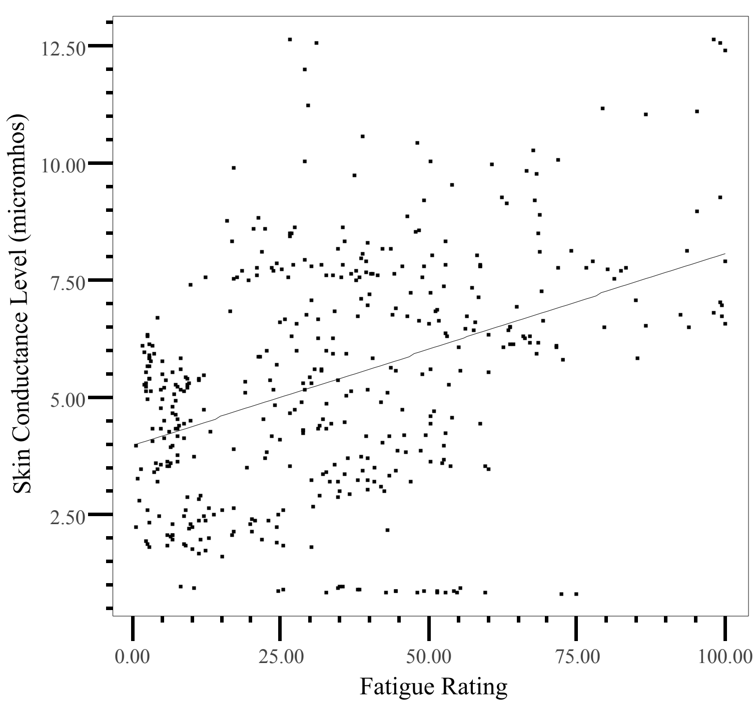

Figure 4-3. Subjective fatigue by skin conductance level.

Influence of Time-on-Task

Subjective-Reports, Task Performance, and Physiological Reactions

A repeated measures multivariate analysis of variance (RM MANOVA) was conducted to determine if there was a significant trial block effect across the dependent measures of subjective reports, task performance, and arousal. A significant trial block difference was found (Wilk's Lambda = 0.22, F (161, 2291) = 3.59, $p < .001$). Follow-up univariate Analysis of Variance (ANOVA) revealed significant trial block differences for subjective fatigue (F (23, 345) = 17.49, $p < .001$), boredom (F (23, 345) = 21.77, $p < .001$), motivation (F (23, 345) = 19.65, $p < .001$), response time (F (23, 345) = 11.32, $p < .001$), response accuracy (F (23, 345) = 1.70, $p = .02$), and skin conductance (F (23, 345) = 2.21, $p = .001$). No significant differences were found for heart rate (F (23, 345) = 0.63, $p = .911$). Figures 4-4, 4-5, and 4-6 represent the respective trends and Table 4-1 presents the descriptive statistics. Note in Figure 4-4 that motivation scores were plotted as the difference from 100 to depict the actual trend of the data.

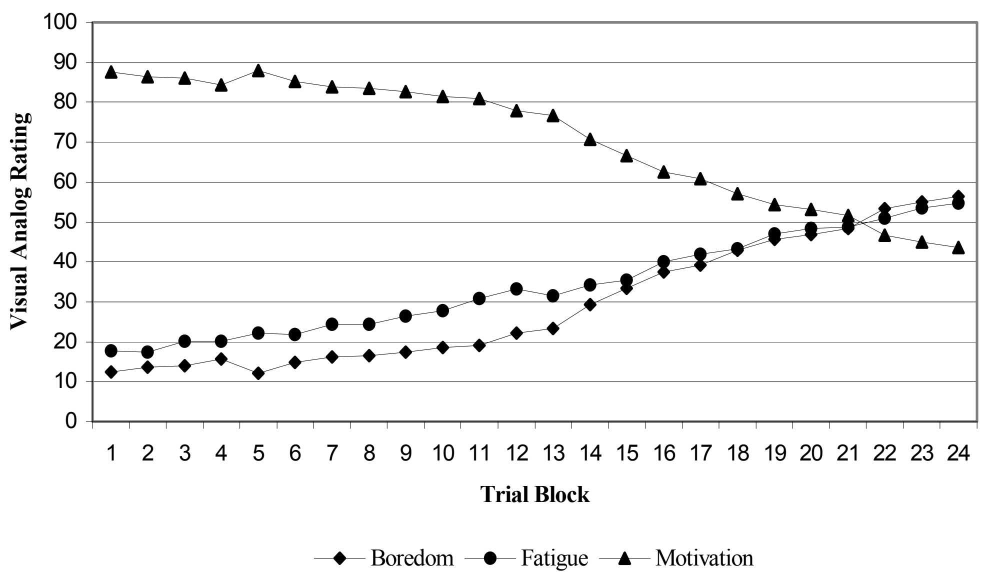

Figure 4-4. Mean ratings of fatigue, boredom, and motivation by trial block.

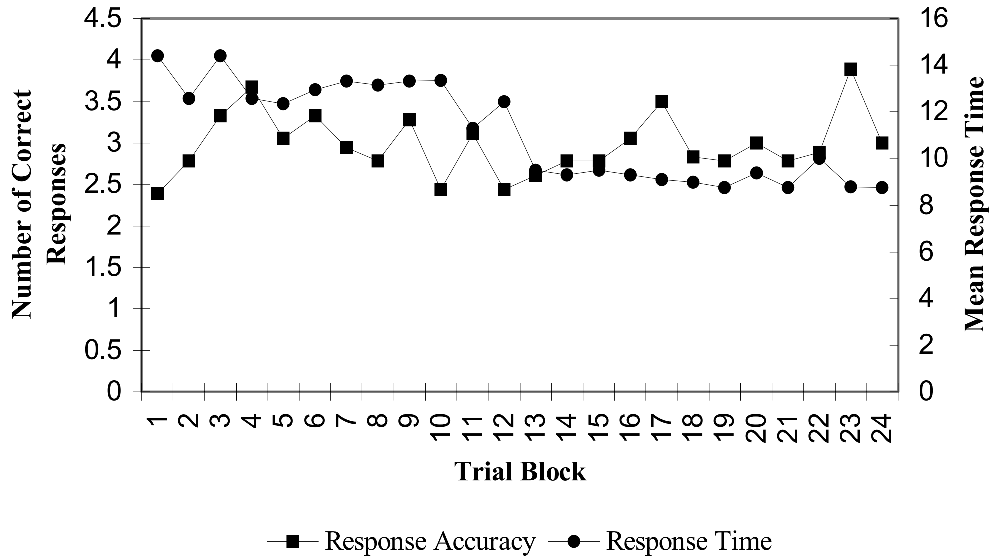

Figure 4-5. Performance by trial block.

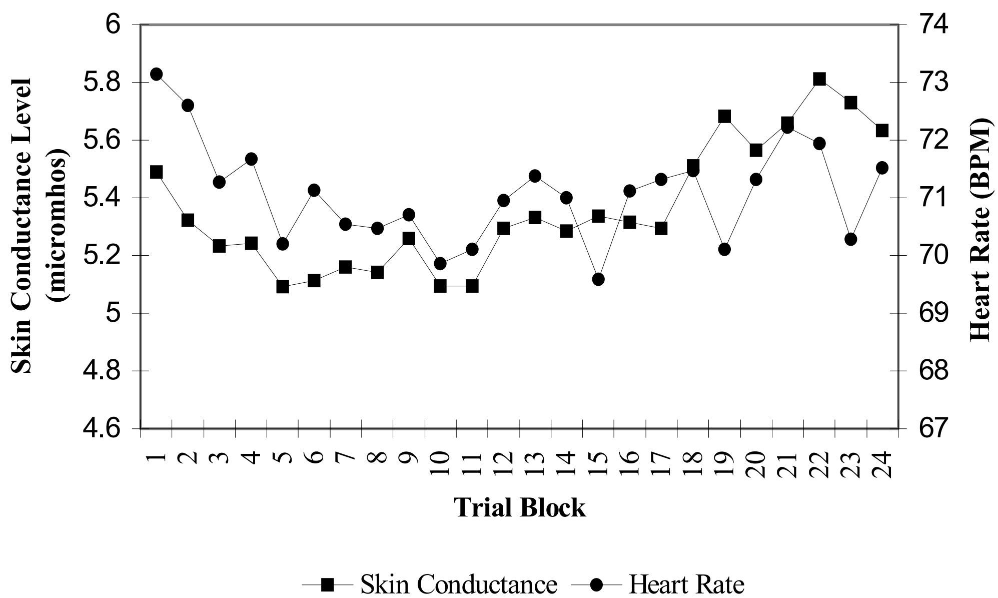

Figure 4-6. Mean ratings of arousal by trial block.

Tukey's HSD follow-up analyses were conducted to determine the location of significant differences within dependent measures. Results revealed a general trend of significantly lower levels of fatigue being reported in the earlier trial blocks when compared with the later trial blocks. For example, significantly less fatigue was reported in TB 5 (*M* = 23.43, *SD* = 14.47), than in TB 22 (*M* = 51.02, *SD* = 31.66). A similar pattern of significance was evident with respect to boredom; significantly lower levels of boredom were reported in earlier trial blocks than in later trial blocks. For example, significantly lower levels of boredom were reported in TB 3 (*M* = 14.34, *SD* = 9.60) than in TB 24 (*M* = 57.25, *SD* = 35.60).

Self-reported motivation revealed an opposite pattern; significantly higher levels of motivation were reported in the earlier trial blocks as compared to the later trial blocks. For example, participants reported being significantly more motivated in TB 2 (*M* = 14.72, *SD* = 12.22) than in TB 20 (*M* = 45.98, *SD* = 32.14). Additionally, response times were significantly faster in the later trial block than in the earlier trial blocks. For example, participants responded significantly faster in TB 19 (*M* = 8.76 sec, *SD* = 2.99) than in TB 1 (*M* = 14.41 sec, *SD* = 4.80).

Significant differences were also noted in response accuracy between TB 23 (*M* = 3.89, *SD* = 1.23) and TB 1 (*M* = 2.39, *SD* = 1.14), TB 10 (*M* = 2.44, *SD* = 1.20), as well as TB 12 (*M* = 2.44, *SD* = 1.50), indicating that participants had significantly better performance accuracy in trial block 23 compared with that of trial blocks 1, 10, and 12. Additionally, a significant difference in mean skin conductance levels was noted between TB 5 (*M* = 5.08, *SD* = 2.30) and TB 22 (*M* = 5.92, *SD* = 2.92), indicating significantly higher arousal in the later block.

Due to the high correlations between fatigue and boredom as well as motivation ($r = .74$, $p < .001$ and $r = .77$, $p < .001$, respectively), in addition to the significant variability of boredom and motivation across trial blocks, two repeated measures multivariate

Table 4-1. Dependent measure descriptive statistics *M,* (*SD*), and *n* by trial block.

	Trial Block							
Dependent Measure	1	2	3	4	5	6	7	8
Fatigue	17.65 (11.65) 18	17.45 (11.39) 18	20.11 (13.70) 18	20.11 (13.08) 18	22.13 (14.46) 18	21.86 (14.49) 18	24.42 (14.23) 18	24.43 (15.30) 18
Boredom	12.42 (10.36) 18	13.61 (10.62) 18	13.94 (9.78) 18	15.61 (12.09) 18	12.15 (9.68) 18	14.83 (12.80) 18	16.23 (13.97) 18	16.52 (14.76) 18
Motivation	13.29 (9.06) 18	14.72 (12.22) 18	14.92 (11.54) 18	14.83 (11.25) 18	13.66 (10.57) 18	15.71 (10.55) 18	16.49 (12.84) 18	16.59 (11.99) 18
Response Accuracy	2.39 (1.14) 18	2.78 (1.22) 18	3.33 (1.03) 18	3.67 (1.24) 18	3.06 (1.35) 18	3.33 (1.14) 18	2.94 (1.47) 18	2.78 (1.00) 18
Response Time (sec)	14.41 (4.80) 18	12.58 (3.25) 17	14.41 (4.80) 18	12.58 (3.25) 17	12.34 (3.20) 17	12.95 (2.62) 17	13.32 (3.52) 18	13.14 (4.11) 17
Loss Time (sec)	4.08 (4.91) 14	3.04 (3.39) 14	4.03 (4.47) 14	4.11 (3.97) 14	2.70 (2.55) 14	4.97 (5.64) 14	5.05 (4.65) 14	5.87 (6.77) 14
Heart Rate (BPM)	73.14 (9.48) 17	72.60 (9.13) 18	71.27 (9.17) 18	71.67 (8.44) 18	70.20 (8.34) 18	71.13 (10.55) 18	70.54 (8.82) 18	70.47 (9.19) 18
Skin Conductance	5.49 (2.20) 18	5.32 (2.22) 18	5.23 (2.21) 18	5.24 (2.38) 18	5.09 (2.34) 18	5.11 (2.44) 18	5.16 (2.81) 18	5.14 (2.84) 18

Table 4-1. Continued

Dependent Measure	Trial Block 9	10	11	12	13	14	15	16
Fatigue	26.38 (16.71) 18	27.71 (17.80) 18	30.91 (18.85) 18	33.28 (20.77) 18	31.49 (18.85) 18	34.31 (21.34) 18	35.47 (21.77) 18	40.07 (24.24) 18
Boredom	17.33 (13.27) 18	18.59 (15.62) 18	19.14 (15.64) 18	22.13 (17.74) 18	23.33 (18.04) 18	29.29 (22.82) 18	33.36 (26.01) 18	37.56 (29.04) 18
Motivation	18.58 (14.40) 18	19.67 (16.70) 18	20.99 (16.71) 18	21.43 (16.76) 18	24.71 (16.07) 18	30.34 (21.04) 18	33.06 (23.03) 18	36.76 (25.48) 18
Response Accuracy	3.28 (1.32) 18	2.44 (1.20) 18	3.11 (1.08) 18	2.44 (1.50) 18	2.61 (1.04) 18	2.78 (1.26) 18	2.78 (1.26) 18	3.06 (1.39) 18
Response Time (sec)	13.33 (3.59) 18	13.34 (3.46) 18	11.31 (2.47) 17	12.42 (2.72) 18	9.49 (2.83) 18	9.29 (2.79) 18	9.49 (2.83) 18	9.29 (2.79) 18
Loss Time (sec)	5.64 (4.87) 14	6.94 (6.60) 14	6.14 (6.95) 15	9.18 (9.07) 15	7.54 (8.05) 15	9.50 (9.90) 15	9.41 (8.67) 15	9.44 (9.51) 15
Heart Rate (BPM)	70.71 (9.26) 18	69.86 (8.96) 18	70.11 (8.41) 18	70.96 (8.32) 18	71.38 (9.29) 18	71.00 (9.58) 18	69.58 (9.75) 18	71.11 (8.47) 18
Skin Conductance	5.26 (2.75) 18	5.09 (2.57) 18	5.09 (2.60) 18	5.29 (2.63) 18	5.33 (2.51) 18	5.28 (2.43) 18	5.34 (2.31) 18	5.32 (2.40) 18

Table 4-1. Continued Trial Block

Dependent Measure	Trial Block 17	18	19	20	21	22	23	24
Fatigue	41.86 (24.62) 18	43.24 (25.20) 18	46.97 (28.44) 18	48.40 (29.59) 18	48.69 (29.77) 18	50.88 (30.88) 18	53.53 (32.27) 18	54.75 (32.77) 18
Boredom	39.14 (28.55) 18	42.87 (29.77) 18	45.71 (30.09) 18	46.88 (31.17) 18	48.44 (33.75) 18	53.26 (31.94) 18	55.09 (32.67) 18	56.44 (33.64) 18
Motivation	38.47 (24.94) 18	39.73 (27.11) 18	43.55 (29.14) 18	45.98 (32.14) 18	47.78 (33.13) 18	50.35 (33.71) 18	52.82 (34.58) 18	55.27 (34.58) 18
Response Accuracy	3.50 (1.20) 18	2.83 (1.34) 18	2.78 (1.48) 18	3.00 (1.28) 18	2.78 (1.11) 18	2.89 (1.23) 18	3.89 (1.23) 18	3.00 (1.37) 18
Response Time (sec)	9.11 (2.88) 18	8.98 (3.75) 18	8.76 (2.99) 18	9.37 (3.25) 18	8.76 (3.29) 18	10.00 (4.20) 18	8.80 (2.30) 18	8.75 (2.04) 18
Loss Time (sec)	8.27 (7.74) 15	10.01 (8.99) 15	8.41 (8.16) 15	10.22 (10.81) 15	11.99 (9.75) 14	11.63 (9.29) 14	10.71 (8.63) 13	15.69 (11.95) 12
Heart Rate (BPM)	71.31 (7.86) 18	71.47 (9.75) 18	70.11 (9.71) 18	71.32 (9.79) 18	72.22 (8.72) 18	71.94 (8.58) 18	70.29 (9.71) 18	71.52 (10.06) 18
Skin Conductance	5.29 (2.30) 18	5.51 (2.55) 18	5.68 (2.71) 18	5.56 (2.51) 18	5.66 (2.69) 18	5.81 (2.97) 18	5.73 (3.00) 18	5.63 (2.86) 18

analysis of covariance (RM MANCOVA) were conducted to account for the variance explained by boredom and motivation, respectively.

A significant trial block difference was found, controlling for boredom (Wilk's Lambda = 0.39, F (115, 1565) = 2.88, $p < .001$). A follow-up univariate ANCOVA revealed significant trial block differences for subjective fatigue (F (23, 322) = 8.71, $p < .001$), and response time (F (23, 322) = 6.51, $p < .001$). No significant differences were found for response accuracy (F (23, 322) = 0.82, $p = .711$), heart rate (F (23, 322) = 1.39, $p = .111$), or skin conductance (F (23, 322) = 1.93, $p = .249$).

A significant trial block difference was also found when controlling for motivation (Wilk's Lambda = 0.52, F (115, 1565) = 1.92, $p < .001$). A follow-up univariate ANCOVA similarly revealed significant trial block differences for subjective fatigue (F (23, 322) = 4.12, $p < .001$), and response time (F (23, 322) = 4.00, $p < .001$). No significant differences were found for response accuracy (F (23, 322) = 0.95, $p = .528$), heart rate (F (23, 322) = 1.37, $p = .120$), or skin conductance (F (23, 322) = 0.76, $p = .779$).

Gaze Behavior

To compare mean fixation durations across viewings, overall mean fixation duration was calculated for trial blocks 1 –12 ($M = 0.47$, $SD = 0.19$), as well as for trial blocks 13 – 24 ($M = 0.44$, $SD = 0.15$) (see Figure 4-7). A paired-samples *t*-test was conducted to compare overall mean fixation durations between the first and second viewings of the tactical scenarios. No significant differences were found for fixation duration (t (10) = 0.95, $p = .37$). However, a significant relationship was found between subjective fatigue and the length of lost gaze data (sec) ($r = .34$, $p < .001$) (see Figure 4-8).

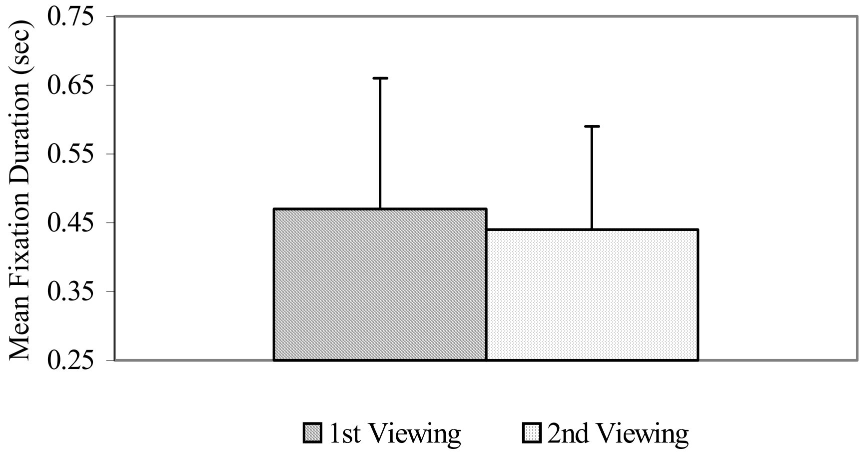

Figure 4-7. Mean fixation duration by viewing.

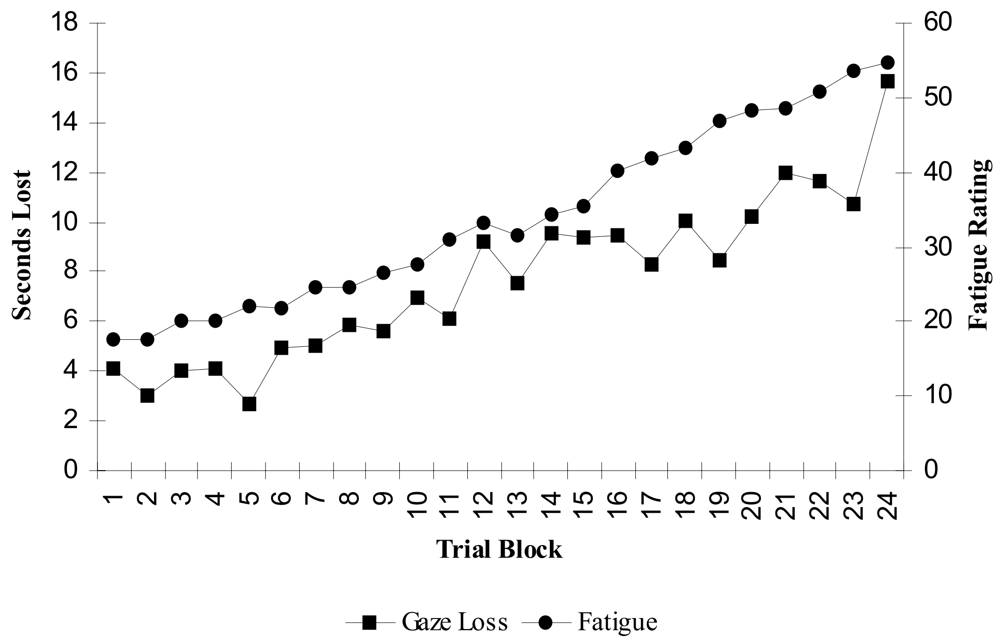

Figure 4-8. Significant relationship between fatigue and lost visual search data.

Summary of Results

The onset and influence of cognitive fatigue was assessed through self-report measures (i.e., VAS), task performance (i.e., response time, response accuracy), gaze behavior (i.e., mean fixation duration), and physiological arousal (i.e., heart rate, skin conductance). These data support the notion that time-on-task promotes the development of cognitive fatigue and fluctuations in performance, as well as arousal. However, counter to original hypotheses, subjective reports of cognitive fatigue were not associated with decreased performance, inefficient visual search patterns, or suppressed arousal. Fatigue was however, related to faster response times and elevated arousal.

CHAPTER 5
DISCUSSION

Anecdotally, cognitive fatigue has been associated with reduced energy and resources necessary to perform at one's highest potential, resulting in increased response times and obstructed decision-making capabilities (Silva & Stevens, 2002). Yet, the pervasive construct of cognitive fatigue has been insufficiently examined in sport populations. The primary purpose of this project was to empirically investigate the onset and influence of cognitive fatigue on multiple performance-relevant dimensions in the context of a simulated ice hockey decision-making task. Time-on-task was predicted to induce cognitive fatigue, a condition that would be characterized by elevated subjective perceptions of fatigue, suppressed arousal, and inefficient visual search patterns. However, the general prediction that cognitive fatigue would influence performance both directly and indirectly by promoting systematic changes in attention, arousal, and response patterns was not supported. Specific findings are discussed, strengths and limitations of the investigation are addressed, directions for future research are proposed, and applied implications of these findings are suggested.

Review of the Findings

Correlates of Subjective Ratings of Fatigue

Increased ratings of subjective fatigue were expected to be associated with decreased performance in both response accuracy and response time. Although response accuracy was not related to fatigue, response time was associated with fatigue. As participants became more fatigued, their response times decreased, a finding counter to the original hypothesis. This finding may be attributable to the participant's prior exposure to the scenarios during the earlier trial blocks (e.g., TB 1- TB 12). That is, although participants were less fatigued during earlier trial blocks, they required more time to respond to the tactical decision due to lack of familiarity with the presented situation, in contrast to when the scenarios were presented the second time (TB 13 – TB 24). Therefore, it is possible that the originally hypothesized relationship may have been obtained if the scenarios in the later trial blocks were novel, rather than repetitive. Another probable alternative explanation is that as participants became more fatigued, bored, and/or less motivated, their primary goal shifted from task performance to task completion. However, this shift was unrelated to performance accuracy, suggesting the presence of a learning effect.

Although no relationship was found between fatigue and mean fixation duration, subjective fatigue was correlated with the length of lost gaze data. This unexpected finding is particularly interesting considering that the lost visual search data may be attributed to variations in blink magnitude, closed eyes, and changes in posture, all of which can result in the inability of the eye tracking unit to accurately capture the retina and/or corneal reflex while tracking visual fixations. Such causal factors could also be indices of fatigue, both directly (e.g., napping) or indirectly (e.g., slouching in the seat), although it can only be hypothesized that they are based on the above correlational evidence.

It was hypothesized that cognitive fatigue would be associated with suppressed arousal. However, higher levels of cognitive fatigue were associated with elevated heart rate and skin conductivity. In contrast to the current study, previous research (e.g., Dureman & Bodén, 1972; Lal & Craig, 2002) that has supported the fatigue-lower arousal relationship have examined physiological changes in arousal after several hours of engagement in long-haul driving simulations. The lack of replication of earlier research here suggests that the arousal deflating effects of fatigue may not be present or recognizable until prolonged exposure to cognitive task demands has elapsed. Additionally, unlike previous studies, the current design simulated the highly physical task of playing ice hockey, rather than a more passive task of continuous driving. By viewing and vividly mentally recreating scenarios individuals are able to elicit a physiological response with a patterning similar to that evoked during actual task completion, albeit to a lesser magnitude (Mann, Mousseau, & Janelle, in review; Lang, 1979). Therefore, participants in the current investigation may have exhibited greater arousal in response to active mental engagement in the simulation of a highly arousing task, an ice hockey game. Consequently, the increased arousal evident in this investigation may be more strongly associated with the task characteristics, rather than cognitive fatigue. Future research is needed to better discern the physiological patterning of arousal associated with cognitive fatigue resulting from a sport-related task.

Influence of Time-on-Task on Dependent Measures

In general, time-on-task influenced subjective states, performance, and arousal. Most notably, time-on-task, as predicted, was successful at producing elevated levels of cognitive fatigue. However, initial predictions pertaining to the pattern of change across trial blocks for boredom, motivation, response time, response accuracy, heart rate, skin conductance, and gaze behavior were not supported.

Performance incentives and dynamic video scenarios were implemented to maximize participant involvement and motivation, while minimizing boredom (McMorris & Graydon, 1996). Despite this, boredom began to increase and motivation decrease following trial block 14 (see Tables 4-2 and 4-3). It is likely that after viewing two blocks of "repeated" scenarios (TB 13 and 14) that participants had already viewed within blocks 1 to12, they began to withdraw and disengage themselves from the task as indicated by their subjective reports. Independently controlling for boredom and motivation, MANCOVA supported this contention, revealing each variable's influence on response accuracy and skin conductance. However, fatigue and response time were not influenced by boredom or motivation.

It was further hypothesized that time-on-task would promote decreased performance, observable through increased response time and decreased response accuracy. Counter to initial hypotheses, response time *decreased* as time-on-task increased (see Table 4-4). As noted previously, this pattern may have been due to the participant's familiarity with the repeated tactical scenarios, or withdrawal from the task. Interestingly, a negative relationship between time-on-task and performance accuracy was not evident, indicating that participants did not sacrifice accuracy for speed in decision-making strategies.

Additionally, it was hypothesized that time-on-task would elicit suppressed arousal. However, heart rate did not fluctuate as a function of time-on-task. In contrast, skin conductivity was higher in later, rather than earlier trials. The discrepancy in arousal measures in reference to time-on-task, yet significant association between heart rate and skin conductance with perceptions of cognitive fatigue, suggests that further empirical investigation is warranted to determine the degree and direction of the triangular relationship between arousal, task engagement duration, and subjective fatigue.

Due to the excessive loss of visual fixation data, an incomplete assessment of visual search efficiency was not possible, however, a partial analysis of visual fixation duration was completed. In the paired-sample comparison of the mean fixation durations for viewings one (TB 1 –12) and two (TB 13 –24), it is evident that the mean fixation duration decreased as time-on-task increased, however the difference of .02 seconds was not significant, possibly due to the small sample with useable data ($N = 11$). However, in accord with the original hypotheses, trends suggest that as the period of cognitive task engagement lengthens and fatigue develops, visual search patterns become more inefficient, requiring more total fixations to be made to extract relevant information, thereby not maximizing the utility of the display (Williams, 2000). These trends require further empirical investigation.

Strengths, Limitations, and Directions for Future Research

The current investigation adopted an explicit and definitive operational definition of cognitive fatigue, examined the construct from multiple perspectives (i.e., subjectively, behaviorally, and physiologically), and extended the research to sport applications. An additional strength of this study's design is that the continued cognitive involvement of players in the actual competitive scenario was accounted for with the creation of a 60-minute tactical cognitive task. Although it can be argued that sport specific elements of ice hockey such as, line changes and period breaks, could moderate the effects of fatigue, it is important to return to Job and Dalziel's (2001) definition of fatigue which emphasizes *insufficient* rest in the development and persistence of fatigue. Therefore, the question becomes, can such minimal, in-game breaks be considered sufficient to heed the development of fatigue? During such breaks players are given physical rest, yet they are required to "keep their heads in the game" in preparation for their next shift or the next period. In sum, by maximizing the similarities between the actual and laboratory tasks the current investigation was able to assess for the development and onset of cognitive fatigue with temporal sensitivity.

Despite attempts to maximize ecological validity, the attempt to provide control when comparing visual search patterns between the first twelve trial blocks and the last twelve, resulted in the same scenarios being presented in both conditions. Although performance feedback was not provided to the players, the repeated scenarios may have prompted the development of boredom, as well as reduced response time as a result of the players' familiarity with the content. Therefore, it is recommended that future researchers, when implementing similar protocol, use distinct and novel scenarios throughout the task, while controlling for content. As such, more accurate comparisons of performance over time may be made while controlling for extraneous variables, namely boredom.

Similarly, much of the fatigue research has generally failed to account for related psychological phenomena, namely boredom and motivation. Such factors were specifically assessed here, revealing the relatedness of such variables to fatigue, as well as their influence on performance related constructs (e.g., response accuracy, skin conductance).

As with most phenomena, fatigue does not occur in isolation, but maintains a reciprocal relationship with a variety of other factors. Therefore, it would be beneficial to empirically examine a host of other mood, personality/individual differences, experience/expertise, and competition-related variables.

For example, future studies should consider the moderating influence of various mood states on the perception and influence of cognitive fatigue. It is assumed that mood can affect both the speed, as well as the efficiency of information processing, and thereby influence performance (Matthews, 1992). Specifically, mood has been associated with competitive sport performance; positive moods (e.g., happy, energetic, and enthusiastic) were correlated with better performance (Totterdell, 1999). Additionally, pre-competition mood states have been suggested to influence appraisals of an ensuing performance (Mellalieu, 2003). For example, negative mood states may prompt greater attention to be directed to developing fatigue symptoms than a positive mood state, since negative mood states tend to signal that a situation is atypical/challenging and requires additional energy and effort in order to be resolved (Schwarz, 2000). Therefore, more in-depth pre and posttest assessment of mood states (e.g., POMS; McNair, Lorr, & Droppleman, 1992; PANAS; Watson, Clarke, & Tellegen, 1988), as well as continued in-task assessment of mood, may be able to provide a more detailed indication of the potential intervening role of various mood states (both positive and negative; Mellalieu, 2003) in the development, perception, and influence of cognitive fatigue in sport.

Additionally, potentially significant individual differences, such as self-esteem, have been shown to have performance implications (e.g., Di Paula & Campbell, 2002) and may further moderate cognitive fatigue. Specifically, high self-esteem, the belief that one is capable and successful, is often associated with attempts to bring about success and confirm one’s sense of self-value (Sommer & Baumeister, 2002). In contrast, low self-esteem is correlated with low levels of confidence in one's skills, abilities, and overall worth. Moreover, individuals with low self-esteem generally have lower expectations for their own performance and success. Di Paula and Campbell (2002) found that when faced with potential failure, individuals high in self-esteem were more persistent at overcoming the adversity than those low in self-esteem. Specifically, high self-esteem was associated with greater motivation to work harder when the potential reward/level of success is significant because individuals with high self-esteem are "motivated to achieve success', rather than "avoid failure," as is typical of individuals with low self-esteem. Therefore, the recognition and influence of fatigue, as well as persistence in a fatigue state, may be moderated by an individual's level of self-esteem.

The amount of experience or level of expertise achieved by an athlete may also influence the effects of cognitive fatigue. When addressing the development of expertise, Ericsson, Krampe, and Tesch-Römer (1993) emphasize the significance of rest between deliberate practice sessions, yet they underscore the need for participants to exert maximum effort during practice. However, such high levels of exertion can only be maintained for a limited duration. Additionally, if sufficient rest does not follow such intense, deliberate practice, Ericsson and colleagues (1993) suggest that exhaustion and prolonged cognitive fatigue will result. In spite of this, experience and continued practice can prompt adaptation and quicker recovery. Therefore, future research should consider the level of expertise/experience (i.e., degree of adaptation) as a moderating factor in the onset, development, and influence of cognitive fatigue in sport.

Furthermore, future investigations should explore how various competition-related variables may influence the development of fatigue. For example, the addition of magnified performance pressures (e.g., tied or championship games) increase the number of stressors that must be dealt with, reducing the amount of energy and resources available for task completion and the management of fatigue (Henschen, 2000). Additionally, performance-relevant factors of feedback and reinforcement can influence an athlete's level of enjoyment, mood, and perceptions of control, and therefore may have a moderating influence on fatigue (Henschen, 2000). Consequently, future research should explore how fatigue develops in the presence of other performance-relevant stressors through the variation of task constraints and performance feedback (e.g., time pressures, reinforcement).

Preliminary evidence suggests that there may be interactive effects between physical and cognitive fatigue, with physical fatigue moderated by psychological states, namely cognitive fatigue (Holding, 1983). Therefore, following the development of a better understanding of the construct of cognitive fatigue in isolation, the next step would be to examine the interactive effects of cognitive and physical fatigue. By constructing three experimental groups, namely, (1) cognitive fatigue only, (2) physical fatigue only, and (3) the combination of cognitive and physical fatigue, the independent and interactive effects of fatigue could be delineated.

A similar design may also be applied to better understanding the influence of practicing in blocks within a training session to reduce the development of fatigue (both physical and mental). By isolating mental practice (e.g., observational learning, mental imagery, reviewing of film), the overall cognitive demands are reduced, allowing the athlete to engage in more effective training, than physical practice alone, which requires resources to be divided among both cognitive and physical tasks simultaneously (Wulf &

Shea, 2002). Additionally, the intervals between blocks, as well as the alternation of demands, may provide sufficient rest and recovery, minimizing fatigue. Therefore, future investigations should explore the effectiveness of alternating between physical and mental practice to reduce the development of fatigue, as well as monotony, a promoter of fatigue (Wulf & Shea, 2002; Henschen, 2000).

Applied Implications

Although the current investigation's findings are preliminary, the potential practical implications of these, as well as the results of future investigations, are promising. Specifically, in the current investigation performance (i.e., response accuracy) was not influenced by cognitive fatigue or time-on-task yet, fluctuations in arousal were evident. Such changes suggest that participants were working harder and less efficiently (i.e., increased arousal) later in the session, a pattern that cannot be maintained without eventual consequence (Henschen, 2000). Therefore, by understanding the effects of cognitive fatigue, athletes may become better equipped to maximize their performance potentials through modifications in training, and an increased ability to manage cognitive fatigue.

Through greater understanding of the construct of cognitive fatigue, it may be possible to reorganize training and practice regimens, as well as coaching philosophies. In the most basic sense, coaches and athletes can become more aware of how players are affected by the cognitive demands associated with practice and competition. Specific consideration may be given to how intermissions should be handled, as well as attention directed to preparations both the night prior to competition, as well as immediately preceding performance, to ensure that each player has had a period of sufficient rest necessary to eliminate any resonating cognitive fatigue (Macchi et al., 2002).

Additionally, by providing sufficient rest during practice, competitions, and the off-season it may be possible to avoid athlete burnout, which often results from excessive physical and mental training demands (Henschen, 2000). Understanding the effects of cognitive fatigue on performance can open the doors for related training practices and learning how to cope when confronted with a fatigued state.

By manipulating or inducing organismic constraints (e.g., fatigue) during practice sessions, players may learn to become more attentive to fatigue symptoms and be taught to successfully inhibit the development and/or influence of fatigue. Specifically, training programs may include biofeedback techniques to increase awareness of the physiological changes associated with cognitive fatigue. That is, through practice and awareness training, athletes become capable of adapting to fatiguing conditions (Ericsson et al., 1993).

Additionally, practice sessions could alternate between physical and mental training. Wulf and Shea (2002) recommend division of skills into physical practice and observational learning sessions to reduce the amount of cognitive resources used. In turn, training session can be prolonged, while further increasing the effectiveness and efficiency of practice.

The maintenance of appropriate attention is not only important for task performance (Nideffer, 1993), but also for athlete safety. Specifically, reduced peripheral attention or misdirected attention, attentional biases commonly associated with stressors (e.g., fatigue), have been suggested to reduce an athlete's ability to respond maximally to potentially threatening or dangerous stimuli (Williams, Tonyman, & Andersen, 1991; Wegner, 1994). Therefore, an indirect benefit of coping with and early identification of fatigue may be injury reduction. By effectively coping with or avoiding the development of fatigue, athletes will be less susceptible to distraction, and thereby able to maintain appropriate focus and awareness, potentially reducing the likelihood of incurring an injury as the result of misdirected or reduced peripheral attention.

Again, it is important to emphasize that the findings of this study are preliminary, yet they open the door for numerous future investigations and hold promise for performance enhancement applications.

Conclusion

Cognitive fatigue is a concern within virtually any performance domain; however, minimal research has examined the construct within a sport context. Specifically, prior to the current investigation, there has been no evidence to indicate how prolonged decision-making and resulting cognitive fatigue may be manifested physiologically, subjectively, or behaviorally in athletes. Therefore, the present study assessed changes in athletes' performance, subjective reports of performance states, and physiology in relation to time-on-task within a simulated, dynamic, ice hockey scenario, using a multi-method approach. Results indicated that a sport simulation and cognitive tactical task were sufficient in promoting the development of cognitive fatigue. Though the findings counter the original hypotheses, illustrating increased arousal and decreased response time under prolonged task-exposure, it is suggested that cognitive fatigue is distinctly manifested physiologically, subjectively, and behaviorally in athletes. In sum, although continued research is necessary to further advance the current understanding of the onset and influence of cognitive fatigue in sport, the current investigation was successful in revealing preliminary evidence concerning the relationship among subjective perceptions of cognitive fatigue, time-on-task, performance, attention, and arousal.

APPENDIX A
DEMOGRAPHIC QUESTIONNAIRE

Δατε:______________________ Παρτιχιπαντ Ιδ#________________________

ΔΕΜΟΓΡΑΠΗΙΧ ΘΥΕΣΤΙΟΝΝΑΙΡΕ

---

1. ΠΕΡΣΟΝΑΛ

Ναμε: ____ Αγε: _________ Μαφορ: ____________________________

Ε μαιλ αδδρεσσ: _______________________________ Πηονε νυμβερ: _________________________________

Εψε Χολορ: _________________ Δο ψου ωεαρ χορρεχτιϖε λενσεσ (γλασσεσ ορ χονταχτσ)? _________________

Αρε ψου χυρρεντλψ τακινγ ανψ μεδιχατιον (οϖερ τηε χουντερ ορ πρεσχριπτιον)? ____________

Ιφ ΨΕΣ, δοεσ τηε μεδιχατιον ηαϖε α δροωσψ σιδε εφφεχτ? ____________

2. ΙΧΕ ΗΟΧΚΕΨ ΒΑΧΚΓΡΟΥΝΔ

Πριμαρψ Ποσιτιον: ______________________________ Σεχονδαρψ Ποσιτιον: _____________________________

Ηιγηεστ Λεϖελ οφ Χομπετιτιον (ε.γ., χολλεγιατε): _________________________

α) Τοταλ # ψεαρσ πλαψινγ: ____________ β) Λαστ ιχε ηοχκεψ γαμε χομπετεδ ιν (Μοντη & Ψεαρ): _____

χ) Αϖεραγε # οφ ηουρσ πραχτιχεδ ωεεκλψ δυρινγ ψουρ λαστ σεασον οφ πλαψ: ___________

δ) Αϖεραγε # οφ χομπετιτιονσ περ ωεεκ δυρινγ ψουρ λαστ σεασον οφ πλαψ: _____________

ε) Αϖεραγε # οφ σηιφτσ περ περιοδ δυρινγ ψουρ λαστ σεασον οφ πλαψ: _____________

φ) Αϖεραγε σηιφτ λενγτη δυρινγ ψουρ λαστ σεασον οφ πλαψ: ______________

γ) Ηαϖε ψου ρεχειϖεδ ανψ αωαρδσ ορ ωον ανψ χηαμπιονσηιπσ?

____

Ιφ ψεσ, πλεασε λιστ τηε 3 μοστ ρεχεντ (ινχλυδινγ τηε σεασον & λεϖελ οφ πλαψ):

1. ____ ________

2. ____ ________

3. ____ ________

3. ΜΙΣΧΕΛΛΑΝΕΟΥΣ

α) Ον αϖεραγε, ηοω μανψ ηουρσ οφ σλεεπ δο ψου γετ εαχη νιγητ?

____

β) Αππροξιματελψ ηοω μανψ ηουρσ οφ σλεεπ διδ ψου ηαϖε λαστ νιγητ?

____

χ) Αππροξιματελψ ηοω μανψ ηουρσ οφ σλεεπ δο ψου γετ τηε νιγητ πριορ το α χομπετιτιον? ________

δ) Ωουλδ ψου χονσιδερ ψουρσελφ α μορνινγ περσον ΟΡ α νιγητ οωλ ?

____

ε) Ηαϖε ψου χονσυμεδ χαφφεινε (ι.ε., σοδα, χοφφεε, τεα, χηοχολατε) ιν τηε λαστ 4 ηουρσ? ____________

f) Ηαϖε ψου χονσυμεδ ανψ αλχοηολ ιν τηε λαστ 24 ηουρσ? ____________________

g) Ωηεν ωασ τηε λαστ τιμε τηατ ψου ατε α μεαλ? ____________________

h) Ηοω μανψ ηουρσ περ ωεεκ, ον αϖεραγε, δο ψου πλαψ ϖιδεο γαμεσ?

____

i) Please rate your overall video game playing ability:

1 2 3 4 5

Poor Average Expert

j) Please rate your familiarity with ice hockey video games:

1 2 3 4 5

Never Played Some Experience Extremely Familiar

APPENDIX B
INFORMED CONSENT DOCUMENT

Informed Consent

Protocol Title: The onset and effect of cognitive fatigue on simulated sport performance.

You are being asked to participate in a research study. Before you give your consent to volunteer, it is important that you read the following information and ask as many questions as necessary to be sure you understand what you will be asked to do.

Investigators:
Melanie Mousseau, B.S.
University of Florida
Department of Exercise and Sport Sciences

Christopher Janelle, Ph.D.
University of Florida
Department of Exercise and Sport Sciences

Purpose of the research study: To determine the effects of mental fatigue on sport performance.

What you will be asked to do in the study: You will be asked by the Primary Investigator listed above to:

- Meet in the Motor Behavior and Human Performance Laboratory at the University of Florida located in the Florida Gym room 132 at a predetermined time.
- Read and complete this document, stating that you understand what will be required of you as a participant in this study and are willing to participate.
- Complete a brief questionnaire regarding how you feel.
- Complete a demographic questionnaire. You have the right to withhold any information that you do not wish to share.
- Learn how to interact with the simulation task. Sit in front of a screen and wear a headband that communicates with the eye tracking system.
- View a series of hockey scenarios, answer multiple-choice questions pertaining to the scenarios, and rate how you feel during the task.

Time required: 90 minutes maximum.

Risks and Discomforts: There are no anticipated risks or discomforts associated with your participation.

Benefits: Potential benefits include a better understanding of your mental fatigue thresholds and what you can do recognize and counteract the potential negative performance effects of fatigue. Additionally, you will gain insight into how you make decisions during a game.

Compensation: You will not be compensated for your participation; participation is strictly voluntary.

Confidentiality: Your identity will be kept confidential to the extent provided by law; any information obtained through this testing that can be identified with you will remain confidential.

Voluntary Nature of Participation: Your participation in this study is completely voluntary. Your choice of whether or not to participate will not influence your future relations with the University of Florida. If you decide to participate, you are free to withdraw your consent and to stop your participation at any time without penalty or loss of benefits to which you are entitled.

Questions about the Study: If you have any questions about the study or results, please ask or contact:
MELANIE MOUSEAU, BS, Graduate Assistant - Sport and Fitness Program, Department of Exercise and Sport Sciences, Florida Gym Room 121, 392-0580 x1369, mousseau@ufl.edu

OR
CHRISTOPHER M. JANELLE, Ph.D.; Director - Performance Psychology Laboratory, College of Health and Human Performance, Florida Gym Room 132E, 392-9575 x1270, cjanelle@hhp.ufl.edu

Whom to Contact about your Rights as a Research Participant:
UFIRB Office, Box 112250, University of Florida, Gainesville, FL 32611-2250; phone 392-0433

Signatures:
As a representative of this study, I have explained the purpose, the procedures, the benefits, and the risks that are involved in this research study.

Primary Investigator:________________________________ Date:____________________

I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant:____ Date:_________________

APPENDIX C
INSTITUTIONAL REVIEW BOARD APPLICATION

1. TITLE OF PROTOCOL: The onset and effect of cognitive fatigue on simulated sport performance.

2. PRINCIPAL INVESTIGATOR(s):
MELANIE MOUSEAU, BS, Graduate Assistant - Sport and Fitness Program, Department of Exercise and Sport Sciences, Florida Gym Room 121, 392-0580 x1369, mousseau@ufl.edu

3. SUPERVISOR (IF PI IS STUDENT):
CHRISTOPHER M. JANELLE, Ph.D.; Director - Performance Psychology Laboratory, College of Health and Human Performance, Florida Gym Room 132E, 392-9575 x1270, cjanelle@hhp.ufl.edu

4. DATES OF PROPOSED PROTOCOL:
From: January 2003 To: July 2003

5. SOURCE OF FUNDING FOR THE PROTOCOL: None

6. SCIENTIFIC PURPOSE OF THE INVESTIGATION: To determine the effects of cognitive fatigue on sport performance as indicated by response time and accuracy.

7. DESCRIBE THE RESEARCH METHODOLOGY IN NON-TECHNICAL LANGUAGE. Consent from participants will be obtained prior to inclusion. An initial assessment of fatigue, boredom, and motivation will be taken using a self-report visual analog scale (VAS) representation of the constructs of interest. Participants will then complete a demographic questionnaire. Following completion of the demographic questionnaire, participants will be introduced to the task and given a period of time to acquire familiarity with the testing process and demands of the task. Specifically, participants will be seated in front of a large projection screen on which simulated ice hockey scenarios will be presented. These scenarios will be brief with a duration ranging from 10 to 30 seconds. At the completion of each scenario, a short question related to the scenario will appear on the screen, along with response options (e.g., The right winger should … A) Pass Left B) Skate with the puck C) Pass Right D) Pass Center). During this skill acquisition period, participants will also become familiar with the computerized VAS used to assess fatigue, boredom, and motivation during the task. Once the participant has become familiar with the testing procedure. An eye tracking system will be calibrated to record their eye movements and the actual testing session will begin. The testing session will not exceed 60 minutes and will included 15 Trial Blocks consisting of one VAS assessment of fatigue, boredom, and motivation and five ice hockey scenarios with follow-up questions. At the completion of the testing session participants will be debriefed and any questions will be answered.

8. POTENTIAL BENEFITS AND ANTICIPATED RISK. There are no anticipated risks associated with participation in this study. Potential benefits include a better understanding of individual fatigue thresholds and what should be done to counteract the potential negative performance effects of fatigue. Additionally, participants will have the opportunity to gain insight on their sport-specific decision making capabilities and related visual search patterns.

9. DESCRIBE HOW PARTICIPANT(S) WILL BE RECRUITED, THE NUMBER AND AGE OF THE PARTICIPANTS, AND PROPOSED COMPENSATION (if any): A maximum of 30 participants will be recruited from the University of Florida men's ice hockey team after contact with the coaching staff, as well as from Sport and Fitness classes within the Department of Exercise and Sport Sciences. Participants will range in age from 18 to 35 years. Participation is voluntary and participants will not be compensated unless enrolled in a participating Sport and Fitness course. If extra credit is offered by the instructor for participation, compensation will not exceed 2% of the student's final grade in the course.

10. DESCRIBE THE INFORMED CONSENT PROCESS. INCLUDE A COPY OF THE INFORMED CONSENT DOCUMENT (if applicable).
Please see attached.

____
Principal Investigator's Signature

____
Supervisor's Signature

I approve this protocol for submission to the UFIRB:

____

Dept. Chair/Center Director Date

APPENDIX D
TACTICAL QUESTIONS AND CORRECT RESPONSES

The puck carrier should:	Skate the puck out of the zone	Ice the puck	*Pass the puck to the left winger*	Fall and try to draw a penalty
What is your job if you are the blue right winger?	*Take the red left winger*	Take the red centerman	Take the red right winger	Take the puck
Shoot:	*High glove side*	Low glove side	High blocker side	Low blocker side
What was the read on the play?	*2-on-2*	1-on-2	2-on-3	1-on-3
If you were the centerman with the puck, you should have:	Taken a slap shot	Deeked	Passed right	*Taken a one-time shot*
As the white defenseman who just lost the puck, you should have:	Taken the puck to the corner and froze it	Avoided the earlier hit	Covered the net	*Taken the puck behind the net for protection*
After winning the face-off, you are the white defenseman in possession of the puck. You should:	Skate backwards until pressured	*Make a D-to-D pass*	Shoot the puck up the boards	Make a direct pass to the right winger
You are the white defenseman, your job is to:	*Close the gap on the puck carrier*	Continue to play the 2-on-1	Back in	Take the loose man

You are the blue defenseman and have good center support, your best decision is to:	Force the puck carrier up ice	Cross-check the puck carrier	*Hit and pin the puck carrier*	Switch off with the centerman
As the puck carrier, you should:	*Shoot*	Take the puck behind the net	Pass	Wait for a better option
The most dangerous offensive man on the ice is:	The puck carrier as he comes out of the corner	The right defenseman entering the zone	*The loose man in front of the net*	All are equally important
As the blue defenseman on the player with the puck, your job is to:	*Take the body*	Take the puck	Skate with him and press	Get in front of him
The correct decision for the white defenseman is:	2-on-1	1-on-1 with a backchecker	*To block the shot*	Get out of the way
As the goalie, you should:	Hug the post	Poke-check	Wait for the defenseman to take the body	*Anticipate the pass*
Based on the goalie's positioning, you should shoot:	High glove side	High blocker side	Low blocker side	*Low glove side*
You are the white centerman and have won the draw, you should:	*Tie-up the blue centerman*	Support the puck	Skate to the right winger side	Skate straight up ice
If you were #10 on offense, what should you do?	Shoot	*Deeke*	Back pass	Dump the puck deep
You are the blue player in the slot, your best option is to:	Pass the puck back to the winger	Receive the pass and attack the goalie	*Take a one-time shot*	Set-up in the corner

What should the middle defenseman do?	*Stay in the middle and wait for more support*	Take the right winger	Take the centerman	Support the other defenseman on puck side
The puck carrier should:	Skate the puck out of the zone	Dump the puck to clear the zone	Circle back into his zone	*Pass to his left winger*
As the blue attacker, you should:	Try to deeke the defender closest to you	Skate straight down the boards	*Dump the puck deep*	Shoot on goal
The blue defenseman should have:	Continued to back in	*Redirected the backchecker that is off the puck to the closet offensive player and play the puck carrier*	Redirected the backchecker and continued to back in	Switched off with the blue backchecker
The white defender should:	Chase directly behind the offensive attacker	*Skate a direct line back to the near post*	Dive	Look for a secondary attacker
It is a 2-on-2, the defenseman should:	*Play it as 2 separate 1-on-1's*	Continue to back in	Step-up immediately, taking the body	Step-up and force the puck carrier into the corner
Based on the position of the white backcheckers, the white defenseman should:	Hold his position	*Eliminate a passing lane and force the puck carrier wide*	Immediately challenge the puck carrier	Take the loose man
As the blue defenseman, you should:	*Hip check*	Turn and contain	Block the shot	Play a 2-on-1
The white team on offense is playing a 2-1-2 system. # 7 should:	Pressure the puck carrier immediately	*Wait for his teammate in front of the net to check-off the attacker*	Stay where he is	Pull out of the zone

The most dangerous player on the ice is:	The current puck carrier	A late attacker coming into the zone	*The white forward beside the net*	The blue defenseman
You have just received puck high in the slot, you should:	Take a one-time shot	*Pass to the winger driving the net*	Deeke the defenseman defending you	Skate the puck wide
The white defenseman should:	*Step-up and take the body*	Stay in the middle, it is a 2-on-1	Force the player well before the blue line	Hit the backchecker
After beating the first defenseman, the white puck carrier should:	Skate to the corner and set-up	Deeke the next defenseman	*Shoot*	Drop pass
A race for the loose puck ensued, the blue skater should have:	*Taken the body at contact*	Dove after the puck	Hooked the white skater after being beat	Poke-check the white forward
You are the offensive man away from the puck, you should:	Pick the defenseman	Slow down to create a gap	*Put your stick on the ice and drive the net for a pass*	Shoot
You are the blue forward with the puck, you determine that:	You have a break away	It's a 1-on-1	*It's a 1-on-2*	It's a 3-on-3
You just received the puck from the goalie, you:	Skate with the puck as long as you can	*Initiate a quick transition*	Turn and take the puck deep behind your net	Pass it to the winger furthest up the ice
The white forward without the puck should:	*Drive the net*	Pick the defenseman	Skate wide for a pass	Crisscross with the puck carrier
You are the shooter, your best shooting option would be:	High glove side	*Low stick side*	High blocker side	Low glove side
As the blue puck carrier you want to:	*Continue to attack the zone with speed*	Pass the puck across the blue line	Buy time for your teammates to catch up	Cut across the blue line

You are the white defenseman turned backward to play a 1-on-1, which of the following is your best choice?	*Close the gap and force the attacker wide*	Play the 2-on-1	Stop and step-up to hit the attacker	Skate to the near post
As the puck carrier, you should:	Setup in the corner	*Pass to the man in the slot*	Shoot	Drive the net
You are on the breakaway, what will you do?	*Shoot blocker side*	Shoot glove side	Shoot 5-hole	Deeke to your backhand
As the white offensive player approaching the blue line, you read:	2-on-1	1-on-1	*2-on-3*	2-on-2
Where should you shoot?	Low glove side	*High glove side*	Low blocker side	High blocker side
As the white forward, your best option is to:	*Drive the net on your forehand*	Go to your backhand	Shoot	Take the puck behind the net
As the puck carrier, in your current position you should:	Drive the net	Turn up ice and cycle the puck	*Setup behind the net*	Shoot
With the defenseman in pursuit of the puck carrier, at mid-ice the puck carrier should:	Try to deeke the defenseman	*Dump the puck deep to avoid a turnover*	Shoot on net	Drop pass to supporting winger
The white defenseman should attempt:	To contain	*An impact hit*	To take the puck	To play the pass
As the blue defenseman closest to the puck carrier, you determine the best play is to:	Give up the blue line	*Step-up and take the white attacker*	Allow your partner to take the puck carrier and you take the loose man	Wait for help

You are the attacking forward, you should:	Look for a passing option	Skate around the defenseman who has his back to you	*Shoot*	Make a drop pass
As the white defenseman, you are looking for:	Containment	*An impact hit*	A pass	Help from the backchecker
The correct read for the blue defenseman is:	1-on-1	2-on-1	3-on-2	*3-on-3 with a backchecker*
As the puck carrier you should:	*Continue to take the shot*	Take the open ice and then shoot	Pass across the ice	Pass to the forward standing in front of the net
As the shooter, your target is:	High glove side	5-hole	Low glove side	*Stick side*
It is a 3-on-3, the most dangerous player on the ice is:	The puck carrier	The left winger	*The centerman*	The right defenseman entering the zone
You have just skated around the white defenseman, you now decide to:	Take the puck deep into the corner	*Drive the net*	Look for a pass option	Shoot
You are the puck carrier, you should:	Drop pass	*Shoot far side*	Shoot backhand	Setup in the corner
The defenseman, #77, should:	*Notice that he has a backchecker and force the puck carrier*	Continue to back in	Let the goalie play the shooter	Read a 5-on-5
You are the white defenseman playing a 1-on-1, you:	*Read support, so step-up on the attacker*	Try to take the puck off the attacker	Turn and skate back to the post	Take the body by stopping and lunging at the attacker

The third blue backchecker to enter the zone is responsible for:	Supporting the defenseman	*Picking up the white offensive player in the slot*	Chasing the puck carrier into the slot	Eliminating a passing lane to the white defenseman entering the zone
The white team made two glaring mistakes. They were:	They did not finish their check	They stopped moving their feet	*Both A and B*	Neither A nor B

APPENDIX E
PARTICIPANT INSTRUCTIONS

Thank you for coming today to participant in this study, which will be looking at how fatigue develops in ice hockey players through the use of simulated on ice scenarios. Specifically during the session you will be answering questions related to your ice hockey background as well as your experiences in the session. Additionally, you will be viewing various ice hockey scenarios that will be followed by tactical decisions related to the previously viewed video clip. Both how you perform, as well as how quickly you respond will be calculated and you will be notified after the session to determine how you performed in comparison to other ice hockey players. Therefore, both your speed and accuracy in decision-making is important to your overall performance.

Prior to beginning the session I will be fitting you with several non-invasive sensors that will be measuring some of your physiological responses (i.e., heart rate) during the task. I will also be placing a cotton headband on you, which helps me to track where your head is. Do you have any questions up to this point? Before we get started, please read through this form that reviews what will be happening today. Please feel free to ask me any questions that you may have.

The next form, as mentioned in the review, that I would like for you to complete tells me a little more about you and your ice hockey background. Please answer the questions as best as possible. Please let me know if I can clarify anything for you.

Ok, now I will be applying the sensors I mentioned earlier. First, I am going to clean the skin on the forearm with some rubbing alcohol. Next, I am going to place these three stickers on your forearms, two on your non-dominant arm, and one on your dominant. Now I am going to clean the palm of your non-dominant hand with some cleaning scrub and water and place these two sensors on the inside edge of your palm. Does everything feel comfortable? We will now move closer to the projection screen to set-up the system that will be monitoring your eye movements.

Does everything still feel comfortable? Ok, we now move onto to a practice session.

Periodically you will be presented with the screen seen here depicting three horizontal bars/lines, each anchored by two polar adjectives. When this screen appears use the mouse in your dominant hand to click and place a “mark” on each of the bars/lines. Please place the mark on the portion of the bar which most accurately reflects how your feel *at that moment*. When you see the words “no tiredness at all” and “complete exhaustion,” think of how mentally worn-out or fresh/activated you feel. Because you are not doing anything physical, please concentrate on how you feel mentally, focusing on the sensations you would experience after studying or reading, rather than running or working out. Do you understand how to report how you are feeling with this scale and what you are attending to? Another pair of words that you will see is “very interested” and “very bored.” Once again please use the mouse to mark where you feel you are in respect to boredom and the competition. Specifically, if you feel completely engaged and interested in the task you would place you mark on the left side of the bar. Yet if you feel completely bored and you find your mind wandering you would place your mark on the right side. And if you are neither bored nor very interested you would place the mark in the center region of the bar. Do you understand how to report how you are feeling with this scale and what you are attending to? The third pair of words that you will see are “highly motivated” and “not motivated at all.” When this scale appears think of how concerned and invested you are in your overall performance. If you want to perform well and are exerting as much effort as possible, you would place the mark on the left hand side of the bar. Yet, if you are only going through the motions in order to end the session, and are not concerned with your performance or if you win or lose, you would place the mark on the far right of the bar. However, if you are trying to perform well, but not necessarily giving it your all, you would place the mark in the center region. Do you understand how to report how you are feeling with this scale and what you are attending to?

If at any point you accidentally misplace the mark on the line you will be able to reposition your mark simply by clicking on another portion of the bar prior to submitting your response. Here is the mouse, practice placing a mark on the line on the area that corresponds to how you fell *now*.

Do you have any questions up to this point? Remember that when these scales appear to think of how you are feeling at that moment with respect to the competition and respond as honestly and accurately as possible.

We will now move onto practice the primary task. What you will be seeing is a sample hockey scenario followed by four response selections. Your objective is to select *the most appropriate* response as quickly and accurately as possible. You will only be allowed to submit one answer, but your response selection can be changed an unlimited number of times before you click the continue button. But keep in mind that you will have a maximum of one minute to submit a final response. Please now use the mouse to select an answer, but before submitting that response change your answer and select an alternative response. If you feel comfortable with this select the continue button.

At the end of the experimental session after you submit your final responses to the scales you will see a prompt to call me back into the testing room. Before we move on, do you have any questions? The practice session has now ended and you will now begin the competition session.

APPENDIX F
VISUAL ANALOG SCALE (VAS)

Very Interested		Very Bored
No tiredness at All		Complete Exhaustion
Highly Motivated		Not Motivated at All

APPENDIX G
DEBRIEFING SCRIPT

Thank you again for your participation. I will now remove the sensors from your hand and ask that you remove the three on your forearms. Now that you have completed the task, I will explain to you what the purpose of your participation was.

This task was designed to examine how mental fatigue develops on multiple levels in athletes, namely ice hockey players. During the course of the task your heart rate, skin conductance (i.e., how sweaty your hands were), and your eye movements were monitored to help gain an understanding of what happens when athletes become mentally worn out. Additionally, how well and how quickly you performed was recorded, although unfortunately I do not have rewards to give to the top performers, I apologize, but hope that you enjoyed your experience.

If you are interested in receiving information about your own performance, please provide me with your e-mail address, and I will send your personal results and general study finding at the conclusion of the study. Do you have any questions?

Once again, thank you for participating and I do ask that you do not discuss the study with any potential participants/teammates. Thanks and have a good day.

LIST OF REFERENCES

Abernethy, B. (2001). Attention. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of sport psychology* (2nd ed.) (pp. 53-85). New York: John Wiley & Sons, Inc.

Barcikowski, R., & Robey, R. R. (1985). Decisions in single group repeated measures analysis: Statistical tests and three computer packages. *The American Statistician, 38,* 248-250.

Bartlett, F.C. (1943). Fatigue following highly skilled work. *Proceedings of the Royal Society, Series B, 131,* 247-257.

Bartley, S. H., & Chute, E. (1947). *Fatigue and impairment in man.* New York: McGraw-Hill.

Bompa, T.O. (1999). *Periodization: Theory and methodology of training* (4th ed.). Champaign, IL: Human Kinetics.

Bompa, T.O. (2000). *Total training for young champions: Proven conditioning programs for athletes ages 6 to 18.* Champaign, IL: Human Kinetics.

Broadbent, D.E. (1958). *Perception and communication.* London: Pergamon.

Brown, I. D. (1994). Driver fatigue. *Human Factors, 36,* 298-314.

Brunier, G., & Graydon, J. (1996). A comparison of two methods of measuring fatigue in patients on chronic haemodialysis: Visual analogue vs. Likert scale. *International Journal of Nursing Studies, 33(3),* 338-348.

Campbell, D.T., & Stanley, J.C. (1969). *Experimental and quasi-experimental designs for research.* Chicago, IL: Rand McNally & Company.

Cherry, C. (1953). Some experiments on the recognition of speech with one and with two ears. *Journal of Acoustical Society of America, 25,* 975-979.

Cox, R.H. (1994). *Sport psychology: Concepts and applications.* Madison, WI: Brown & Benchmark.

Craig, A., & Cooper, R. E. (1992). Symptoms of acute and chronic fatigue. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance: Vol. 3. State and trait* (pp. 289-339). London: Academic Press.

Davey, C.P. (1973). Physical exertion and mental performance. *Ergonomics, 16 (5),* 595-599.

Davey, P.R., Thorpe, R.D., & Williams, C. (2002). Fatigue decreases skilled tennis performance. *Journal of Sport Sciences, 20,* 311-318.

Davies, D.R., Shackleton, V.J., & Parasuraman, R. (1983). Monotony and Boredom. In G.R.J. Hockey (Ed.), *Stress and fatigue in human performance* (pp. 1-32). New York: Wiley.

Desmond, P. A., & Hancock, P. A. (2001). Active and passive fatigue states. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload, and fatigue* (pp. 455-465). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Desmond, P. A., & Matthews, G. (1997). Implications of task-induced fatigue effects for in-vehicle countermeasures to driver fatigue. *Accident Analysis and Prevention, 29,* 515-523.

Di Paula, A., & Campbell, J.D. (2002). Self-esteem and persistence in the face of failure. *Journal of Personality and Social Psychology, 83,* 711-724.

Duchowski, A.T. (2002). *Eye tracking methodology: Theory and practice.* London: Springer.

Dureman, E.I., & Bodén, C. (1972). Fatigue in simulated car driving. *Ergonomics, 15,* 299-308.

Ericsson, K.A., Krampe, R.T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100 (3),* 363-406.

Fairclough, S.H. (2001). Mental effort regulation and the functional impairment of the driver. In P.A. Hancock & P.A. Desmond (Eds.), *Stress, workload, and fatigue* (pp.479–502). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Fernandez-Duque, D., & Johnson, M.L. (1999). Attention metaphors: How metaphors guide the cognitive psychology of attention. *Cognitive Science, 23,* 83-116.

Gift, A.G. (1989). Visual analogue scales: Measurement of subjective phenomena. *Nursing Research, 38,* 286-288.

Gopher, D. (1992). The skill of attention control: Acquisition and execution of attention strategies. In D.E. Matthews & S. Kornblum (Eds.), *Attention and performance, XIV: Synergies in experimental psychology, artificial intelligence, and cognitive neuroscience.* Cambridge, MA: MIT Press.

Hancock, P. A., & Verwey, W. B. (1997). Fatigue, workload, and adaptive driver systems. *Accident Analysis and Prevention, 29,* 495-506.

Henschen, K. (2000). Maladaptive fatigue syndrome and emotions in sport. In Y.L. Hanin (Ed.), *Emotions in sport* (pp. 231-242). Champaign, IL: Human Kinetics.

Herzberg, P.A. (1989). *Principles of statistics.* Malabar, FL: Robert E. Krieger Publishing Company.

Hockey, G.R.J. (1970). Changes in attention allocation in a multi-component task under loss of sleep. *British Journal of Psychology, 61,* 473-480.

Hoddes, E., Zarcone, V., Smythe, H., Phillips, R., & Dement, W.C. (1973). Quantification of sleepiness: A new approach. *Psychophysiology, 10,* 431-436.

Holding, D. H. (1983). Fatigue. In G. R. J. Hockey (Ed.), *Stress and fatigue in human performance* (pp. 145-167). New York: Wiley.

James, W. (1890). *The principles of psychology.* New York: Holt.

Janelle, C.M., Singer, R.N., & Williams, A.M. (1999). External distraction and attentional narrowing: Visual search evidence. *Journal of Sport & Exercise Psychology, 21,* 70-91.

Job, R. F. S., & Dalziel, J. (2001). Defining fatigue as a condition of the organism and distinguishing it from habituation, adaptation, and boredom. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, workload, and fatigue* (pp. 466-475). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Lal, S.K.L., & Craig, A. (2002). Driver fatigue: Electroencephalography and psychological assessment. *Psychophysiology, 39,* 313-321.

Lang, P.J. (1979). A bio-informational theory of emotional imagery. *Psychophysiology, 16,* 495-512.

Lazarus, R.S. (2000). How emotions influence performance in competitive sports. *The Sport Psychologist, 14,* 229-252.

Lorist, M.M., Klein, M., Nieuwenhuis, S., De Jong, R., Mulder, G., & Meijman, T. F. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology, 37,* 614-625.

Macchi, M.M., Boulos, Z., Ranney, T., Simmons, L., & Campbell, S.S. (2002). Effects of an afternoon nap on nighttime alterness and performance in long-haul drivers. *Accident Analysis and Prevention, 34,* 825-834.

Mann, D.T.Y., Mousseau, M.B., & Janelle, C.M. (in review). Precompetition appraisals of emotion reflected in competition physiology.

Matthews, G. (1992). Mood. In A. P. Smith & D. M. Jones (Eds.), *Handbook of human performance: Vol. 3. State and trait* (pp. 161-193). London: Academic Press.

Matthews, G., Davies, D. R., Westerman, S. J., & Stammers, R. B. (2000). *Human performance: Cognition, stress and individual differences.* Philadelphia, PA: Taylor & Francis.

Matthews, G., & Desmond, P.A. (2002). Task-induced fatigue states and simulated driving performance. *The Quarterly Journal of Experimental Psychology, 55A(2),* 659-686.

McMorris, T., & Graydon, J. (1996). The effect of exercise on soccer decision-making tasks of differing complexities. *Journal of Human Movement Studies, 30,* 177-193.

McNair, D.M., Lorr, M., & Droppleman, L.F. (1992). *Revised manual for the Profile of Mood States.* San Diego, CA: Educational and Industrial Testing Services.

Mellalieu, S.D. (2003). Mood matters: But how much? A comment on Lane and Terry (2000). *Journal of Applied Sport Psychology, 15,* 99-114.

Moolenaar, M., Desmond, P.A., Mascord, D.J., Starmer, G.A., Tattam, B., & Volkerts, E.R. (1999). The effects of ephedrine on the development of fatigue in a prolonged driving-related task. *Human Psychopharmacology, 14,* 415-427.

Moran, A.P. (1996). *The psychology of concentration in sport performers: A cognitive analysis.* East Sussex, UK: Psychology Press.

Morris, T.L., & Miller, J.C. (1996). Electrooculographic and performance indices of fatigue during simulated flight. *Biological Psychology, 42,* 343-360.

Muscio, B. (1921). Is a fatigue test possible? *British Journal of Psychology, 12,* 31-46.

Navon, D., & Gopher, D. (1979). On the economy of the human-processing system. *Psycholgical Review, 86,* 214-255.

Nideffer, R.M. (1993). Concentration and attention control training. In J.M. Williams (Ed.), *Applied sport psychology: Personal growth to peak performance.* (pp. 243-261). Toronto: Mayfield.

Petri, H. L. (1991). *Motivation: Theory, research, and applications.* Belmont, CA: Wadsworth, Inc.

Reber, A.S. (1995). *Penguin dictionary of psychology* (2nd ed.). London: Penguin.

Reilly, T. (1996). Fitness Assessment. In T. Reilly (Ed.), *Science and soccer* (pp. 26-49). London: E & FN Spon.

Reilly, T., & Smith, D. (1984). Influence of metabolic loading on a cognitive task. In E.D. Megaw (Ed.), *Contemporary Ergonomics 1984* (pp. 104-109). London: Taylor & Francis, Ltd.

Reilly, T., & Smith, D. (1986). Effect of work intensity on performance in psychomotor task during exercise. *Ergonomics, 29 (4),* 601-606.

Ravizza, K. (1993). Increasing awareness for sport performance. In J.M Williams (Ed.), *Applied sport psychology: Personal growth to peak performance* (2nd ed.) (pp.148-157). Mountain View, CA: Mayfield.

Salmela, J.H., & Ndoye, O.D. (1986). Cognitive distortions during progressive exercise. *Perceptual and Motor Skills, 63,* 1067-1072.

Schmid, A., & Peper, E. (1993). Training strategies for concentration. In J.M. Williams (Ed.), *Applied Sport Psychology: Personal Growth to Peak Performance* (2nd ed.) (pp. 262-273). Mountain View: Mayfield.

Schönpflug, W. (1983). Coping efficiency and situational demands. In G.R.J. Hockey (Ed.), *Stress and fatigue in human performance* (pp. 299-330). New York: Wiley.

Schwarz, N. (2000). Emotion, cognition, and decision making. *Cognition and Emotion, 14(4),* 433-440.

Silva, J.M., & Stevens, D.E. (2002). *Psychological Foundations of Sport.* Boston: Allyn and Bacon.

Sirevaag, E.J., & Stern, J.A. (2000). Ocular measures of fatigue and cognitive factors. In R.W. Backs & W. Boucsein (Eds.), *Engineering Psychophysiology: Issues and applications* (pp. 269-287). Mahwah, NJ: Lawrence Erlaum.

Sommer, K.L., & Baumeister, R.F. (2002). Self-evaluation, persistence, and performance following implicit rejection: The role of trait self-esteem. *Personality and Social Psychology Bulletin, 28,* 926-938.

Totterdell, P. (1999). Mood scores: Mood and performance in professional cricketers. *British Journal of Psychology, 90(3)*, 317-328.

Treisman, A.M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology, 12,* 242-248.

Watson, D., Clarke, L.A., & Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54,* 1063-1070.

Wegner, D.M. (1994). Ironic processes of mental control. *Psychological Review, 101,* 34-52.

Williams, A.M. (2000). Perceptual skill in soccer: Implications for talent identification and development. *Journal of Sport Sciences, 18,* 737-750.

Williams, A.M., & Davids, K. (1997). Assessing cue usage in performance contexts: A comparison between eye-movements and concurrent verbal reports. *Behavior Research Methods, Instruments, & Computers, 29(3),* 364-375.

Williams, A.M., Davids, K., & Williams, K. (1999). *Visual perception and action in sport.* London: E & FN Spon.

Williams, J.M., Tonyman, P., & Andersen, M.B. (1991). The effects of stressors on coping resources on anxiety and peripheral narrowing. *Journal of Applied Sport Psychology, 3,* 126-141.

Wulf, G., & Shea, C.H. (2002). Principles derived from the study of simple skills do not generalize to complex skill learning. *Psychonomic Bulletin & Review, 9(2),* 185-211.

Yerkes, R.M., & Dodson, J.D. (1908), The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology of Psychology, 18,* 459-482.

Zaichkowsky, L.D., & Baltzell, A. (2001). Arousal and performance. In R. N. Singer, H. A. Hausenblas, & C. M. Janelle (Eds.), *Handbook of sport psychology* (2nd ed.) (pp. 319-339). New York: John Wiley & Sons, Inc.

BIOGRAPHICAL SKETCH

Melanie Mousseau was born and raised in North Smithfield, RI. Melanie began her quest for higher education in 1997 at Mary Washington College in Fredericksburg, VA, where she majored in psychology. Pursuing her interest in sport psychology, Melanie completed an honors senior thesis entitled, “Home Advantage: Does Anxiety Contribute?” and was awarded the distinction of “outstanding senior psychology major.” After receiving her BS in May 2001, Melanie continued her trek south, enrolling in the graduate program in exercise and sport sciences at The University of Florida, specializing in sport and exercise psychology under Dr. Christopher Janelle. During her tenure as a master’s student Melanie worked as a tennis instructor within the Sport and Fitness Program at The University and pursued various research interests including cognitive fatigue and mental imagery in sport. Melanie is currently pursuing her Ph.D. at UF as a doctoral fellow, continuing her research on cognitive fatigue in sport. Following completion of her degree Melanie intends on implementing the skills that she has developed as a researcher, teacher, and performance enhancement consultant.