

**Measuring and modeling the effects of fatigue on performance:
Specific application to the nursing profession**

Linsey Marinn Barker

Dissertation submitted to the faculty of
Virginia Polytechnic Institute and State University
to partially fulfill the requirements of a

Doctor of Philosophy
In
Industrial and Systems Engineering

Maury A. Nussbaum, Chair
Kari L. Babski-Reeves
Brian M. Kleiner
Tonya L. Smith-Jackson

July 21, 2009
Blacksburg, Virginia

Keywords: fatigue, medical errors, nursing, structural equation modeling, performance

Measuring and Modeling the Effects of Fatigue on Performance: Specific Application to the Nursing Profession

Linsey Marinn Barker

(Abstract)

High rates of medical errors are well documented within the healthcare industry. Nurses, in particular, play a critical role in the quality and safety of healthcare services. Fatigue is a factor that has been linked to stress, safety, and performance decrements in numerous work environments. Within healthcare, however, a comprehensive definition of fatigue encompassing multiple dimensions has not been considered, but is warranted since nurses perform tasks consisting of diverse physical and mental activities. As such, “total fatigue” was examined, as were interactions between its underlying dimensions and the effects of these dimensions on performance, in the context of actual and simulated nursing work.

In a survey study (Chapter 2), registered nurses reported relatively high levels of mental, physical, and total fatigue, and higher levels of fatigue were associated with perceived decreases in performance. Work environment variables, such as work schedule or shift length, were also related to differences in reported fatigue levels.

An experimental study investigated causal effects of mental and physical fatigue on mental and physical performance (Chapter 3). Mental fatigue affected a measure of mental performance, and physical fatigue had a negative effect on measures of physical and mental performance. A multidimensional view of fatigue that considers direct and crossover effects between mental and physical dimensions of fatigue and performance is relevant when quantifying effects of fatigue on performance.

A model of the relationships between fatigue dimensions and performance in nursing was developed using structural equation modeling techniques (Chapter 4). The model supported the existence of a total fatigue construct that is directly affected by mental and physical fatigue levels. The final model also provides quantitative path coefficients defining the strength of relationships between mental and physical dimensions of fatigue, total fatigue, and mental and physical performance.

The current research provides an increased understanding of fatigue levels in registered nurses across work environments, as well as the underlying causal mechanisms between dimensions of fatigue and performance decrements. The findings and the final model can aid in designing interventions to reduce or eliminate the contributions of fatigue to the occurrence of medical errors.

Acknowledgements

Pursuing a doctoral degree has not always been easy, and there are a number of people who I would like to thank and acknowledge for their unwavering support, sage pieces of advice, and cheerleading to help me along the way. First, to my advisor, Dr. Maury Nussbaum, thank you for your support, guidance, and patience with everything that I did in graduate school. You let me find my own path, but were there to help keep me on track whenever I started to wander too far. Since day one, you have provided me with countless opportunities that have enabled me to reach my goals. I only hope that I can have the same positive impact as an advisor in my own career.

I would also like to extend a heartfelt thanks to the other faculty members who served on my committee: Dr. Kari Babski-Reeves, Dr. Brian Kleiner, and Dr. Tonya Smith-Jackson. Not only was your support invaluable in shaping and challenging my ideas and improving the quality of my research, but you also served as wonderful role models for a career in academia. I am also extremely grateful for my other faculty mentors: Dr. Michael Agnew, Dr. Karen DePauw, and Dr. Eileen Van Aken. You have always been available to listen, guide, and encourage me in fulfilling my goals related to every aspect of graduate education and a holistic graduate experience.

I sincerely appreciate the contributions of Leif Alleman, Rory Brannan, David Clark, Joshua Dowden, Joshua Halferty, Seung-Yeun Han, and Erin Mahony in conducting the laboratory study. Your enthusiasm and hard work made each red X, each trip up the stairs, and each scratch in the hall possible. And to the members of the Industrial Ergonomics and Biomechanics Lab, and in particular, Sunwook Kim, I cannot thank you enough for always being available for equipment testing, brainstorming, venting, socializing, and words of encouragement.

To my co-workers at the National Rehabilitation Hospital, David Brennan and Justin Carter, thank you for fostering my interest in research and human factors, and for giving me the confidence and “real-world” experiences to take the plunge and pursue a graduate degree. I would also like to acknowledge the nurses of the Virginia Nurses Association, specifically Theresa Gaffney and Dr. Lorna Facticeau, your support in conducting the survey study and your insight into nursing practice were critical contributions to the work.

Finally, this would not have been possible without my two families. My Virginia Tech family - Myrna Callison, Elizabet Haro, Laura Hughes, Stephen Kalista, Meredith Katz, Tim Lockridge, and Brennan Shepard – could always be counted on for laughs, support, encouragement, distraction, inspiration, and understanding. I will treasure you as lifelong friends and I could not have done this without you. Last, but most importantly, I want to thank Scott and Jessica Barker (my brother and sister-in-law) and Samuel and Sherry Barker (my parents). You have been my foundation, and have given me the strength to keep pushing throughout this journey, and my entire life. Your faith in me has never wavered, and I know that with your support, anything is possible.

Table of Contents

List of Tables	vi
List of Figures	vii
Chapter 1: Introduction	1
Objectives	2
Preliminary Model	3
Summary	4
Chapter 2: Fatigue, performance, and the work environment: A survey of registered nurses	6
Abstract	6
Introduction.....	7
Methods	10
<i>Sample</i>	10
<i>Procedures</i>	10
<i>Measures</i>	10
<i>Analyses</i>	13
Results.....	14
<i>Fatigue levels</i>	17
<i>Performance</i>	17
<i>Relationships between fatigue and performance measures</i>	18
<i>Differences in fatigue levels across demographic and work environment variables</i>	21
Discussion	25
<i>Study sample</i>	25
<i>Mental, physical, and total fatigue levels</i>	27
<i>Acute and chronic fatigue states</i>	28
<i>Fatigue and performance</i>	29
<i>Differences in fatigue levels across demographic and work environment variables</i>	30
Conclusions.....	33
Chapter 3: Effects of task demands on the development of mental and physical fatigue and associated changes in mental and physical performance: an experimental study of simulated nursing work	34
Abstract	34
Introduction.....	35
Methods	39
<i>Experimental Design</i>	39
<i>Participants</i>	39
<i>Measures</i>	39
<i>Procedures</i>	45
<i>Analysis</i>	49
Results.....	50
<i>Task time</i>	50
<i>Fatigue levels</i>	51
<i>Physical performance</i>	52

<i>Mental performance</i>	53
Discussion	55
<i>Effects of task demands on fatigue</i>	55
<i>Effects of fatigue on performance</i>	57
<i>Limitations and future directions</i>	59
Conclusions	62
Chapter 4: Total fatigue as a mediator in relationships between distinct dimensions of fatigue and performance: A structural equation modeling approach among registered nurses	64
Abstract	64
Introduction	65
Methods	69
<i>Overview</i>	69
<i>Model Specification</i>	71
<i>Analyses</i>	73
Results	75
<i>Measurement Model</i>	75
<i>Initial Model SEM Analysis</i>	79
<i>Model Modification and Comparisons</i>	80
<i>Model Validation</i>	82
Discussion	84
Conclusions	89
Chapter 5: Conclusions and Recommendations	91
Summary of outcomes	92
Recommendations for future research	96
<i>Defining and measuring fatigue and performance</i>	96
<i>Additional factors associated with fatigue and performance</i>	102
Final conclusions	104
References	106
APPENDICES	124
APPENDIX A: FATIGUE IN NURSING SURVEY SET – INSTRUCTIONS AND DEMOGRAPHIC DATA	125
APPENDIX B: NURSING PERFORMANCE INSTRUMENT	129
APPENDIX C: LABORATORY STUDY PARTICIPANT DEMOGRAPHICS	130
APPENDIX D: LABORATORY STUDY INFORMED CONSENT FORM	131
APPENDIX E: LABORATORY STUDY ARITHMETIC AND DISTRACTION QUESTIONS	135
APPENDIX F: LABORATORY STUDY NURSING TREATMENT NOTES	137

List of Tables

Table 1. Demographic characteristics of sample and reported aspects of the work environment.	16
Table 2. Summary of fatigue scale results.	17
Table 3. Results from questions comprising the Nursing Performance Instrument (N = 799). ..	18
Table 4. Correlations (r_s) among fatigue measures (all correlations are significant, with $p < 0.001$).	20
Table 5. Correlations (r_s) among fatigue and performance measures.	20
Table 6. Effects of demographic and work environment variables on F-RSQ, FAS, and OFER fatigue measures (* = significant effect; $p < 0.05$)	21
Table 7. Effects of demographic and work environment variables on SOFI fatigue measures (* = significant effect; $p < 0.05$).	22
Table 8. Simulated nursing tasks.	47
Table 9. Nursing work tasks in the different mental and physical demand conditions.	49
Table 10. Summary of ANOVA results (p -values) regarding the effects of Physical Demand (PD), Mental Demand (MD), and Gender on fatigue measures. Dependent measures are normalized change scores (except as noted), and are presented as means (SD).	52
Table 11. Summary of ANOVA results (p -values) regarding the effects of Physical Fatigue (PF), Mental Fatigue (MF), and Gender on physical performance measures. Dependent measures are normalized change scores and are presented as means (SD).	53
Table 12. Summary of ANOVA results (p -values) regarding the effects of Physical Fatigue (PF), Mental Fatigue (MF), and Gender on mental performance measures. Dependent measures are normalized change scores and are presented as means (SD).	55
Table 13. Correlations (r_s) and covariances among model direct measures (upper, correlation values; lower, covariance values).	77
Table 14. Squared multiple correlations (R^2) for indicator variables and path coefficients* between indicator and latent variables in measurement model.	78
Table 15. Goodness of fit indices for the measurement, initial, modified, alternate, and validated models. The second column indicates contemporary criteria for acceptable fit.	79
Table 16. Standardized direct, indirect, and total effects of fatigue dimensions on performance as determined by the SEM. Coefficients are presented as initial / final model estimates.	83
Table 17. Evaluation of model hypotheses.	85

List of Figures

Figure 1. Conceptual model of fatigue and performance in healthcare workers.	4
Figure 2. Differences in F-RSQ Mental and Physical scores (higher = increased fatigue) across work schedules. Here, and in the remaining figures, error bars indicate standard deviations.	22
Figure 3. FAS scores (total fatigue) with respect to sleep duration (higher = increased fatigue).	23
Figure 4. SOFI Lack of Energy scores across weekly work duration (higher = increased fatigue).	24
Figure 5. OFER Acute and Chronic fatigue scores across work schedules (higher = increased fatigue).	25
Figure 6. Participant placing the box in the “high” (a) and “low” (b) target locations.	44
Figure 7. Screen-shot of patient status parameters for sample patient.	48
Figure 8. Initial conceptual model relating mental, physical, and total fatigue to mental and physical performance. The direction of hypothesized relationships is indicated with + and - signs. Indicator variables for each of the five latent variables comprise the measurement model and are also included in the conceptual model. Paths set to equal 1, in order to establish a scale for latent variables are shown in the model.	73
Figure 9. Initial SEM (n = 352), with standardized path coefficients and squared multiple correlations (R^2) shown for the dependent latent variables. * = significant at $p < .05$	80
Figure 10. Alternate SEM (n = 352), showing standardized path coefficients and R^2 for dependent latent variables. * = significant at $p < .05$	82

Chapter 1: Introduction

Health care is the second largest industry in the United States and one of the fastest-growing sectors of the U.S. economy (Blosser, 2006; Bogner, 1994, Ch.2). In this industry, which is known for its complexity and unique organizational characteristics, performance decrements leading to medical errors and/or worker injuries are becoming an especially serious problem. In 2001, among private sector industries in the U.S., hospitals had the second highest absolute number of worker injuries and illnesses, and an overall incidence rate of 8.8 per 100 full-time equivalent workers (Janowitz et al., 2006). Further, in the U.S. alone medical errors are estimated to cause more than one million injuries and up to 98,000 patient deaths each year (Kohn et al., 1999).

While high rates of medical errors and worker injuries are well documented across the healthcare industry, nurses, in particular, play a critical role in the quality and safety of healthcare services. There are over 2.8 million licensed nurses in the United States who are directly involved in providing patient care across health care delivery locations (hospitals, nursing homes, homes, schools, workplaces, etc.). Nurses provide a majority of direct patient care in hospitals including assessment, monitoring, evaluation, and delivery of care or treatment plans. Thus, the performance of nurses during their daily work tasks is likely closely linked to patient outcomes (Page, 2004; Tourangeau et al., 2006). In addition, nurses are often exposed to high physical and mental demands in their work, and several previous studies have identified nurses as having a particularly high risk among healthcare workers for developing occupational illnesses and injuries (Carayon, 2007; Colligan et al., 1979; Punnett, 1987; Stubbs, 1983).

In any given context within the healthcare domain, the specific causal or most critical factor(s) leading to safety or quality performance decrements may vary. Numerous studies have sought to improve worker performance and safety by focusing on a specific task, healthcare specialty, or environmental factor (Clarke et al., 2006; Emam et al., 2002; Howard et al., 2002; Salas et al., 2005; Squires et al., 2005). While many of these studies have demonstrated a reduction in errors or injuries, they were narrowly focused and their results may only be valid in a specific context (Clarke et al., 2006). Few studies have considered potential pervasive factors (e.g., sleep deprivation and fatigue) that might influence performance across workers, tasks, and contexts.

Definitions of these factors, however, have been inconsistent in existing research, and causal relationships between these factors and performance decrements related to medical errors have not been clearly established (Gaba et al., 2002; Owens, 2001; Samkoff et al., 1991). Quantifying these factors, which are prevalent in workers throughout healthcare systems, may enable organizations and the industry to improve the quality of patient care and reduce injuries more efficiently (Clarke et al., 2006; Tourangeau et al., 2006).

Fatigue is a factor that has been linked to stress, safety, and performance decrements in numerous work environments. As such, the role of fatigue in medical errors and healthcare worker safety should be further clarified. Previous investigations of the relationship between fatigue and performance in healthcare have focused on specific components of fatigue; for example, sleep deprivation in medical trainees, or physical fatigue in laparoscopic surgeons. However, a more comprehensive definition of fatigue encompassing multiple dimensions (e.g., mental fatigue and physical fatigue) has not been considered in existing research. Healthcare workers, and more specifically registered nurses, perform tasks consisting of diverse physical and mental activities. As such, “total fatigue”, the interactions between its underlying dimensions, and the effects of these dimensions on performance, should all be further studied. For the purposes of this research, the following definition is used:

Total fatigue is a state comprised of at least two dimensions: mental fatigue and physical fatigue. Mental and physical fatigue dimensions are present in nurses exposed to excessive mental and physical demands through their work tasks and schedules. These fatigue dimensions contribute to a state of total fatigue, which over time can result in these workers not being able to function at their normal capacity and can lead to an increased risk for injury or medical error.

By quantifying the dimensions of total fatigue and their effects on performance in healthcare workers, we can better define the construct of fatigue and ultimately develop targeted interventions to minimize the adverse effects of fatigue on performance.

Objectives

The overall aim of this research was to measure and model components of total fatigue in registered nurses, and to identify their effects on performance during nursing tasks. Specifically,

the research consisted of three phases. In Phase 1, registered nurses (RNs) working in a range of healthcare environments were surveyed to measure their perceptions of fatigue levels, fatigue dimensions, and performance levels present during their work. Phase 2 consisted of a laboratory study during which workload factors were manipulated to facilitate the development of mental and physical fatigue in participants. Performance on mental and physical tasks was measured to determine the relationships between fatigue dimensions and changes in performance. Phase 3 integrated findings from Phases 1 and 2 and used structural equation modeling techniques to develop a model relating mental fatigue, physical fatigue, and total fatigue to mental and physical performance in nurses. This model was intended to guide future research in this area and the design of potential interventions to reduce fatigue and/or improve performance.

Each of the three phases comprising this dissertation research was designed to accomplish a specific aim as follows:

Specific Aim #1: To quantify the perceived levels and dimensions of fatigue in registered nurses working in diverse healthcare environments.

Specific Aim #2: To quantify the effects of mental and physical fatigue on mental and physical performance during nursing work tasks. Multiple levels of mental and physical fatigue were induced in participants through varying simulated work task demands in a laboratory setting. Resulting fatigue levels were measured subjectively and objectively through surveys of nurse perceptions and physiological measures.

Specific Aim #3: To develop a quantitative model of the relationships between fatigue dimensions and performance in a nursing context. This model enables future researchers to estimate the likelihood of changes in performance based on measured levels of fatigue. The model can also be used to guide interventions to eliminate or counteract negative effects of fatigue on worker performance and safety in healthcare systems.

Preliminary Model

The research was guided by an initial proposed comprehensive model (Figure 1), which was hypothesized based on existing fatigue research, frameworks, and models. The model suggests

that a total fatigue construct does exist and that it encompasses at least two dimensions, physical fatigue and mental fatigue. In addition, it is proposed that physical fatigue affects physical performance directly and that mental fatigue affects mental performance directly. Indirect effects between physical fatigue and mental performance and between mental fatigue and physical performance are also included in the model. Each of the three phases of research relates to an overall understanding of the fatigue and performance relationships within this model. Additional factors, such as job task factors, psychosocial factors, and individual factors, are included in this conceptual model; however, these factors are not explicitly considered as part of the current research. These other factors relating to fatigue in nurses will be explored in future work using some of the data and findings obtained from this dissertation research.

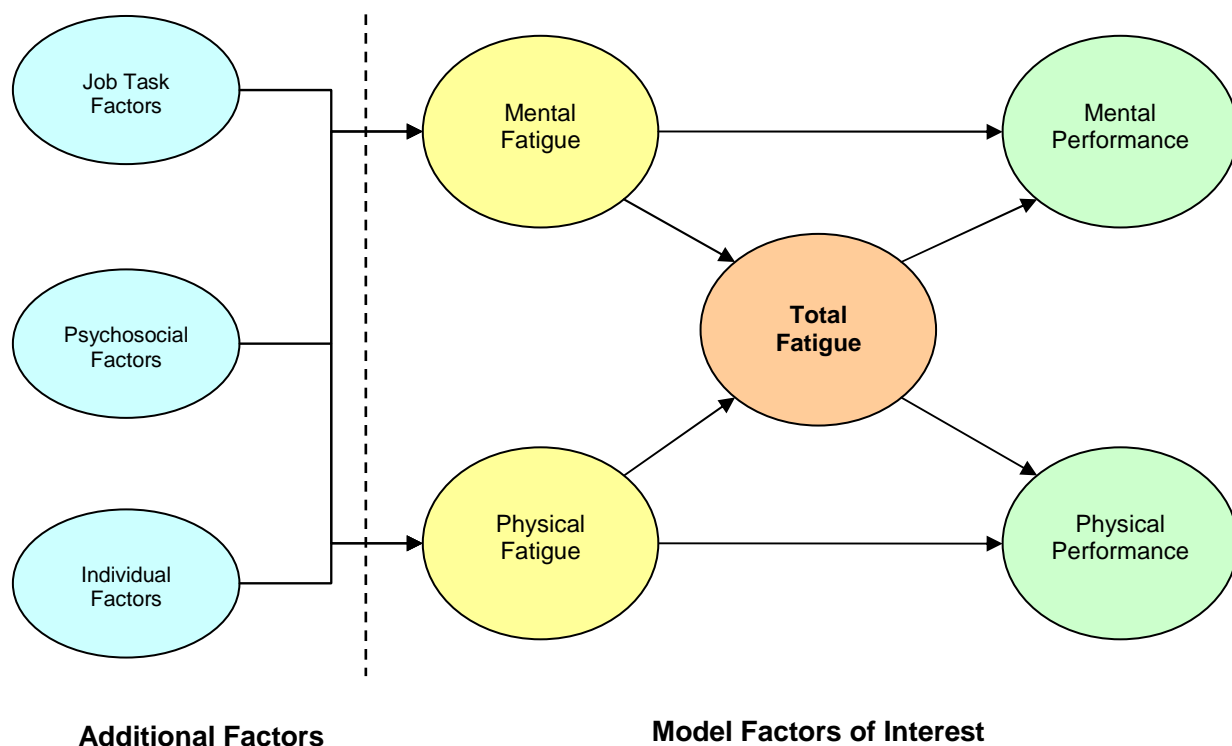


Figure 1. Conceptual model of fatigue and performance in healthcare workers.

Summary

This research makes contributions to the fields of human factors and industrial engineering, as well as the health care industry as a whole. By investigating total fatigue and the factors

influencing fatigue for registered nurses and the healthcare industry, our body of knowledge related to total fatigue has been expanded. The overall goal of this research was to quantify both perceived and objective measures of total fatigue in these workers and to identify performance consequences of fatigue that may lead to increased risk of occupational injuries or medical errors in nursing.

Registered nurses' perceptions of mental, physical, and total fatigue levels were quantified and were found to be relatively high compared to other industries. Differences in fatigue levels across demographic and work environment (e.g., shift length, shift schedule) variables were also identified. In the laboratory study, mental and physical fatigue levels did significantly affect measures of mental and physical performance following completion of simulated nursing tasks. Finally, a quantitative model relating fatigue dimensions and performance was estimated. The final model supported the existence of a total fatigue construct comprised of both mental and physical fatigue dimensions. Direct and indirect effects between mental and physical fatigue and mental and physical performance were also confirmed by the model; and, causality for these effects was supported by the findings from the laboratory study.

Future research will continue to expand on these findings by incorporating additional work organizational and psychosocial factors into the model relating fatigue and performance. Ultimately, the findings from this and future related research projects will provide ergonomists, healthcare organizations, and nursing professional associations and policymakers quantitative data and models which better define the relationships between workload, work organizational, and psychosocial factors and dimensions and states of fatigue in these workers. In the future, these findings may provide an increased ability to predict when fatigue-related performance decrements will occur and what types of performance are most impacted, in order to develop appropriate interventions.

Chapter 2: Fatigue, performance, and the work environment: A survey of registered nurses

Abstract

Background: High rates of medical errors have been documented within the healthcare industry. Fatigue is a factor that has been linked to performance decrements in numerous industries, including healthcare. Due to the nature of their work, nurses may be particularly susceptible to multiple dimensions of fatigue, and their performance is closely linked to patient safety.

Objectives: Perceived levels of mental, physical, and total fatigue, as well as acute and chronic fatigue states, were quantified in registered nurses from a range of work environments. Relationships between dimensions of fatigue and performance were also investigated, as were differences in fatigue levels across demographic and work environment variables.

Methods: 745 registered nurses completed an online survey comprised of eight survey instruments designed to measure mental, physical, and total fatigue dimensions; acute and chronic fatigue states; and performance.

Results: Registered nurses reported higher levels of total fatigue than mental fatigue or physical fatigue. Further, mental fatigue levels were higher than physical fatigue levels, and acute fatigue levels were 31% higher than chronic fatigue levels, although nurses did report a moderate level (~50%) of chronic fatigue. Fatigue dimensions and states were negatively correlated with perceived performance, further supporting the role of fatigue in nursing performance. Shift length and hours worked per week were associated with changes in physical and total fatigue levels; longer shifts or increased hours worked per week led to higher levels of fatigue. Mental, physical, and total fatigue levels were also related to shift schedule.

Conclusions: Registered nurses reported relatively high levels of mental, physical, and total fatigue, and all fatigue dimensions and states were significantly negatively correlated with performance. Work environment variables also were significantly associated with differences in perceived levels of fatigue. Thus, by altering the work environment it may be possible to reduce fatigue levels and ultimately also reduce the rates of medical errors.

Keywords: total fatigue, acute fatigue, chronic fatigue, performance, nursing

Introduction

High rates of medical errors and worker injuries have been established as serious contemporary challenges within the healthcare industry (Janowitz et al., 2006; Kohn et al., 1999; Tourangeau et al., 2006; Treanor, 2000; Van Cott, 1994). Due to their role in providing a majority of direct patient care, the performance of nurses is closely tied to the quality and safety of healthcare services (Page, 2004; Tourangeau et al., 2006). Further, amongst healthcare workers worldwide, nurses have a relatively high risk of developing occupational illnesses and injuries (Ando et al., 2000; Carayon, 2007; Colligan et al., 1979; Knibbe et al., 1996; Lagerstrom et al., 1995; Punnett, 1987; Smedley et al., 1997; Stubbs, 1983; Trinkoff et al., 2002).

In any given context within the healthcare domain, the specific causal or most critical factor(s) leading to safety or performance decrements may vary. Numerous studies have taken a context-specific approach to improve worker performance and safety by focusing on a specific task, healthcare specialty, or environmental factor (Clarke et al., 2006; Emam et al., 2002; Howard et al., 2002; Salas et al., 2005; Squires et al., 2005). While many of these studies have demonstrated a reduction in errors or injuries, they were somewhat narrowly focused and may not have applicability to improving performance and safety in other healthcare work environments or worker populations (Clarke et al., 2006). Fewer studies have considered potential pervasive factors that might influence performance across workers, tasks, and environments (DeMoss et al., 2004; Faucett, 2005; Howard et al., 2002; Piko, 2006). Considering factors that might influence performance regardless of context may enable organizations and the industry to improve the quality of patient care and reduce errors more efficiently (Clarke et al., 2006; Tourangeau et al., 2006).

Fatigue is one particular factor, which has been linked to stress, safety, and performance decrements in numerous work environments (Goode, 2003; Leung et al., 2006; Leung et al., 2004; Lorist et al., 2000; Miller, 2005; Ochoa et al., 1998; Schellekens et al., 2000). Within nursing, fatigue has been found to be related to nursing injuries and adverse health consequences (Geiger-Brown et al., 2004; Josten et al., 2003; Lipscomb et al., 2004; Trinkoff et al., 1998; Yip, 2001), nursing satisfaction levels (Edell-Gustafsson et al., 2002; Geiger-Brown et al., 2004; Josten et al., 2003; Taylor et al., 2004), and patient safety (Carayon et al., 2005; Rogers, A. E. et

al., 2004b). Specifically, fatigue and work-related stress are associated with an increased prevalence of low back pain and musculoskeletal disorders in the neck, shoulders and knees in nurses from a number of countries around the world (Smith et al., 2003; Trinkoff et al., 2002; Yip, 2001). With regard to patient safety and medical errors, fatigue is related to an increased risk for error in nursing tasks due to slowed reaction times, lapses of attention to detail, errors of omission, compromised problem-solving, reduced motivation, and decreased energy (*Implications of fatigue on patient and nurse safety*, 2005; Rogers, A. E. et al., 2004b; Scott et al., 2006).

Fatigue is a complex construct, and which has not yet been clearly defined independent of context (Ahsberg, 2000; Akerstedt et al., 2004; Friedberg et al., 1998; Hockey, 1983; Soh et al., 1996). A summary of existing literature indicates that fatigue is a multicausal, multidimensional, nonspecific and subjective phenomenon which results from prolonged activity and psychological, socioeconomic, and environmental factors that affect both the mind and the body (Soh et al., 1996; Tiesinga et al., 1996). Although occupational fatigue is frequently defined as a multidimensional construct (Ahsberg, 2000; De Vries et al., 2003; Tiesinga et al., 1996), much of the existing research related to fatigue in nursing has focused solely on sleep, emotional exhaustion, and burnout components and their implications for performance and safety (AbuAlRub, 2004; Aiken et al., 2001; Chen et al., 2001; Gold et al., 1992; Kandolin, 1993; Lindborg et al., 1993; Suzuki et al., 2005; Taylor et al., 2004). However, as nursing work frequently consists of both physically and mentally demanding tasks, a broader definition of occupational fatigue – one that includes physical and mental dimensions related to the broader construct of total fatigue – is critical for understanding the consequences of fatigue in this population. In addition, the general literature related to fatigue distinguishes between fatigue states, acute and chronic. Many existing models or definitions of occupational fatigue do not differentiate between these states, and assume that occupational fatigue is acute (Winwood et al., 2005). Nurses, though, are frequently exposed to long working hours with little recovery time between shifts (Josten et al., 2003; Rogers, A. E. et al., 2004b; Winwood et al., 2006b); thus, both chronic and acute fatigue states should be considered.

Finally, workload, stress and other environmental factors that may influence levels of fatigue likely vary across healthcare work environments. Several of the existing studies investigating the relationships between work hours, workload, fatigue and performance in nursing have focused on critical care environments (Carayon et al., 2005; Scott et al., 2006). Yet, fatigue may be present and impacting performance and ultimately nurse and patient safety across a range of healthcare environments. It is thus important to quantify dimensions and states of fatigue across a range of diverse nursing work environments.

In summary, nurses are frequently required to complete long working hours and a combination of both physically and mentally demanding tasks, which may lead to increased levels of multiple dimensions (mental and physical) of fatigue as well as acute and chronic fatigue states. However, these demands, and the resulting levels of fatigue, may vary across healthcare work environments and may have implications for both patient and nurse safety. Further research is needed to better quantify the levels of fatigue present in diverse nursing work environments. The relationship between fatigue and performance within nursing should also be further considered. To that end, the goals of this study were to quantify the perceived dimensions and states of fatigue present in registered nurses; investigate the relationships between perceived fatigue and perceived performance; and identify differences in perceived fatigue levels and dimensions across demographic and work environment variables in registered nurses.

Based on the exposure to mental and physical demands and increasing prevalence of extended work hours within nursing work environments, the hypotheses for the study were that: (1) mental fatigue, physically fatigue, and total fatigue dimensions will be present within the nursing population; (2) nurses will have higher levels of acute fatigue than chronic fatigue; (3) perceived fatigue will be negatively correlated with perceived performance; and (4) demographic and work environment factors will be associated with different levels of perceived fatigue in registered nurses.

Methods

Sample

Registered nurses (RNs), currently employed in a hospital, community or public health setting, ambulatory care, or nursing home/extended care facility, were recruited to participate. Nurses were recruited through convenience sampling in cooperation with several nursing organizations and publications. Specifically, advertisements describing the study were placed in the Virginia Nurses Association's newsletter, Nursing Spectrum Magazine, and Virginia Nurse Today. Advertisements were also placed on websites of the Virginia Nurses Association and New York Nurses Association and sent out through listservs of the Virginia Nurses Association, Montgomery Regional Hospital, Arizona Nurses Association, and University of Missouri Health Systems.

Procedures

Study advertisements provided a brief overview of the purpose of the survey and directed participants to an online survey created using Survey Monkey (Copyright ©1999-2007 SurveyMonkey.com). Instructions for completing the surveys and relevant information regarding the purpose of the research and confidentiality procedures were included within the online survey itself. The Virginia Tech Institutional Review Board approved the study prior to any data collection. To minimize recall bias, participants were instructed to complete the survey at the end of a work shift. Data collection occurred between February 2008 and April 2009.

Measures

Eight survey instruments and six free response questions were compiled to form a "Fatigue in Nursing Survey Set" (FNSS). The instruments were selected to ensure comprehensive measurement of total, physical, and mental fatigue as well as measures of fatigue states, performance, workload, and psychosocial factors. Demographic data were also collected, including age, gender, ethnicity, years of experience, education (degree), type of healthcare organization, shift schedule, and percentage of time spent on direct patient care (Appendix A). The entire FNSS was reviewed by four registered nurses from the Virginia Nurses Association (VNA) for relevance to nursing, readability, clarity of items, and clarity of instructions. Based

on pilot testing with nurses from the VNA, participants could complete the FNSS in approximately 15-20 minutes.

Fatigue: The Swedish Occupational Fatigue Inventory (SOFI) was used to measure perceived fatigue related to work across five dimensions: lack of energy, physical exertion, physical discomfort, lack of motivation, and sleepiness (Ahsberg, 2000; Ahsberg et al., 1997). This inventory consists of 20 items that are each rated on a 7-point scale ranging from 0 (not at all) to 6 (to a very high degree). Respondents are asked to rate each item based on the extent to which they felt each expression when they were most tired. The SOFI has been previously tested on multiple worker populations and found to be both reliable and able to discriminate between fatigue from mental versus physical work (Ahsberg, 2000; Ahsberg et al., 1997).

The Fatigue-Related Symptoms Questionnaire (F-RSQ) was included to measure two dimensions of fatigue (Yoshitake, 1978). This questionnaire consists of 16 symptoms commonly associated with fatigue, and which are grouped into two categories (physical and mental fatigue). The questionnaire includes symptoms such as: inability to concentrate, tremoring in the limbs, and feelings of stress. Participants are asked to simply indicate whether or not they are experiencing each symptom at any specific moment. The F-RSQ has been shown to be sensitive to fatigue levels resulting from varying work task demands (Chen et al., 2003; Murata et al., 1991; Yoshitake, 1978), and has been used to measure physical and mental fatigue during nursing tasks (Soh et al., 1996).

The Fatigue Scale (FAS) was used to measure total fatigue (De Vries et al., 2003; Michielsen et al., 2003; Michielsen et al., 2004). The FAS includes 10 items rated on a 5-point rating scale (1 = never to 5 = always). Items within the scale relate to either physical fatigue or mental fatigue, but the FAS differs from the SOFI in that it is unidimensional and the only score reported is an overall score for total fatigue. Previous research has demonstrated that this scale has good reliability and content validity for measuring fatigue in a general or worker population (De Vries et al., 2003; Michielsen et al., 2003; Michielsen et al., 2004).

To measure the fatigue states present, the Occupational Fatigue Exhaustion Recovery (OFER) scale was used (Winwood et al., 2005). The OFER scale was developed to measure chronic fatigue, acute fatigue, and inter-shift recovery in workers. It consists of 15 items, and responses are given using a 7-pt scale ranging from strongly agree to strongly disagree based on experiences of fatigue and strain at work and home over the past few months. This scale is unique in that it has been tested extensively on healthcare workers, specifically nurses, and has been demonstrated to have high internal and test-retest reliability, and to be free of gender bias. It can distinguish between acute and chronic fatigue states and measure the recovery from fatigue between work shifts (Winwood et al., 2006a; Winwood et al., 2005).

Performance: A Nursing Performance Instrument (NPI, Appendix B) was developed to evaluate nurses' perceptions of their mental and physical performance. This instrument consists of nine items that relate to aspects of performance during nursing work tasks (see Table 4, below). The NPI was developed by first reviewing several existing performance measurement tools within nursing, namely the Schwirian Six Dimension Scale of Nursing Performance (Schwirian, 1978), the Modified Scale of Nursing Performance (Battersby et al., 1991), the Self Report of Competence (Garland, 1996), and the Physician Mental Work Load Measure (Bertram et al., 1990; Bertram et al., 1992). The Work Limitations Questionnaire (Lerner et al., 2001), was also reviewed for items that might be suitable for inclusion in the NPI. This questionnaire was designed to evaluate workers' abilities in relation to mental and physical demands (Lerner et al., 2001), and has been used investigate the relationship between low back pain and work performance in nurses (Denis et al., 2007). A set of 29 potential items was sent to the staff and Board of Directors of the VNA for expert review of the appropriateness of the content to diverse nursing contexts, readability, clarity of items, and clarity of instructions. These reviews helped to establish the face and content validity of the instrument. Based on feedback from this review, the list of items was shortened to a nine-item format. All nine items had a six-point response scale ranging from Strongly Disagree to Strongly Agree. The final version of the NPI was reviewed and supported with respect to content validity by two RNs from the VNA.

Additional Instruments and Questions: The FNSS included three additional questionnaires that measured psychosocial factors, workload, and personality attributes. Nurses' perceptions of

psychosocial factors in their environment and their workload were also collected through a modified Job Content Questionnaire (Karasek et al., 1998). The Physician Workload Instrument (PWI) was used to determine nurses' perceived levels of workload. Finally, the Jenkins student activity survey was included to determine Type A personality tendencies (Yarnold et al., 1994). Results from these instruments are not included here, as they are beyond the scope of this dissertation. Future work will be conducted to investigate the relationships between psychosocial factors, workload, personality tendencies and fatigue and performance.

Analyses

Survey responses were scored according to the criteria specified for each instrument, and scores for all scales and subscales were calculated. Scores on the SOFI, F-RSQ, and FAS were used to quantify the levels of mental, physical, and total fatigue present in nurses. Scores on the OFER were used to quantify levels of chronic fatigue, acute fatigue, and intershift recovery in nurses. Scores on items from the NPI were used to quantify aspects of performance. NPI items 1, 2, 5, 7, and 9 were reverse coded in all analyses so that higher scores indicated higher performance. Cronbach's alpha values were used to evaluate the reliability of all subscales within the SOFI, FAS, and OFER, and for all items in the NPI.

Prior to any subsequent statistical tests, all measures were tested for normality by evaluating symmetry in histograms and using the Shapiro-Wilk's statistic. For non-normally distributed measures, transformations were attempted and non-parametric statistics were employed where appropriate. Several of the fatigue measures were found to have a non-normal distribution of residuals and Box-Cox transformations were performed to achieve normality for the F-RSQ Mental and Physical, FAS, and OFER Acute scores (all summary results are given in the original units). Residuals of the SOFI PE, PD, and LoM scores were also non-normal; however, transformations failed to achieve normality and those variables were analyzed using non-parametric statistics.

Wilcoxon signed-rank tests were used to identify differences between mental, physical, and total fatigue levels from the SOFI and F-RSQ. A Wilcoxon signed-rank test was also used to evaluate differences in fatigue states by determining whether levels of acute fatigue were higher than

chronic fatigue. Relationships among perceived mental, physical, and total fatigue levels, fatigue states (acute and chronic), and performance were examined using nonparametric correlation analyses (Spearman's r_s). Pairwise deletion was used for missing data.

Differences in fatigue measures across demographic and work organizational variables were examined using a multivariate analysis of variance (MANOVA) of the F-RSQ, FAS, and OFER fatigue measures. The initial MANOVA model included 16 demographic and work environment independent variables: gender, age, ethnicity, marital status, number of dependents, hours of sleep per night, years as an RN, work setting, years in that work setting, percentage of time spent on direct patient care, hours per week spent on primary nursing jobs, other jobs, hours per week spent on all jobs, work schedule, and shift length. Backward elimination was employed to remove independent variables from the model (Farmer et al., 1975; Huberty et al., 2006). Variables were removed one at a time based on the highest p -value until only variables with $p < 0.15$ remained in the model. Subsequent univariate analyses of variance (ANOVAs) were used to determine which of the six remaining demographic and work environment variables (ethnicity, hours of sleep per night, years in current work setting, work schedule, hours per week spent on all jobs, and shift length) had significant associations with differences in fatigue measures. Tukey's post-hoc comparisons were performed on all significant factors where relevant. As the fatigue measures from the SOFI were non-normal and transformations were not successful, the Kruskal-Wallis test was used to evaluate differences in the SOFI measures across demographic and work environment variables. All statistical tests were performed in SAS 9.2 (SAS Institute Inc., Cary, NC) and were considered significant when $p < 0.05$.

Results

A total of 1006 registered nurses logged into the survey site and completed some portion of the survey set; of these, 745 completed the entire survey set (completion rate = 74.1%). A majority of respondents were female (94.2%), Caucasian (85.9%), and married (67.8%). A majority of respondents classified their work environment as an acute care setting (80.5%), and over half (51.7%) reported working a standard daytime shift. More than one-third (38%) of the respondents indicated that they work over 40 hours per week at their nursing job and over half (57.7%) indicated that they work on average over 11 hours per shift. A majority of nurses

(80.5%) also indicated that they have no other jobs besides their primary nursing position. Additional demographic characteristics and a summary of the work environment variables for the survey sample are included in Table 1.

Table 1. Demographic characteristics of sample and reported aspects of the work environment.

	N	%		N	%
Age (yrs)			Years as RN		
< 20	1	0.1	< 1	68	7.0
21-30	189	19.0	1-5	171	17.5
31-40	172	17.3	6-10	134	13.7
41-50	282	28.3	11-15	101	10.3
51-60	306	30.8	16-20	110	11.3
> 60	45	4.5	21-25	125	12.8
			>25	268	27.4
Ethnicity			Work setting		
African-American	63	6.4	Acute care hospital	797	80.5
Asian-American	16	1.6	Psychiatric facility	84	8.5
Caucasian	851	85.9	Doctor's office/public health clinic	9	0.9
Foreign National	11	1.1	Educational setting	22	2.2
Hispanic	18	1.8	Long term care	13	1.3
Multiracial	9	0.9	Patient homes	5	0.5
Native American	5	0.5	Correctional facility	2	0.2
Native Hawaiian or other Pacific Islander	2	0.2	Other	58	5.9
Other	16	1.6			
Marital status			Years in current work setting		
Single	190	19.2	< 1	103	10.4
Married	669	67.7	1-5	366	37.0
Divorced or Separated	110	11.1	6-10	197	19.9
Other	19	1.9	11-15	95	9.6
			16-20	94	9.5
			21-25	52	5.3
			> 25	82	8.3
Number of dependents			Work time on direct patient care		
0	400	40.5	76-100 %	487	49.7
1-2	412	41.7	51-75 %	182	18.6
3-4	161	16.3	26-50 %	102	10.4
> 4	15	1.5	1-25%	130	13.3
			No patient care	79	8.1
Hours of sleep per night			Primary Work Schedule		
> 9	9	0.9	Regular daytime shift	513	51.7
8-9	81	8.2	Regular night shift	175	17.6
7-8	233	23.5	Regular evening shift	21	2.1
6-7	387	39.1	2 shift rotation – days/evenings	60	6.0
5-6	246	24.8	3 shift rotation	54	5.4
< 5	35	3.5	Irregular arranged by employer	43	4.3
			Irregular arranged by employee	75	7.6
			Other	52	5.2
Highest educational degree			Usual shift length (hours)		
2 year associates	247	25.2	< 8	20	2.0
3 year degree	61	6.2	8-9	230	23.2
4 year baccalaureate	426	43.4	9-10	109	11.0
Masters	193	19.7	10-11	61	6.1
Ph.D.	5	0.5	11-12	323	32.6
Other	49	5.0	> 12	249	25.1

Fatigue levels

Summary statistics for the fatigue measures are presented in Table 2. Cronbach's alpha values for all scales ranged from 0.72 to 0.91, indicating that all fatigue measures had acceptable reliability (Nunnally, 1978). For the SOFI, the total fatigue dimension (Lack of Energy) was significantly higher than all other dimensions ($p < .0001$). Mental fatigue (Lack of Motivation) levels within the SOFI were significantly higher than physical fatigue (Physical Exertion and Physical Discomfort) levels ($p < .0001$). Sleepiness as measured by the SOFI was also significantly higher than Physical Exertion and Lack of Motivation ($p < .0001$). Mental fatigue levels on the F-RSQ were also significantly higher than physical fatigue levels ($p < .0001$). For the OFER, nurses perceived significantly higher levels of acute fatigue than chronic fatigue ($p < .0001$).

Table 2. Summary of fatigue scale results.

Measure	N	Score Range	Mean	Standard Deviation	Cronbach's Alpha
SOFI	881	0 to 6			
Physical Exertion			1.17	1.24	0.76
Physical Discomfort			2.85	1.49	0.80
Lack of Motivation			2.01	1.56	0.89
Sleepiness			2.76	1.65	0.88
Lack of Energy			4.20	1.45	0.88
F-RSQ	854	0 to 100			
Physical			27.22	20.47	n/a
Mental			36.81	26.14	n/a
FAS	879	0 to 5	2.42	.52	0.72
OFER	874	0 to 100			
Chronic Fatigue			50.07	27.74	0.91
Acute Fatigue			65.55	22.06	0.87
Intershift Recovery			50.1	23.61	0.87

Performance

Cronbach's Alpha for the entire NPI was 0.80, and alpha coefficients for each of the nine items ranged from 0.77 to 0.80 (Table 3), indicating acceptable reliability for this instrument (Nunnally, 1978). Scores for individual items ranged from 3.33 (item 7) to 5.03 (item 5) out of 6, with higher scores representing higher perceived performance.

Table 3. Results from questions comprising the Nursing Performance Instrument (N = 799).

Item	Prompt	Mean	Standard Deviation	Cronbach's Alpha
1	During a work shift, changes in my muscle strength, endurance, or physical energy affect my ability to perform physical tasks associated with my job (e.g., carry items, perform patient handling tasks, walk/drive from patient to patient, etc.)	3.63	1.50	.79
2	I sometimes find it necessary to take short-cuts in patient care	4.02	1.46	.77
3	I always apply the "5 Rights" principle when administering medications	5.03	1.13	.79
4	Throughout a work shift I am able to perform fine motor tasks (e.g., inserting an IV, catheter insertion, medication preparation, etc.) without difficulty	4.98	0.97	.80
5	During a work shift, changes in my concentration or alertness affect my ability to perform patient monitoring, medication administration, and/or documentation tasks	3.78	1.47	.77
6	I am always able to carry out safe nursing practice	4.66	1.17	.78
7	During a work shift, changes in my mood, mental energy, or attentiveness affect my ability to communicate clearly and effectively (e.g., express my opinions, understand what others are saying, etc.) with other nurses, physicians, clinicians, patients or family members	3.33	1.43	.78
8	I always follow existing facility or organizational guidelines for safe patient handling (e.g., use of lift devices, two person lifts, etc.)	4.37	1.30	.79
9	I am sometimes forced to modify my standards to get the work done	3.65	1.51	.78

* Item response scale ranged from 1 (strongly disagree) to 6 (strongly agree). Scores from items 1, 2, 5, 7, and 9 were reverse coded so that higher scores now indicate higher performance.

Relationships between fatigue and performance measures

Pairs of fatigue measures were significantly ($p < 0.001$) and positively correlated (Table 4), excepting the Intershift Recovery measure from the OFER scale, which was negatively correlated with all of the other measures ($p < .001$). Overall, mental fatigue measures (SOFI Lack of Motivation and F-RSQ Mental) were more strongly correlated with each other than with other measures, and physical fatigue measures (SOFI Physical Exertion, SOFI Physical Discomfort, and F-RSQ Physical) were more strongly correlated with each other than with other

measures. FAS scores were most strongly correlated with the other total fatigue measure (SOFI Lack of Energy).

Most performance measure items from the NPI were significantly and negatively correlated with all fatigue measures (Table 5). An exception was the Intershift Recovery measure from the OFER scale, which was positively correlated with all NPI items. NPI item 3 (regarding the “five rights” principal, see Table 3) was the only item that was not significantly negatively correlated with all fatigue measures. It was not significantly correlated with SOFI Physical Discomfort, SOFI Physical Exertion, or FAS.

Table 4. Correlations (r_s) among fatigue measures (all correlations are significant, with $p < 0.001$).

		SOFI					F-RSQ			OFER	
		Physical Exertion	Physical Discomfort	Lack of Motivation	Sleepiness	Lack of Energy	Physical	Mental	FAS	Chronic Fatigue	Acute Fatigue
SOFI	Phys. Discomfort	.53									
	Lack of Mot.	.36	.40								
	Sleepiness	.27	.37	.48							
	Lack of Energy	.41	.57	.47	.45						
F-RSQ	Physical	.38	.57	.22	.21	.32					
	Mental	.33	.37	.45	.25	.43	.38				
FAS	Total Fatigue	.33	.39	.32	.31	.43	.31	.42			
OFER	Chronic Fatigue	.37	.41	.34	.21	.48	.29	.47	.45		
	Acute Fatigue	.35	.46	.29	.21	.54	.40	.50	.50	.65	
	Intershift Recovery	-.36	-.44	-.31	-.31	-.45	-.36	-.43	-.46	-.62	-.63

Table 5. Correlations (r_s) among fatigue and performance measures.

		SOFI					F-RSQ			OFER		
		Physical Exertion	Physical Discomfort	Lack of Motivation	Sleepiness	Lack of Energy	Physical	Mental	FAS	Chronic Fatigue	Acute Fatigue	Intershift Recovery
NPI 1		-.29***	-.45***	-.31***	-.23***	-.38***	-.37***	-.35***	-.28***	-.37***	-.37***	.37***
NPI 2		-.11**	-.10**	-.24***	-.05	-.24***	-.12***	-.23***	-.14***	-.31***	-.27***	.20***
NPI 3		-.02	-.03	-.20***	-.10**	-.10**	-.07*	-.17***	-.07	-.09*	-.13***	.11**
NPI 4		-.14***	-.16***	-.15***	-.11**	-.09**	-.15***	-.20***	-.12**	-.17***	-.18***	.23***
NPI 5		-.17***	-.25***	-.38***	-.19***	-.31***	-.20***	-.42***	-.22***	-.29***	-.34***	.30***
NPI 6		-.12***	-.15***	-.27***	-.13***	-.21***	-.16***	-.24***	-.16***	-.23***	-.26***	.24***
NPI 7		-.20***	-.26***	-.38***	-.19***	-.33***	-.21***	-.42***	-.26***	-.34***	-.35***	.33***
NPI 8		-.09*	-.06	-.23***	-.11**	-.11**	-.12**	-.18***	-.12***	-.15***	-.16***	.12***
NPI 9		-.19***	-.18***	-.25***	-.09*	-.22***	-.17***	-.21***	-.17***	-.37***	-.29***	.22***

*** $p < .001$, ** $p < .01$, * $p < .05$

Differences in fatigue levels across demographic and work environment variables

Fatigue levels were significantly different between levels of several demographic and work environment variables (Tables 6 and 7). Physical fatigue levels as measured by the F-RSQ were different across ethnicities, years in current work setting, hours of sleep per night, work schedules, and shift lengths. Participants with 7-8 or 8-9 hours of sleep per night were significantly less physically fatigued (27-51%) than those with 5-6 or < 5 hours of sleep per night. Nurses working a regular night schedule had F-RSQ Physical scores that were 52% lower than those working a “regular evening” schedule, and 31% lower than those working “rotation days/evenings” schedules (Figure 2). Respondents working 8-9 or 9-10 hour shifts had 29-51% lower F-RSQ scores than those working 10-11 or > 12 hour shifts. Physical fatigue dimensions from the SOFI were significantly affected by gender (PD), sleep hours (PE, PD), years as an RN (PE), educational degree (PE, PD), hours worked per week (PE, PD), shift length (PD), and work setting (PE, PD). Males reported SOFI physical discomfort levels that were 27% lower than females. SOFI PD and PE levels increased 82% as sleep hours per night decreased from 8-9 hours to 5-6 hours. Participants who worked more hours per week also reported higher levels on the SOFI PD and PE scales, and longer shift lengths were also associated with higher Physical Discomfort levels (~20% increase between 9-10 and 10-11 hours per shift). Nurses working in long term care facilities reported the highest levels on the SOFI PD and PE scales (2.40 and 4.00), while nurses working in patient homes and correctional facilities reported the lowest levels (0.25 and 1.38; and 1.25 and 1, respectively).

Table 6. Effects of demographic and work environment variables on F-RSQ, FAS, and OFER fatigue measures (* = significant effect; $p < 0.05$)

	F-RSQ Physical	F-RSQ Mental	FAS	OFER CF	OFER AF
Ethnicity	.0148*	.20	.0024*	.0203*	.08
Years in current work setting	.0117*	.0015*	.0352*	.89	.80
Hours of sleep per night	.0005*	.08	<.0001*	.0011*	.0003*
Total hours worked per week	.38	.34	.34	.0071*	.37
Work schedule	.0016*	<.0001*	.09	.0051*	<.0001*
Shift length	.0002*	.16	.94	.47	.0002*

Table 7. Effects of demographic and work environment variables on SOFI fatigue measures (* = significant effect; $p < 0.05$).

	PE	PD	LoM	SI	LoE
Gender	.31	.0203*	.54	.66	.06
Age	.46	.39	.0003*	<.0001*	.0479*
Ethnicity	.66	.23	.28	.15	.0052*
Marital status	.43	.07	.06	.0109*	.12
Dependents	.23	.44	.99	.98	.25
Sleep hours	.0002*	<.0001*	.19	.0157*	.12
Years as RN	.0387*	.13	.09	.0002*	.0433*
Degree	.0357*	.0392*	.07	.21	.90
Years in work setting	.19	.19	.15	.12	.0414*
Patient care %	.14	.45	.26	.99	.65
Other jobs	.78	.46	.33	.86	.73
Hours worked/week	.0118*	.0007*	.74	.0395*	.0360*
Schedule	.50	.18	.07	.0022*	.0228*
Shift length	.29	.0419*	.09	.0124*	.0024*
Work Setting	.0150*	.0041*	.12	.0281*	.06

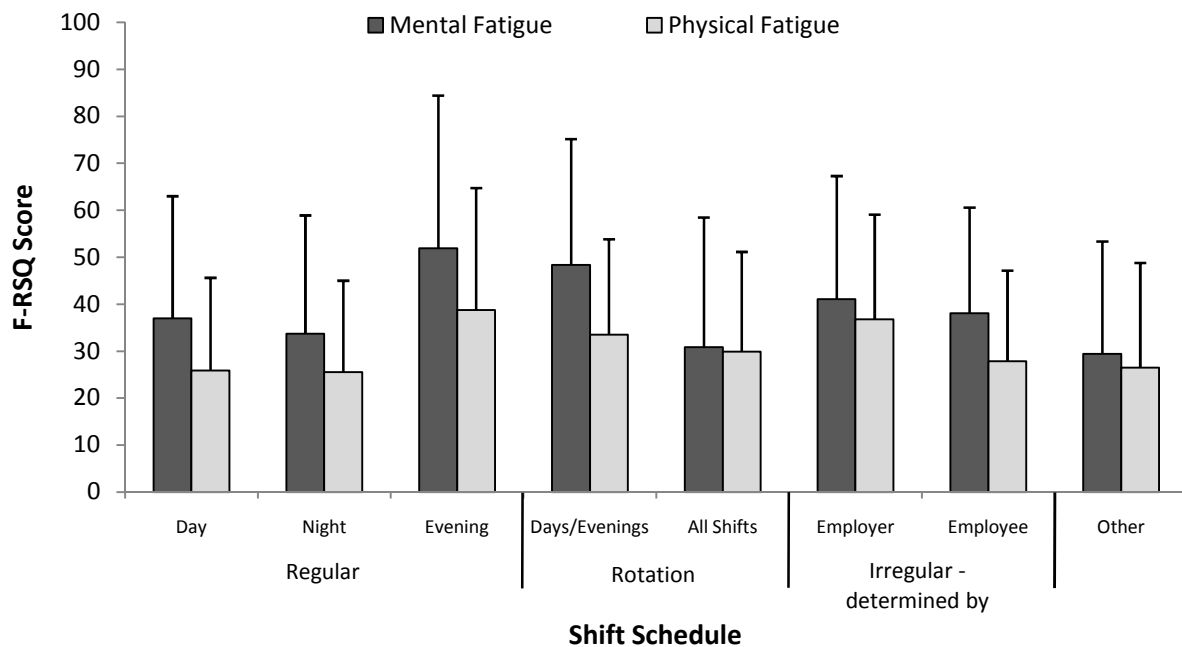


Figure 2. Differences in F-RSQ Mental and Physical scores (higher = increased fatigue) across work schedules. Here, and in the remaining figures, error bars indicate standard deviations.

The F-RSQ mental fatigue measure significantly differed with years in current work setting and work schedule (Table 6). Nurses working a regular night schedule had 43-54% lower scores than those working “regular evening” or “rotation days/evenings” schedules (Figure 2). Further, nurses working “rotation all shifts” schedules had 57-68% lower F-RSQ Mental scores than those working “regular evening” or “rotation days/evenings” schedules. Age was the only demographic factor associated with significant differences in mental fatigue levels as measured by the SOFI Lack of Motivation (Table 7).

Ethnicity, years in current work setting, and hours of sleep per night were all associated with significant differences in total fatigue, measured by the FAS. Participants who slept 7-9 hours per night had 7-20% lower FAS total fatigue levels than those who slept < 6 hours per night. There were also significant differences between 6-7 and < 5 hours of sleep per night; in all cases, less sleep led to higher FAS scores (Figure 3). The SOFI Lack of Energy measure of total fatigue was significantly different across the hours worked per week (Figure 4) and shift length (~18-27% increase between shifts < 10 hours and > 10 hours).

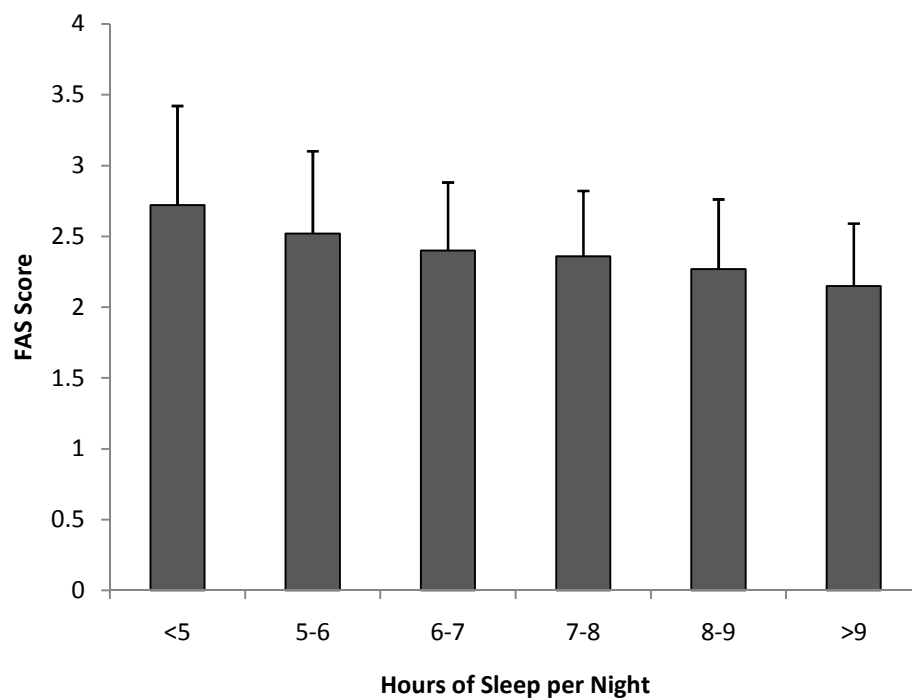


Figure 3. FAS scores (total fatigue) with respect to sleep duration (higher = increased fatigue).

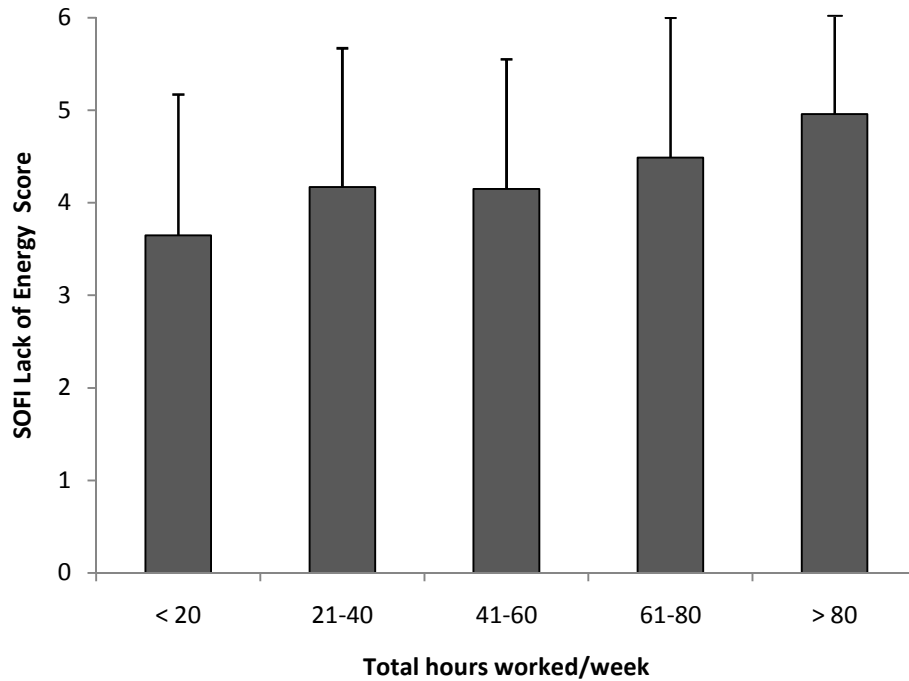


Figure 4. SOFI Lack of Energy scores across weekly work duration (higher = increased fatigue).

Finally, with regard to fatigue states, ethnicity, hours of sleep per night, total hours worked per week, and work schedule all were associated with significant differences in chronic fatigue levels. In contrast, acute fatigue was only significantly different across hours of sleep per night and work schedule. For acute and chronic fatigue, participants who slept 6-9 hours per night had lower scores, 11-17% and 13-67%, respectively, than those who slept 5-6 hours per night. Participants who worked < 20 hours per week had 52-85% lower chronic fatigue scores than those who worked 41-80 hours per week. Acute fatigue scores were significantly lower (Figure 5) for: regular daytime and regular night shifts compared to regular evening (19%); for regular night compared to rotation between days/evenings (16%); for irregular shift schedules determined by the employee or rotation across all shifts compared to regular evening (15-29%); and for rotation across all shifts compared to rotation between days/evenings (25%).

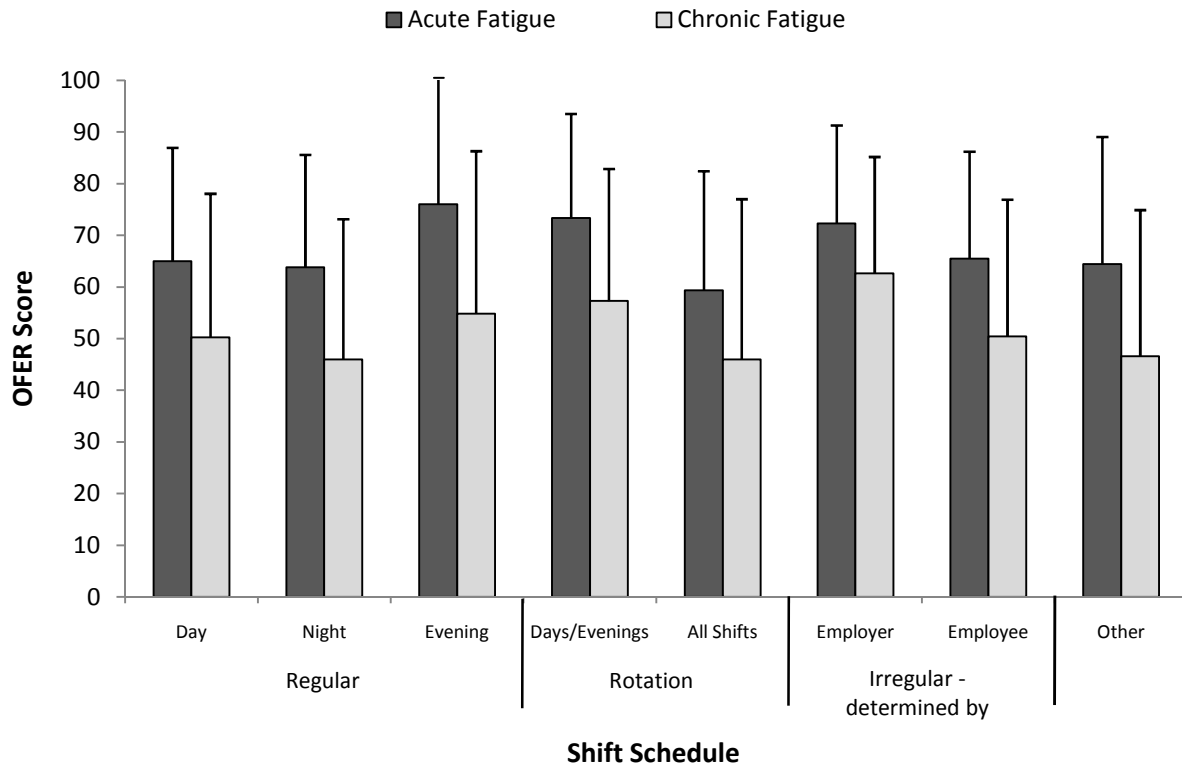


Figure 5. OFER Acute and Chronic fatigue scores across work schedules (higher = increased fatigue).

Discussion

The overall goal of this study was to determine perceived levels of fatigue and the relationship between fatigue and performance among registered nurses. Specifically, registered nurses from a range of work environments were surveyed about their perceived levels of physical, mental, and total fatigue; their overall fatigue state; and their performance.

Study sample

Demographic distributions of the sample closely approximated those found in the 2001 American Nurses Association Health and Safety Survey (ANA, 2001), the 2000 National Sample Survey of Registered Nurses (Spratley et al., 2001), the 2004 National Sample Survey of Registered Nurses ("The registered nurse population: Findings from the 2004 national sample survey of registered nurses," 2004), and those found in more recent published research (Trinkoff et al., 2006). Some differences, however, are apparent. Specifically, the age distribution in the

current sample was slightly older, with a larger percentage of nurses in the 51-65 age range (35.3%) than was reported in the American Nurses Association Health and Safety Survey (28%) or the 2000 National Sample Survey of Registered Nurses (27.3%). However, it was comparable to the sample in the 2004 National Sample Survey of Registered Nurses, which reported 36.7% of registered nurses were age 50 and above. As the RN workforce is aging more rapidly than the overall labor force in the U.S., and by 2010 the average RN is expected to be 45.5 years old (Page, 2004), the current sample likely reflects this aging trend. Quantifying fatigue levels in the current, slightly older, sample of registered nurse is critical, since nursing tasks are often physically demanding and age-related decreases in strength and agility may affect a nurse's fatigue, discomfort, and ability to safely perform work tasks.

The current sample also has a larger percentage of respondents with less than 5 years of experience as an RN (24.7%), compared to the American Nurses Association Health and Safety Survey (14.2%). This change also likely reflects workforce trends within nursing, where high turnover among nurses are leading to a decrease in experienced nurses (ANA, 2001; Sochalski, 2002). This decrease is especially concerning for patient safety, as nurses with less experience appear to commit more rule-based and skill-based errors (Narumi et al., 1999). Additionally, experience level is negatively related to mortality rates in urban and non-urban community hospitals (Tourangeau et al., 2006).

Previous surveys have found that roughly 85% of nursing shifts were 8 to 12 hours in duration, but double-shifts and overtime are becoming increasingly common (Page, 2004; Rogers, 2004; Trinkoff et al., 2006). During approximately 40% of shifts, nurses worked longer than 12.5 hours (Rogers, 2004). In the current sample, 72.5% of nurses reported working shifts of 8 to 12 hours, and only 25.3% reported working shifts longer than 12 hours. The lower percentage of nurses working > 12 hours shifts in this sample, though, may be due to the wording of the question. Nurses were not explicitly instructed to include overtime hours in their shift lengths.

In spite of these differences, the current sample is likely representative of a larger population of RNs in the United States. The older age distribution and the decreases in years of experience, in particular, reflect important trends in worker demographics within this population. These results,

however, may not be generalizable to other nursing groups (e.g., LPNs, NAs) or other healthcare worker populations as the work tasks performed vary across occupations and job titles, and thus perceived levels of fatigue would likely differ.

Mental, physical, and total fatigue levels

Nurses across the world have reported high levels of fatigue, and have listed fatigue as one of the major factors contributing to a decision to leave the profession (Estryn-Behar et al., 1990; Winwood et al., 2006b; Zboril-Benson, 2002). Nurses in the current study reported levels of mental, physical, and total fatigue that were quite high (Table 2). SOFI measures, in particular, were high compared to values reported earlier for a range of occupations (Ahsberg et al., 2000a). Nurses in this study perceived their level of total fatigue (4.20 on a six-point scale) to be higher than mental (2.01) or physical fatigue (1.17), as measured by the SOFI. They also perceived mental fatigue to be higher than physical fatigue for both the SOFI and the F-RSQ, although their physical discomfort levels (2.85 on a six-point scale) were higher than their perceived levels of mental fatigue (2.01) on the SOFI. Soh and Crumpton (1996) also found that nurses reported higher levels of mental fatigue than physical fatigue (measured by the F-RSQ) over the course of an 8-hour work shift. While nursing work is often thought of as primarily mentally vs. physically demanding, which supports higher perceived levels of mental fatigue compared to physical fatigue, the physical demands associated with nursing are substantial and should not be ignored (Trinkoff et al., 2001). Moreover, the higher levels of physical discomfort compared to mental fatigue or physical exertion is deserving of further attention given the relatively high rates of overexertion and occupational injuries amongst this population (Bureau of Labor Statistics, 2005; Punnett, 1987; Stubbs, 1983).

As the current study was unable to control for when nurses completed the surveys relative to a work shift, there may have been recovery biases in reported fatigue levels. Torgen et al. (1999) found that the length of recall time affects the validity of perceived physical demands; therefore, physical fatigue measures may have been especially vulnerable to recall biases. Further, Soh and Crumpton (1996) reported increasing levels of perceived tiredness and body part discomfort at multiple measurement points over the course of a work shift. Future research should continue to include measures of both mental and physical fatigue when quantifying fatigue levels in registered nurses. In addition, whenever feasible, measures of fatigue should be obtained at

regular intervals during and immediately following actual work shifts, to more accurately determine fatigue levels during work and to measure rates of change in fatigue levels over the course of a shift.

Acute and chronic fatigue states

Nurses indicated that they were more acutely than chronically fatigued. Acute fatigue has been defined as a more temporary state which is commonly experienced by healthy people during the course of work or daily life activities (Aaronson et al., 2003). Specifically, acute fatigue occurs in response to work demands and/or stress that deplete available energy (Winwood et al., 2005). Acute fatigue following a work shift is characterized by a decrease in motivation to participate in pleasurable and voluntary non-work activities, and is considered controllable in that it can be reduced by rest or changing tasks (Aaronson et al., 2003; Winwood et al., 2006a). In contrast, chronic fatigue is often viewed as an illness, or a state only experienced by people who are ill (Aaronson et al., 2003). Chronic fatigue is experienced by workers, though, and is associated with “doubt and despair in the capacity to maintain current work patterns; declining interest, involvement, and commitment; reduced concentration and motivation; and negative emotions, combined with physical manifestations of persistent tiredness” (Winwood et al., 2006a, p. 596).

While acute fatigue is generally considered more common in occupational settings, chronic fatigue has more substantial consequences on worker health, well-being, and work performance (Winwood et al., 2005). Although nurses in this study reported higher levels of acute fatigue than chronic fatigue (31% higher), the chronic fatigue levels averaged ~50%, which is classified as a “moderate” level of chronic fatigue and is comparable to levels found among nurses in Australia (Winwood et al., 2005; Winwood et al., 2006b). The moderate level of chronic fatigue found, coupled with the increasing prevalence of extended work shifts in nursing (Trinkoff et al., 2006; Winwood et al., 2006b), may have important implications for both nurse and patient safety. Chronic fatigue levels and inter-shift recovery measures should be considered when evaluating the effectiveness of longer work shifts or overtime scheduling practices among registered nurses.

Fatigue and performance

Fatigue dimensions and fatigue states were correlated with performance measures, further supporting the important role of fatigue in nursing performance. Mental fatigue measures tended to have higher negative correlations with the performance measures than did either physical fatigue or total fatigue. In specific, mental fatigue measures (SOFI LoM and F-RSQ Mental) were most strongly negatively correlated with NPI 5 and NPI 7, which relate to changes in concentration, mood, and mental energy, and the implications for patient monitoring, medication administration, and documentation tasks. These results compliment existing evidence that in healthcare workers, performance on tasks requiring vigilance, attention to detail, or which are long in duration may be particularly susceptible to fatigue-related consequences (Caldwell, 2001; Flin et al., 2003; Howard et al., 2002; Krueger, 1994; Owens, 2001). Physical fatigue measures, in contrast, were most strongly negatively correlated with NPI 1, which relates to muscle strength, endurance, and physical energy abilities relative to physical nursing tasks. Across all fatigue dimensions, the lowest negative correlations were with NPI 3 and NPI 8. These two items related to particular guidelines within nursing practice (i.e., the “5 rights” principle and patient-handling guidelines). Thus, performance guidelines that specifically govern clinical practice may, in some instances, mitigate the effects of perceived fatigue.

Acute fatigue and chronic fatigue both had comparable levels of correlation with all of the NPI items. However, chronic fatigue was more strongly negatively correlated with NPI 2 and NPI 9, both of which relate to taking shortcuts or modifying standards to get work done. Chronic fatigue has been linked to declining interest and reduced motivation in work (Winwood et al., 2006a), again highlighting the importance of continuing to measure chronic fatigue levels in nurses.

When considering the relationships between perceived fatigue and performance within the current study, it is important to acknowledge that the study was cross-sectional. Thus the directionality of relationships between fatigue and performance cannot be determined. Additional, more controlled, experimental research is needed to determine if causal relationships exist between dimensions of fatigue and performance in these workers.

Differences in fatigue levels across demographic and work environment variables

There were differences in perceived levels of physical, mental, and total fatigue, as well as chronic and acute fatigue states for several of the demographic variables (Tables 6 and 7). The highest educational degree reported was associated with differences in physical fatigue measures from the SOFI. Somewhat surprisingly, nurses who reported having earned a PhD had the highest physical fatigue (as reflected in SOFI PE and PD scores). However, the sample size in this group was only 5 nurses. Across other degree categories, 2-year associates degrees or “other” degrees had higher SOFI physical fatigue levels than registered nurses with 4-year baccalaureate or Masters degrees. Educational degree likely influences a nurse’s specific job title or position and associated work tasks. Nurses with less formal education may be less likely to be in supervisory positions or those that might require lower levels of physical demands.

Both physical fatigue, measured using the F-RSQ, and total fatigue, measured using the FAS, were significantly different across ethnicities. Post-hoc comparisons indicated that African-Americans reported significantly lower (18%) physical fatigue levels compared to Hispanic respondents. Post-hoc comparisons for the total fatigue scores, however, did not reveal any significant differences between ethnic groups. This may be due to the small sample size in several of the groups. Existing research has been mixed regarding differences in fatigue levels across ethnicities. Specifically, in a community sample, Latinos have reported higher rates of Chronic Fatigue Syndrome than Caucasians and African-Americans (Jason et al., 1999). In the same sample, Song et al. (1999), found no differences in total fatigue levels on the FAS across ethnic groups; however, there were interaction effects between ethnic groups and age, gender, and socioeconomic status. Older Latinos, female Latinos, and Latinos of higher socioeconomic status had higher total fatigue levels. As the nursing work force is predominantly female, aging, and becoming increasingly ethnically diverse (Spratley et al., 2001), differences in fatigue levels across ethnicities may warrant further attention.

There were differences in physical fatigue, total fatigue, and sleepiness dimensions as well as chronic and acute fatigue levels for different average hours of sleep per night. Higher fatigue levels were associated with fewer hours of sleep per night (Figure 3). Hours of sleep per night were not, however, related to reported mental fatigue levels, either in the SOFI or the F-RSQ

measures. Thus, although registered nurses reported relatively high levels of mental fatigue, these perceptions were not related to reported hours of sleep. Sleep quality, though, was not considered separately from sleep hours, and the former has been suggested as an important predictor of occupational fatigue (Åkerstedt et al., 2004).

Relationships between work environment variables and occupational fatigue dimensions are critical as these variables can, in theory, be influenced through workplace design or controls to reduce fatigue levels. Recent changes in the healthcare industry, including worker shortages and efforts to reduce costs, have also led to increases in extended work hours for nurses, and this has important implications for both nurse and patient safety. Extended work hours have been linked to an increased likelihood of injuries, increased fatigue, decreases in performance and reaction time, and increases in unhealthy life behaviors such as smoking, lack of exercise, alcohol consumption, and poor diet (Trinkoff et al., 2006). Nurses working shifts of 9- or 12-hours have reported higher fatigue levels and lower performance compared to those working 8-hour shifts (Josten et al., 2003). Further, nurses working shifts exceeding 12.5 hours are more than three times more likely to commit an error than nurses who work shorter shifts (Narumi et al., 1999; Rogers, 2004).

Here, longer shift lengths and increased hours worked per week (Figure 4) were associated with higher levels of physical and total fatigue, as well as acute and chronic fatigue. There were no significant differences in mental fatigue, however, across shift lengths or hours worked per week. Åkerstedt et al. (2000) also found that work hours and overtime were not significant predictors of mental fatigue. Further, when controlling for work demands, increasing work hours were associated with lower levels of mental fatigue. These findings are important contributions to the ongoing discussion within the nursing community related to nursing hours and implications for both nursing satisfaction and quality of patient care. While some within the nursing and healthcare communities have expressed support for longer work shifts, as they provide increased days off for nurses and continuity of care for patients (Ganong et al., 1976; Gillespie et al., 1996; Underwood, 1975), the significant negative relationship between longer work hours and fatigue levels identified in both the current and previous studies suggests a continuing cause for concern.

Shift schedule, in contrast, was associated with differences in all fatigue dimensions as well as chronic and acute fatigue state levels (Figures 2 and 5). There is a great deal of research related to the influences of shift schedules on fatigue levels, performance, and well-being in nurses and other healthcare workers (e.g., Gold et al., 1992; Kandolin, 1993; Lindborg et al., 1993; Lipscomb et al., 2002; Muecke, 2005; Patterson et al., 2005; Ruggiero, 2003; Suzuki et al., 2005). Night shifts and rotating shift patterns, in particular, have both been associated with increasing fatigue levels and insufficient recovery from work between shifts (Winwood et al., 2006b). The nature of healthcare, and many nursing positions, however, requires 24-hour service 7 days a week, so evening/night shifts cannot be entirely avoided. There are some shift scheduling parameters (e.g., worker involvement in schedule selection, shift length, rotation patterns), though, which are potentially flexible, and which could reduce negative fatigue-, health-, or performance-related consequences in this population (Josten et al., 2003; Winwood et al., 2006b). A shift-scheduling model that can be used to quantify work-related fatigue across potential shift schedule designs has been developed for use in other industries (Dawson et al., 2001). Additional work is needed, however, to integrate findings related to work hours, shift schedule, and fatigue levels in order to develop similar models or guidelines for healthcare organizations. Such models could be used by nurse managers or administrators to determine potential effects of alternate shift designs on fatigue dimensions and states, and ultimately on worker safety and performance within healthcare.

Inadequate nursing staffing is another contemporary challenge facing healthcare organizations worldwide, and nursing worker shortages have led to an increase in the amount of time nurses spend on non-patient care activities (Aiken, 2001; McKinley, 2005). Staffing levels have been shown to have implications for nursing workload, nursing work activities and performance (Dimick et al., 2001; McCloskey et al., 1988). In the current study, the percentage of time spent on direct patient care activities was not associated with differences fatigue measures, though staffing levels were not directly measured within this survey. Future research should consider more explicitly the role of staffing-related changes in nursing work activities on fatigue and performance in registered nurses.

Conclusions

Nurses (RNs) reported higher levels of mental fatigue than physical fatigue and higher levels of acute fatigue than chronic fatigue. Significant negative correlations were evident between perceived levels of fatigue and performance across all fatigue dimensions and states. As contemporary challenges within healthcare systems, such as nursing shortages, increased patient loads, and decreased resources, continue to place higher demands on the workers, understanding the causal relationships between the work environment, fatigue, and performance will become increasingly critical. Demographic and work environment variables (e.g., shift length, shift schedule, hours of sleep per night, and years of experience in a given work setting) had significant effects on perceived levels of fatigue in registered nurses. Nursing managers and industrial engineers should consider these variables when designing nursing work environments and schedules in order to reduce fatigue levels. Ultimately, by altering the work environment to reduce fatigue levels, we may also reduce the rates of nursing injuries and medical errors.

Chapter 3: Effects of task demands on the development of mental and physical fatigue and associated changes in mental and physical performance: an experimental study of simulated nursing work

Abstract

Background: Within healthcare fatigue has frequently been associated with increased rates of medical error and worker injuries. However, existing research in this sector has not simultaneously considered multiple dimensions of fatigue, and the causal relationships between fatigue and performance have not been clearly demonstrated.

Objectives: The aim of this study was to evaluate hypothesized causal relationships between mental and physical fatigue and performance in a nursing context.

Methods: High and low levels of mental and physical fatigue were induced in 16 participants by varying mental and physical demands during simulated nursing work tasks in a laboratory setting. Resulting changes in fatigue levels were quantified using both subjective and objective measures. Changes in performance on a range of physical and mental tasks were also measured.

Results: Levels of total fatigue, mental fatigue, and physical fatigue increased following completion of the simulated work tasks in all experimental conditions. A higher level of physical fatigue had a negative effect on measures of both physical and mental performance. Increasing mental fatigue, in contrast, had a significant positive effect on a measure of mental performance. There were gender differences in the levels of induced fatigue and changes in performance. Males had lower levels of perceived physical fatigue and smaller changes in physical performance measures.

Conclusions: This study was able to successfully induce total fatigue, mental fatigue, and two distinct levels of physical fatigue in participants. Results indicated that there were causal effects between manipulated levels of mental and physical fatigue and changes in mental and physical performance measures. Thus, a multidimensional view, which considers both direct effects and crossover effects between mental and physical dimensions of fatigue and performance, is relevant when quantifying the effects of fatigue on performance in this context.

Keywords: mental fatigue, physical fatigue, performance, workload, simulated tasks, nursing

Introduction

Human error is a substantial problem in numerous industries. In the healthcare industry, medical errors are becoming an especially serious problem (Kohn et al., 1999; Van Cott, 1994). Roughly 5-15% of patients admitted to U.S. hospitals experience an adverse event, and of those adverse events ~37-52% are considered preventable (Tourangeau et al., 2006). An Institute of Medicine report estimated that preventable medical errors cause more than one million injuries and nearly 100,000 patient deaths in the U.S. each year, making preventable medical error the eighth leading cause of death (Kohn et al., 1999). In addition, the estimated annual healthcare costs of those errors resulting in patient injury are between \$7 - \$14 billion, and costs associated with lost income, lost household production, and disability for these injured patients are estimated to be an additional \$8 - \$15 billion annually (Kohn et al., 1999).

Within healthcare, fatigue is frequently cited as an influential factor in a variety of medical error contexts (Baldwin et al., 2004; Carayon et al., 2005; Gawande et al., 2003; Krueger, 1994; Lamberg, 2002; Owens, 2001). For example, 60% of trainees in anesthesiology both in the U.S. (Gravenstein et al., 1990) and New Zealand (Gander et al., 2000) reported making fatigue-related errors. Additionally, 41% of internal medicine residents indicated that fatigue was a cause of their most significant medical mistake (Wu et al., 1991). Medical trainees surveyed in a number of studies perceive prolonged work hours, fatigue, and lack of sleep all as risk factors for committing a medical error (Browne et al., 1994; Lewittes et al., 1989; McKee et al., 1992). Fatigue has also been shown to lead to individuals “cutting corners” or being more careless in order to exert less effort while completing tasks (Holding, 1983; Papp et al., 2004). In a complex healthcare work environment, such increases in carelessness due to fatigue could contribute to increases in medical errors.

Healthcare is a diverse setting with a variety of workers performing drastically different jobs. There are several populations within healthcare systems who have been identified as being at risk for fatigue, including medical residents, surgeons, emergency department physicians, intensive care unit physicians, and nurses (Berguer et al., 2001; Frey et al., 2002; Josten et al., 2003; Owens, 2001; Sexton et al., 2000). Nurses in particular are increasingly expected to work extended work hours across all shifts (Page, 2004; Rogers, 2004; Trinkoff et al., 2006), and

perform a variety of mentally and physically demanding tasks (Soh et al., 1996). These extended hours and task demands have been linked to an increased risk of work-related injuries, increased levels of fatigue, burnout and job dissatisfaction, and decreases in performance (Trinkoff et al., 2006). Further, the over 2.8 million licensed nurses in the U.S. comprise over 50% of the healthcare worker population in this country and are responsible for providing a majority of patient care across health care delivery locations (Page, 2004; Tourangeau et al., 2006). Their performance is critical when considering the current challenges related to medical errors.

While fatigue has been associated with performance decrements within healthcare, and identified as a perceived causal factor in medical errors, a causal relationship between fatigue and performance has not been established. This may be attributable, at least in part, to the lack of a clear definition of fatigue independent of context (Ahsberg, 2000; Akerstedt et al., 2004; Friedberg et al., 1998; Hockey, 1983; Soh et al., 1996). Existing literature indicates that fatigue is a multicausal, multidimensional, nonspecific, and subjective phenomenon, and which results from prolonged activity and psychological, socioeconomic, and environmental factors that affect both the mind and the body (Ream et al., 1996; Soh et al., 1996; Tiesinga et al., 1996). Until recently, fatigue was often viewed as a unidimensional construct and measured accordingly (De Vries et al., 2003). In contemporary literature, however, fatigue is acknowledged as a multidimensional construct, and thus the construct of “total fatigue” has arisen (De Vries et al., 2003).

As fatigue is experienced by a variety of populations in a variety of contexts, the specific dimensions included, and the emphasis placed on them, in definitions of total fatigue vary substantially. Nurses carry out both mentally and physically demanding tasks such as: patient monitoring, medication administration, documentation, patient and material handling, and needle insertion (Beynon et al., 2001; Page, 2004; Soh et al., 1996; Trinkoff et al., 2001; Wolf et al., 2006). This combination of both mental and physical demands supports the prevalence of both mental and physical fatigue in nurses, and registered nurses from a range of healthcare work environments have reported relatively high levels of both mental and physical fatigue dimensions (Chapter 2).

While there is not yet a consensus regarding a simple definition of mental fatigue, there are references to it, and its impact on performance throughout the literature on fatigue in healthcare workers (Akerstedt et al., 2004; Berguer, 1997; van der Linden et al., 2003b). Generally, mental fatigue can be defined as a psychophysiological state that arises in response to increasing cognitive task demands and results in a perceived sense of weariness, reduced motivation, reduced alertness, and reduced mental performance (Bertram et al., 1990; Leung et al., 2004; van der Linden et al., 2003b).

Physical fatigue occurs throughout the body and can lead to feelings of physical discomfort and a decreased capacity to generate force or power (DeLuca, 2005; Grandjean, 1968; Krueger, 1989, 1994). It consists of both peripheral and central components (Holding, 1983; Zijdwind et al., 2006). Peripheral fatigue relates to metabolic changes in the muscle contraction process such as changes to the contractile apparatus, excitation-contraction coupling, and the accumulation of metabolites and depletion of energy sources (Guillot et al., 2005; Zijdwind et al., 2006). Over time, these changes can lead to a decreased capacity to generate force in the muscles (Guillot et al., 2005; Holding, 1983; Zijdwind et al., 2006). Central fatigue, on the other hand, relates to changes in neuronal control of motor behavior such as cortical excitability changes (Holding, 1983; Zijdwind et al., 2006). Central fatigue can be affected by expectancy of work demands and motivation (Grandjean, 1968; Holding, 1983; Krueger, 1994). As such, physical fatigue should not be considered in isolation from mental fatigue, since changes in cognitive resources leading to mental fatigue might impact motivation and central fatigue. Furthermore, physical work requires cognitive resources and thus contributes to the overall level of mental fatigue (Bertram et al., 1990; Collins et al., 2003; van der Linden et al., 2003b).

Past research on fatigue has often separated work activities into physical and mental categories, so that individual dimensions of fatigue (i.e., physical or mental fatigue) can be more clearly defined and measured (Emam et al., 2001; Luttmann et al., 1996; Soh et al., 1996; Uhrich et al., 2002; van der Linden et al., 2003a; van der Linden et al., 2003b; Veldhuizen et al., 2003). By only considering these dimensions in isolation, however, potential interactive and crossover effects on mental or physical performance cannot be evaluated. Previous evidence indicates that physical fatigue and mental fatigue do interact to affect performance (e.g., Davis et al., 2002;

Leyman et al., 2004; Lorist et al., 2002; Lundberg et al., 2002; Marcora et al., 2009; Van Cott, 1994). As nurses experience both mental and physical fatigue and perform tasks that require adequate mental and physical performance, an understanding of the relationships between fatigue and performance in this population requires simultaneous consideration of both mental and physical fatigue and their direct and indirect effects on performance.

In summary, the prevalence of medical errors within healthcare is a substantial problem. Given their role in providing healthcare services, nurses' performance is closely tied to patient safety. Fatigue is a construct that has been associated with performance decrements in a number of industries including healthcare. Registered nurses report experiencing multiple dimensions of fatigue (mental and physical), which might have implications for both mental and physical aspects of performance. However, existing research related to fatigue in healthcare has not simultaneously measured both mental and physical fatigue dimensions and their direct and crossover relationships with mental and physical performance. Further, fatigue levels have not been experimentally manipulated; thus, causal relationships between fatigue and performance have not been adequately demonstrated or supported. As such, the role of fatigue in medical errors should be further clarified.

The overall goal of this study was to evaluate hypothesized causal relationships between mental and physical fatigue, and performance during nursing tasks. Two levels of mental and physical fatigue were induced in participants by varying task demands in a laboratory setting. Resulting fatigue levels were measured subjectively (perceptual responses) and objectively (physiological measures). Performance on a range of mental and physical tasks was also measured. The hypotheses for the study were, first, that increasing levels of mental demands would cause higher levels of mental fatigue and decreased mental performance following the work. Second, that increasing levels of physical demands would cause higher levels of physical fatigue and decreased physical performance following the work. Third, that induced levels of mental and physical fatigue would interact to affect mental and physical performance.

Methods

Experimental Design

Participants completed four experimental sessions involving simulated nursing tasks. Mental and physical demands of these tasks were manipulated to induce high and low levels of mental and physical fatigue. A repeated measures design was used, in which participants were exposed to all four combinations of two levels (high and low) of mental and physical fatigue in separate sessions. Balanced Latin Squares were used to specify the order of exposure, to minimize potential confounding effects. Participants also completed an initial orientation session to allow for familiarization with experimental tasks and performance measures.

Participants

Sixteen participants completed the study, with equal numbers of males and females. All participants were 20 to 24 years old (participants 18 to 30 were eligible) in order to minimize potential age-related differences. The mean (SD) ages of male and female participants were 21.5 (1.5) and 21.1 (1.6) years, respectively. All participants except one were currently-enrolled university students, who were able to complete three hours of physically and mentally demanding work. Participants were also required to be (by self-report) healthy, exercise at least three times per week, and be free of recent/present musculoskeletal injury, chronic diseases, or cardiovascular conditions. A summary of participant demographics is included in Appendix C.

Measures

Dependent measures included a set of fatigue measures to quantify the levels of physical, mental, and total fatigue induced within each of the experimental sessions, a set of physical performance measures, and a set of mental performance measures. A majority of the dependent measures were collected prior to and following the work tasks segment of each experimental session to examine differences between initial and final levels of fatigue and performance. However, a few fatigue measures were collected throughout the experimental sessions.

Fatigue measures:

The fatigue measures included a set of three fatigue surveys. The Swedish Occupational Fatigue Inventory (SOFI) was used to measure five dimensions of fatigue: lack of energy, physical

exertion, physical discomfort, lack of motivation, and sleepiness (Ahsberg, 2000; Ahsberg et al., 1997). The SOFI asks participants to rate the extent to which they are feeling 20 distinct expressions, using response scales ranging from 0 (not at all) to 6 (to a very high degree). Dimension scores from this inventory have been used to quantify physical (physical exertion, physical discomfort), mental (lack of motivation), and total fatigue (lack of energy) levels in a range of worker populations (Ahsberg, 2000; Ahsberg et al., 1997). The Fatigue-Related Symptoms Questionnaire (F-RSQ) was also used to measure physical and mental fatigue (Yoshitake, 1978). The F-RSQ asks participants to indicate whether or not they are experiencing each of a set of 20 symptoms commonly associated with fatigue. Symptoms are grouped into two categories, corresponding to physical fatigue and mental fatigue. The F-RSQ has been shown to be sensitive to fatigue levels resulting from varying work task demands (Chen et al., 2003; Murata et al., 1991; Yoshitake, 1978), and has been used to measure physical and mental fatigue during nursing tasks (Soh et al., 1996). Finally, a fatigue questionnaire (FQ) developed by Chalder et al. (1993) was used to measure total fatigue. Participants were asked to respond on a 4-point scale (ranging from 1 = much worse than usual to 4 = much better than usual) regarding their feelings related to 11 fatigue symptoms. This questionnaire was developed to measure the severity of total fatigue and has been found to have good internal reliability as well as both face and discriminant validity (Chalder et al., 1993)

Additional measures of mental and physical fatigue were also used, and these were obtained throughout the work tasks. Ratings of perceived exertion (RPE), using Borg's (1982) CR10 scale, were solicited at the start of each task and during the work tasks at 3 min intervals. This scale ranges from 0 (nothing at all) to 10 (extremely strong, almost max) and participants choose the number that best represents their current level of physical exertion (Borg, 1970, 1982). Ratings on this scale have been demonstrated as valid indicators of fatigue levels during nursing (Soh et al., 1996) and other work tasks (Ahsberg et al., 2000a; Barnekow-Bergkvist et al., 2004; Borg, 1982, 1998; Oberg et al., 1994; Varghese et al., 1994). Participants practiced using the scale while performing a wall-squat task during the initial orientation session. Average RPEs for each experimental session were used as dependent measures.

Heart rate (HR) was also collected throughout the tasks, using an RS800 Polar Heart Rate Monitor (Lake Success, NY). HR data have been demonstrated to be valid measures of workload and fatigue during nursing tasks (Soh et al., 1996) and other physical and mental tasks (Ahsberg et al., 2000a; Astrand, 1960; Gamberale, 1972; Kilborn, 1971; Meshkati, 1988a, 1988b; Sammer, 1998). Specifically, increases in heart rate have been shown to be related to general physical fatigue (Astrand, 1960; Gamberale, 1972; Kilborn, 1971), and heart rate variability, calculated as the standard deviation, is sensitive to varying levels of mental workload (Kamath et al., 1993; Meshkati, 1988a, 1988b). As mental workload is a contributing factor to mental fatigue, heart rate variability may also be considered an indirect measure of mental fatigue. Average HR (bpm) was used as a dependent measure of physical fatigue; standard deviation between consecutive heart rates (heart rate interval fluctuations) was used as a dependent measure of mental fatigue.

Performance measures:

Both physical and mental performance were measured using a set of physical performance measures (PPM) and mental performance measures (MPM). Each measure within the PPM and the MPM was collected at baseline (the start of each experimental session) and upon completing the work tasks at the end of each experimental session.

The first PPM was force variability during an upright pulling task similar to the one described in Kroll et al. (2000). For this task, participants stood with 30 degrees of trunk flexion (verified with goniometric measurement), their feet shoulder width apart, and knees slightly bent. An adjustable chain with a horizontal handle at the top was attached to a load cell (SM-500, Interface Inc., Scottsdale, AZ) located in between the participant's feet. Participants were asked to pull up on the bar gradually and attempt to straighten the upper part of their body. During the orientation session, each participant's maximum voluntary contraction (MVC) for the task was collected. A target force, equivalent to 25% of maximal effort, and based on measured forces, postures, and anthropometry, was determined using commercial software (3D Static Strength Prediction Program™, version 6.0.2, Regents of The University of Michigan, Ann Arbor, MI). For the actual PPM, participants performed three 15-second trials of a force-matching task. The target force was displayed as a single white line on a computer monitor placed directly in front of

the participant. As participants pulled up on the bar, the actual force was displayed on the screen as a red line with a 3-second sweep across the screen. Participants were instructed to pull up on the bar so that their force matched the target force, and sustain their force at the target level. Forces were sampled at a frequency of 1 kHz, low pass filtered at 15 Hz, and the first second and last 4 seconds of each trial were removed for analysis. The coefficient of variation (COV) of the force fluctuation, averaged across the three trials, was obtained as a performance measure. Existing evidence suggests that force fluctuations during sustained contractions are sensitive to muscle fatigue across a range of muscles and target force levels (Clark et al., 2005; Dundon et al., 2008; Missenard et al., 2008; Sosnoff et al., 2006); thus force variability, rather than MVC, was used as a performance measure here.

A grooved pegboard (Lafayette Instrument model 32025, Lafayette, IN) was used as a measure of both speed and precision. The grooved pegboard measures gross movements of hands, fingers and arms, as well as fingertip dexterity and speed during assembly tasks (Fleischman et al., 1954; Tiffin, 1948). It has been used to assess fine motor performance in healthcare (Kaufman, 1987) and other occupational contexts that require fine and gross motor dexterity and coordination (Ghiselli, 1973; Sawyer et al., 2006). Participants completed two trials with the grooved pegboard, one for each hand.

Postural control of the lumbar spine was measured using an unstable seat apparatus similar to the one developed by Cholewicki (2000), the Wobble Chair (Lee et al., 2008). Participants were seated in a plastic chair mounted on a central pivot point, and which in turn was mounted on a triaxial force platform (AMTI™, Watertown, MA) with four adjustable springs positioned around the center. By changing the distance of the springs from the center, the restorative moment applied to the seat, and ultimately the task difficulty, can be controlled. Spring distances were calculated for each participant using the gravitational gradient method described in (Tanaka et al., 2009) and set at 60%. Participants were asked to sit with their arms crossed and eyes closed for a 75-second trial. Force platform measures were sampled at 1 kHz, converted to center-of-pressure time series (Winter, 2004) and from these several measures of “sway” were calculated (Prieto et al., 1996): ellipse area, total travel distance of the COP trajectory (distance), and mean velocity in both the antero-posterior (AP) and medial-lateral

(ML) directions. Such measures are often used to indicate the level of postural control (or stability) during upright stance, and are sensitive to fatigue and workload (DiDomenico, 2003; DiDomenico et al., 2005; Lin et al., 2009). Moreover, poorer postural control of the lumbar spine, specifically, is associated with low-back pain (Mientjes et al., 1999; Nachemson, 1985; Panjabi, 1992; Takala et al., 1997). As nurses have a relatively high incidence of low back pain (Denis et al., 2007; Yip, 2001), measures of spinal stability were considered more appropriate for this population than traditional measures of postural stability during upright stance (Cholewicki et al., 2000). The Wobble Chair allows for assessment of seated posture, wherein postural control of the lumbar spine can be assessed in isolation from control of the lower body joints (Cholewicki et al., 2000; Lee et al., 2008; Slota et al., 2008).

The final PPM was a novel box placement task. Participants performed a series of 10 trials in which they placed a rectangular box (31.75 x 33 cm) into three target locations (Figure 6). The target locations were set at “low”, “mid” and “high” elevations; low was on the floor, mid was on a table (76.2 cm off the ground), and high was set at hand height when a participant’s arm was positioned with their upper arm parallel to the ground and their elbow bent at 90°. All target locations were mounted on pivots and could be rotated. The box had two parallel handles (3.2 cm in diameter, spaced 12.7 cm apart) and was weighted to 10% of the participant’s body weight. For each trial, the participant began with the box on the ground (the “start position”). They then walked 3 m to a computer and referred to a chart to determine the placement order for the trial (e.g., mid-low-high). The participant then returned to the start position, picked up the box, and placed it in the three target locations in the specified order. The distances between the start position and the high, mid, and low target locations were 1.5, 2.7, and 2.7 m, respectively, and the distance between each of the target locations was ~ 0.9 m. Participants then returned the box to the start position and began the next trial. This pattern was repeated until the participant had completed 10 trials. Participants were instructed to complete the trials as quickly as possible but not to run. Their overall completion time for all 10 trials was recorded, as was the accuracy of their placements within each trial. Between each trial each target location was rotated to a new orientation. The set of 10 placement orders was randomly selected and was consistent across sessions in order to ensure equal travel distance; however, the placement orders were randomly ordered each time this task was performed. A repetitive box lifting task has been used

to evaluate occupational physical performance changes in soldiers after prolonged work and sleep deprivation (Nindl et al., 2002), and box lifting tasks are regularly used to evaluate physical performance of workers during functional capacity evaluations (Gouttebauge et al., 2004; Isernhagen et al., 1999; Johnson et al., 2001; Matheson et al., 2002; McKenney, 2000). The box placement task developed here was based on these existing measures and was intended to measure whole-body motor control and performance.

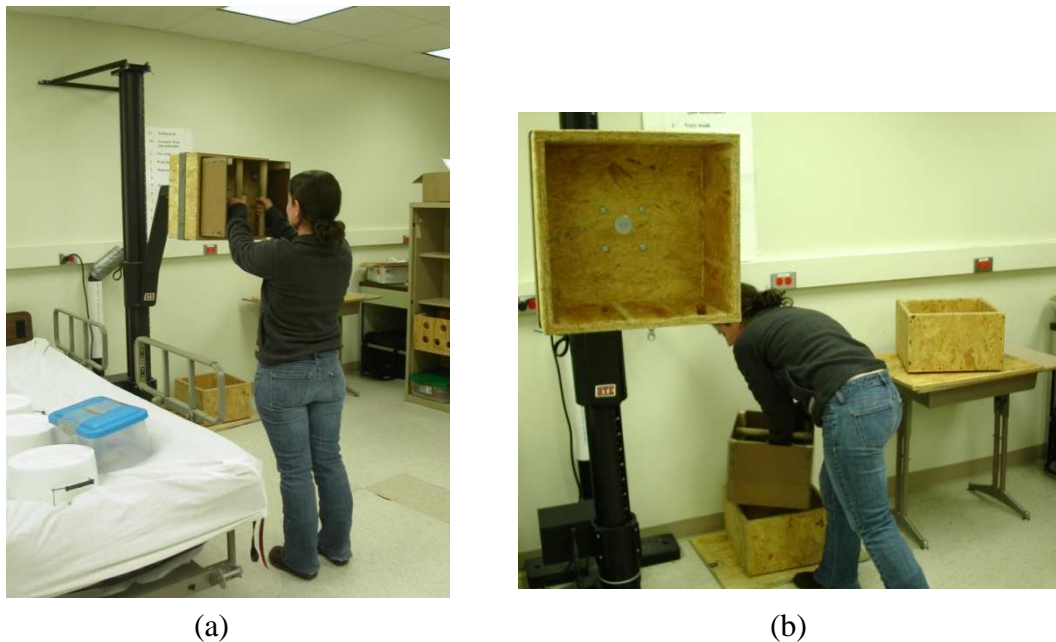


Figure 6. Participant placing the box in the “high” (a) and “low” (b) target locations.

The MPM were used to measure mental performance. As these tests were administered multiple times throughout the experimental sessions, special attention was paid to learning and/or training effects in selecting the measures. Nursing tasks involve vigilance, memory, arithmetic and problem-solving skills, thus standardized cognitive assessments targeting these skills were selected for the MPM. The tests were selected from the Automated Neuropsychological Assessment Metrics (ANAM), a computerized assessment tool developed by the Department of Defense, which measures processing speed, cognitive efficiency (accuracy/time), and memory (Kane et al., 1997; Reeves et al., 1996). The following ANAM subtests were administered: visual vigilance, code substitution (measures visual search, sustained attention, working memory), mathematical processing, logical reasoning, and running memory continuous

performance (measures sustained attention, concentration, and working memory). Performance on ANAM subtests is quantified by reaction time (RT) as well as a percentage score. ANAM has been used to evaluate cognitive function in a number of occupational settings and has been demonstrated as being sensitive to a variety of stressors such as fatigue, sleep deprivation, and general work stress (Cook et al., 2005; Hancock et al., 2001; Harris et al., 1996; Jordan et al., 1996; Lowe et al., 2007).

Procedures

During the orientation session, an informed consent procedure approved by the Virginia Tech Institutional Review Board was completed, including a general overview of the procedures and guidelines for the study (Appendix D). The mental and physical work tasks were demonstrated and participants were given an opportunity to practice the tasks and performance measures in order to minimize learning effects. Demographic data including participants' age, gender, ethnicity and fitness level were also collected.

Experimental sessions were scheduled at least 48 hours apart and at the same time of day to minimize residual fatigue and circadian rhythm effects. At the start of each experimental session, the heart rate monitor was affixed to the participant and participants completed baseline measures of fatigue and performance (SOFI, FRS-Q, FQ, PPM, MPM). The order of the fatigue and performance measures was consistent pre- and post-sessions, and across experimental sessions: force fluctuation task, pegboard, wobble chair, box placement, ANAM tests, and fatigue surveys.

Participants then completed three cycles of a set of nursing tasks with high and low mental and physical demands. As fatigue is correlated with workload, the tasks were designed to vary the workload and thus induce higher or lower levels of mental and physical fatigue. At the conclusion of the session, participants completed the post-session measures for fatigue and performance.

Simulated work tasks: Specific tasks were designed based on a review of relevant literature, pilot testing, and feedback from four registered nurses with experience working in acute care

facilities. Participants performed a sequence of seven major tasks (Table 8), several of which consisted of multiple subtasks, three times per session. The tasks took place in several rooms and hallways within a university academic building, and which were designed to simulate situations in an actual healthcare environment. The primary room contained a “nursing workstation”, a hospital bed, and supply shelves. The workstation was comprised of a desktop computer and a standard desk, as well as speakers that played a repeating loop of hospital sounds (e.g., equipment alarms, ambulance sirens, waiting room ambient noise) during high mental demand sessions. Two “patient rooms” were located approximately 9 m down the hall from the nursing workstation. Patient status parameters for six patients were displayed in sets of two in the patient rooms (Figure 7).

Table 8. Simulated nursing tasks.

Task	Description
Patient Transportation / Arithmetic Word Problems	Participants pushed a standard medical-surgical hospital bed (Hill-Rom model 820, Hill-Rom Services, Inc., Batesville, IN) approximately 111 m in a large loop down a 2.5 m wide corridor, making eight turns (combination of left and right). While pushing the bed, participants answered up to seven orally recited arithmetic word problems (Appendix E).
Patient Data Entry	Participants walked to the patient room and retrieved a set of patient notes. They returned to the nursing station and typed the notes into the appropriate field on the computer. Nursing notes were each 80-85 words and contained four highlighted abbreviations of standard medical treatment or documentation terms (Appendix F).
Medication Distribution	Participants first retrieved medications from pharmacy locations throughout the building. They then calculated medication dosages based on patient information presented on the nursing workstation computer. They counted out the appropriate number of each “pill” (small colored beads) and placed the pills into a medication cup for each patient. Medications were dispensed two at a time; participants would walk to the first pharmacy location, pick up the first two medications, return to the workstation, calculate dosages and dispense pills for the two patients receiving those medications, and then deliver the medication cups to the patient rooms using a medication cart.
Monitoring/ Recording Patient Status parameters	While delivering medications to the patients, participants memorized a set of parameters (e.g., heart rate, blood pressure) for two patients (Figure 2) and then returned to the nursing workstation and entered those parameters into each patient’s electronic chart on the nursing workstation computer.
Change Bed Sheet	Participants changed the hospital sheet on the bed. They then lowered and raised each of the four side rails.
Patient Transportation / Arithmetic Word Problems	Participants repeated the patient transportation task described above.
Supply Re-shelving	Participants moved supply bins from lower shelves (vertical distance from floor: 5 and 38 cm) to upper shelves (vertical distance from floor: 71 and 104 cm) on a supply shelving unit.

Patient Name: XXX

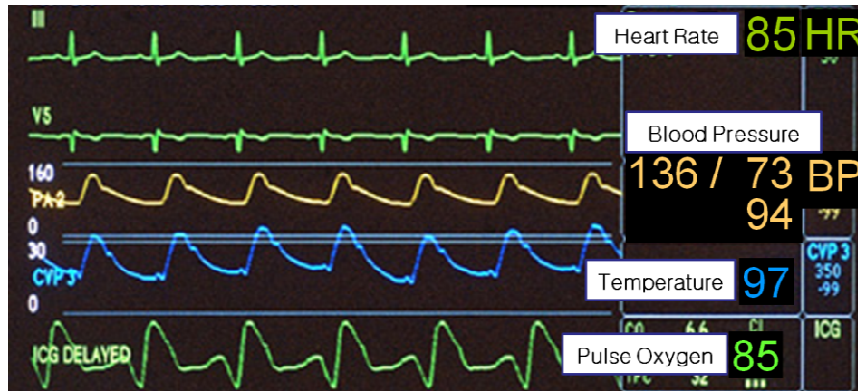


Figure 7. Screen-shot of patient status parameters for sample patient.

The seven tasks above (Table 8) were uniform across experimental sessions. Physical and mental demands associated with these tasks, however, were varied depending on the level of physical and mental fatigue being induced (Table 9).

Table 9. Nursing work tasks in the different mental and physical demand conditions.

Task	Mental Demands		Physical Demands	
	Low	High	Low	High
Patient Transportation / Arithmetic Word Problems	Simple addition	Multiplication/division	No additional weight on bed	273 kg of additional weight on bed
Patient Data Entry	No abbreviation substitutions required	Look up and enter medical abbreviations	Typing while seated	Typing while standing
Medication Distribution	Simple counting	Dosages are calculated using division, distracting questions asked during calculations (Appendix E)	Medications located on same floor, medication cart has no additional weight	Medications located down 2 or 3 flights of stairs, medication cart has 136 kg additional weight
Monitoring/Recording Patient Status parameters	Record only HR; no time limit	Record HR, BP, and Pulse Oxygen; 45 seconds to memorize	No additional weight on cart	136 kg of weight on cart
Change Bed Sheet	N/A	N/A	No additional weights on bed; hands unoccupied	273 kg (4, 68.25 kg weights) on bed; hands occupied
Patient Transportation / Arithmetic Word Problems	Simple addition	Multiplication/division	No additional weight on bed	273 kg of additional weight on bed
Supply Re-shelving	N/A	N/A	Two supply boxes must be moved (11 and 24.2 kg)	Four supply boxes must be moved (22, 26.4, 33, and 44 kg)
<i>Throughout session:</i>				
Distracting noise	No noise	Repeating loop of hospital sounds		
Items carried			Patient clipboard	Patient clipboard, 11 kg nursing supply box (23 x 36 x 15 cm, no handles)

Analysis

The total time spent completing the work tasks across experimental sessions was calculated. An analysis of variance (ANOVA) was performed to determine whether there were significant differences in total time spent on work tasks for low and high levels of mental and physical demands, and whether there was a gender effect on total task time. As there was a possibility of

recovery prior to completion of all performance measures at the end of each session, the time between the completion of the work tasks and the start of each performance measure was also calculated. ANOVAs were performed to determine whether there were differences in this delay time across mental and physical demand levels and between males and females.

Prior to any subsequent statistical evaluations, all fatigue and performance measures were evaluated for normality by assessing symmetry in histograms and using the Shapiro-Wilk statistic. Two measures, the SOFI Physical Exertion score and the F-RSQ physical fatigue score, were found to have non-normal residuals and were transformed using a Box-Cox transformation ($\lambda = -0.5$ and shift parameter $c = 1$). Normalized change scores were calculated for all perceived fatigue measures and all performance measures. The former were obtained by subtracting the 'pre' score from the 'post' score and dividing by the scale range. Change scores for performance measures were calculated as $(\text{post} - \text{pre}) / \text{pre}$. Both were converted to percentage changes. Absolute measures were used for the fatigue measures obtained during the sessions: RPE (average) and HR (average, standard deviation).

Two-sided t -tests were performed on all change scores to determine whether there were significant changes in fatigue or performance levels after completing the work tasks across all conditions. Initial mixed-factor ANOVAs were performed on all of dependent variables, with gender and order of exposure to conditions included initially as between-subject factors, and physical demand and mental demand and their interaction included as within-subject factors. Order of exposure was found to be non-significant ($p > .30$) for all perceived fatigue measures and all performance measures ($p > .35$), and order was thus removed from the model for all subsequent analyses. All statistical tests were performed in JMP 7.0.1 (SAS Institute Inc., Cary, NC) and were considered significant when $p < .05$.

Results

Task time

There were significant effects of mental and physical demand ($p < .0001$, for both) on total task time. Participants completed the low mental demand conditions 26% faster than the high mental demand conditions, and the low physical demand conditions 31% faster than the high physical

demand conditions. Mental and physical demand did not have any significant effects on the delay times between completion of work tasks and initiation of performance measures ($p = .13 - .98$). There was a significant effect of gender on the time between work task completion and the start of the ANAM tests ($p = .02$). This was likely due to differences in completion times for the box placement task between genders; males took 25% less time to complete the box placement task.

Fatigue levels

Based on normalized change scores for the perceived fatigue measures, mental, physical, and total fatigue levels increased significantly during all experimental conditions. Two exceptions were the SOFI Lack of Motivation score and the SOFI Sleepiness score, which both decreased on average (-0.13% and -0.39%, respectively) during the low physical demand condition, indicating slightly lower levels of perceived fatigue at the end of those sessions.

Physical demand and gender had significant effects on several fatigue measures (Table 10). Physical demand had significant effects on SOFI Physical Exertion, SOFI Lack of Energy, Average HR, and RPE, with higher values obtained during the high physical demand conditions and indicating increased fatigue. Females had significantly larger changes in perceived physical fatigue than males, based on the SOFI Physical Discomfort (8.85 vs. 0.91%) and F-RSQ Physical (15.63 vs. 3.13%). Females also had significantly higher Average HR (113.73 vs. 93.35 bpm) across all experimental conditions. Mental demand and the interaction effect between physical and mental demand did not have significant effects on any of the fatigue measures. There was a trend for an interaction effect between physical and mental demands on RPE. The Average RPE measure increased between low and high physical demand conditions, regardless of mental demand condition; however, this increase was lower in magnitude for high mental demand conditions compared to low mental demand conditions.

Table 10. Summary of ANOVA results (p -values) regarding the effects of Physical Demand (PD), Mental Demand (MD), and Gender on fatigue measures. Dependent measures are normalized change scores (except as noted), and are presented as means (SD).

Measure	Physical Demand			Mental Demand			$PD \times MD$	Gender
	Low	High	p	Low	High	p	p	p
SOFI Physical Exertion	3.13 (5.29)	11.85 (10.59)	<.0001*	8.59 (9.64)	6.38 (9.16)	0.21	0.71	0.12
SOFI Physical Discomfort	2.60 (8.32)	7.16 (12.84)	0.10	5.47 (10.71)	4.30 (11.37)	0.67	0.23	0.001*
SOFI Lack of Motivation	-0.13 (9.07)	1.82 (16.18)	0.52	1.30 (14.76)	0.39 (11.32)	0.77	0.58	0.56
SOFI Sleepiness	-0.39 (14.83)	2.73 (15.54)	0.29	1.43 (15.50)	0.91 (15.03)	0.86	0.93	0.77
SOFI Lack of Energy	6.12 (13.09)	15.89 (16.58)	0.006*	10.03 (13.83)	11.98 (17.38)	0.57	0.79	0.06
F-RSQ Physical	7.42 (10.93)	11.33 (15.99)	0.15	10.55 (14.59)	8.20 (12.94)	0.38	0.25	0.0086*
F-RSQ Mental	5.86 (15.22)	9.38 (21.30)	0.38	5.08 (16.45)	10.16 (20.19)	0.20	0.77	0.21
FQ	-4.17 (10.03)	-7.10 (14.14)	0.28	-4.73 (11.60)	-6.53 (13.00)	0.51	0.51	0.29
HR (bpm) [#]	98.87 (14.36)	112.74 (16.70)	<.0001*	106.13 (16.40)	105.70 (17.82)	0.74	0.69	0.04*
HR Variability (msec) [#]	180.19 (70.81)	164.61 (43.32)	0.19	179.83 (55.26)	164.47 (61.64)	0.17	0.38	0.29
RPE [#]	1.79 (1.66)	2.76 (1.73)	<.0001*	2.18 (1.79)	2.37 (1.73)	0.26	0.09	0.13

* significant at $p < .05$

[#] data are mean values within a session

Physical performance

For physical performance measures, average performance on the pegboard increased significantly across all experimental conditions. Accuracy on the box placement task also improved across all experimental conditions, however this improvement was not significant ($p = .052$). Performance on two of the four wobble chair measures (ML Velocity and AP Velocity) significantly improved across all conditions, while changes in the Ellipse Total and Distance measures were not significant ($p = .62$ and $.72$, respectively). Performance on the force fluctuation task decreased significantly across the conditions. Performance on the Box Placement Time measure decreased in the high physical demand, low mental demand, and high mental demand conditions, though this difference was not significant across all conditions ($p = 0.07$).

Physical fatigue had a significant effect on physical performance (Table 11). Specifically, exposure to high levels of physical fatigue resulted in greater increases in box placement times, indicating that performance on this task was more negatively affected by the higher physical demands. The effects of physical fatigue on the Force Fluctuation and Wobble Chair – AP Velocity measures were suggestive, with higher levels of physical fatigue again leading to decreased performance. Males had smaller change scores for the Box Placement Time than females (-.05 vs. 3.67%), indicating that their performance on this measure improved slightly after completing the work tasks across all experimental conditions, while performance among females decreased. Mental and physical fatigue and their interaction did not significantly affect any other of the physical performance measures.

Table 11. Summary of ANOVA results (*p*-values) regarding the effects of Physical Fatigue (*PF*), Mental Fatigue (*MF*), and Gender on physical performance measures. Dependent measures are normalized change scores and are presented as means (SD).

Measure	Physical Fatigue			Mental Fatigue			<i>PF x MF</i>	Gender
	Low	High	<i>p</i>	Low	High	<i>p</i>	<i>p</i>	<i>p</i>
Force Fluctuation	4.93 (16.94)	12.96 (23.55)	0.14	10.47 (18.38)	7.41 (23.07)	0.57	0.19	0.42
Pegboard - Left Hand	-4.39 (7.75)	-2.36 (8.79)	0.82	-2.35 (8.90)	-2.81 (8.07)	0.81	0.87	0.37
Pegboard - Right Hand	-2.80 (8.19)	-3.05 (8.67)	0.48	-4.69 (7.39)	-2.75 (8.93)	0.31	0.61	0.29
Box Placement - Accuracy	2.81 (8.27)	1.99 (11.02)	0.74	2.89 (9.09)	1.91 (10.34)	0.69	0.9963	0.64
Box Placement - Time	-1.11 (7.77)	4.73 (6.75)	0.0016*	0.53 (7.30)	3.09 (8.18)	0.15	0.41	0.06*
Wobble Chair - Ellipse Total	-3.71 (62.85)	11.25 (57.20)	0.28	4.72 (52.50)	2.82 (67.66)	0.89	0.79	0.14
Wobble Chair - ML Velocity	-21.12 (19.24)	-16.33 (18.98)	0.32	-20.07 (19.62)	-17.38 (18.81)	0.58	0.43	0.18
Wobble Chair - AP Velocity	-19.60 (23.94)	-7.76 (30.19)	0.078	-13.71 (29.50)	-13.65 (26.22)	0.99	0.41	0.11
Wobble Chair - Distance	-4.27 (35.85)	7.28 (31.57)	0.18	1.36 (32.34)	1.65 (36.12)	0.97	0.94	0.25

* significant at $p < .05$

Mental performance

For mental performance measures, performance on the Logical Relations Score and Code Substitution Score measures decreased in all experimental conditions, though not significantly (*p*

= .10 and .27). Performance on the Simple Reaction Time RT and Math Processing RT improved across all experimental conditions, though again, not significantly ($p = .12$ and $.18$). Performance on the Running Memory Continuous RT tasks improved significantly across all experimental conditions, while performance on the 2 Choice Reaction Time RT, Code Substitution Delayed RT, and Code Substitution Delayed Score measures decreased significantly across conditions.

Several of the mental performance measures were significantly affected by gender, physical fatigue, mental fatigue, and the interaction between physical and mental fatigue (Table 12). The interaction effect between physical and mental fatigue was suggestive for changes in 2-Choice Reaction Time Scores. When physical fatigue was low, change scores on the 2-Choice Reaction Time Score measure increased with mental fatigue. In contrast, in high physical fatigue conditions, the change scores decreased with mental fatigue. Mental fatigue had a significant effect on the Code Substitution Reaction Times, and there was a suggestive trend for the effect of physical fatigue on this measure. Reaction times on this test actually improved in the high mental demand conditions (2.07% faster), though, compared to the low mental demand conditions (8.41% decrease in performance). However, with regard to physical fatigue, the change scores indicated decreases in performance (6.59%) in the high physical fatigue conditions and increases in performance (0.25%) in low physical fatigue conditions. Physical fatigue also had a significant effect on reaction times in the Logical Relations task. Again, in the high physical demand conditions performance on this measure decreased (1.27%) while in the low physical demand conditions performance increased (9.97%). Finally, gender had a significant effect on reaction time in the Memory Search measure. Across all conditions, male reaction times increased (4.12%), while female reaction times decreased (6.57%). Thus, male performance on this task was worse after completing the work tasks and female performance improved following the work tasks.

Table 12. Summary of ANOVA results (p -values) regarding the effects of Physical Fatigue (PF), Mental Fatigue (MF), and Gender on mental performance measures. Dependent measures are normalized change scores and are presented as means (SD).

Measure	Physical Fatigue			Mental Fatigue			$PF \times MF$	Gender
	Low	High	p	Low	High	p	p	p
Simple Reaction Time RT	-4.90 (13.99)	-1.18 (16.62)	0.31	-1.29 (15.90)	-4.79 (14.82)	0.33	0.37	0.71
2-Choice Reaction Time RT	5.63 (13.28)	3.58 (15.80)	0.57	7.54 (16.74)	1.67 (11.41)	0.11	0.23	0.61
2-Choice Reaction Time Score	0.87 (7.27)	2.30 (5.55)	0.41	0.81 (5.80)	2.36 (7.06)	0.37	0.08	0.27
Code Substitution RT	-0.25 (17.38)	6.59 (19.33)	0.13	8.41 (19.05)	-2.07 (16.73)	0.02*	0.43	0.48
Code Substitution Score	0.26 (6.12)	-1.64 (3.27)	0.16	-0.49 (2.82)	-0.90 (6.47)	0.76	0.96	0.09
Math Processing RT	-4.24 (20.17)	-3.15 (24.05)	0.85	-2.41 (21.14)	-4.98 (23.14)	0.65	0.65	0.87
Math Processing Score	4.06 (24.31)	2.81 (19.73)	0.83	0.20 (8.36)	6.67 (29.82)	0.26	0.90	0.36
Logical Relations RT	-9.97 (20.31)	1.27 (23.94)	0.04*	-1.68 (20.94)	-7.03 (24.45)	0.32	0.63	0.21
Logical Relations Score	-1.32 (7.44)	-2.24 (9.50)	0.63	-1.03 (6.00)	-2.54 (10.43)	0.43	0.48	0.23
Running Memory Continuous RT	-4.44 (10.67)	-5.56 (11.11)	0.66	-4.75 (10.87)	-5.25 (10.94)	0.84	0.92	0.71
Running Memory Continuous Score	-0.09 (19.67)	-1.19 (8.91)	0.78	-1.87 (10.99)	0.59 (18.52)	0.52	0.33	0.63
Code Substitution Delayed RT	6.48 (21.71)	4.82 (23.63)	0.77	5.26 (26.10)	6.05 (18.70)	0.89	0.66	0.64
Code Substitution Delayed Score	-5.30 (12.11)	-4.24 (6.31)	0.65	-4.21 (7.68)	-5.33 (11.29)	0.64	0.82	0.69
Memory Search RT	-2.07 (13.96)	-0.38 (23.75)	0.72	0.87 (20.45)	-3.32 (18.25)	0.38	0.21	0.0408*
Memory Search Score	-1.04 (4.63)	-0.97 (4.43)	0.95	-1.61 (3.80)	-0.40 (5.09)	0.27	0.29	0.83

* significant at $p < .05$

Discussion

Effects of task demands on fatigue

Total fatigue, as measured by the SOFI-Lack of Energy and FQ scales, increased (~ 4 – 16%) across all experimental conditions (Table 10). Physical fatigue, as measured by the SOFI Physical Exertion, SOFI Physical Discomfort, and F-RSQ Physical scales measures, also increased (~3 - 12%) during all the experimental conditions. Perceived levels of physical fatigue were sensitive to the manipulation of physical demands, being larger in the high physical

demand conditions (Table 10), and supporting the initial hypothesis that increasing physical demands would result in higher levels of physical fatigue. Moreover, levels of perceived physical fatigue at the end of high physical demand conditions, as measured by the SOFI PE and F-RSQ Physical scales, were comparable to levels of physical fatigue reported by registered nurses (Chapter 2).

Perceptions of mental fatigue, measured using the F-RSQ Mental scale, also increased following exposures to all levels of mental and physical demands (Table 10). Though not significant, changes in F-RSQ Mental fatigue were higher on average in the high vs. low mental demand conditions (10 vs. 5%). Thus, while the work tasks in general did lead to increased perceived levels of mental fatigue, and F-RSQ Mental fatigue changes were larger in high mental demand conditions, the initial hypothesis regarding causality was not supported. Simulated mental demand levels, however, may not have been representative of those present in actual nursing environments. Reported mental fatigue levels upon completion of the high mental demand conditions here (SOFI LoM: 0.9-1.2; F-RSQ Mental: 17.2-25.8) were notably lower than values reported by registered nurses (Chapter 2) using the same measures (SOFI LoM: 2.0; F-RSQ Mental: 36.8).

Although mental fatigue has been successfully induced in a laboratory setting by having participants perform cognitively demanding tasks (Ahsberg, 2000; van der Linden et al., 2003a), comparisons were made between fatigued and non-fatigued conditions rather than between two levels of mental fatigue. Nursing work is mentally demanding, though, and a recent survey of registered nurses indicated that nurses actually perceive higher levels of mental fatigue in their work than physical fatigue (Chapter 2). Therefore, it is important to consider multiple levels of mental fatigue rather than an absence of this construct when investigating causal relationships between fatigue and performance. Future work should build on the trends in mental fatigue levels observed here, and consider extending the duration of work tasks or increasing mental demands during the “high” condition to achieve distinct levels of mental fatigue.

There was a gender effect on fatigue levels, with females showing greater changes in both perceived and physiological measures of fatigue across experimental conditions. Existing

research related to occupational fatigue has also found that females perceive higher levels of fatigue (Ahsberg et al., 2000b; Akerstedt et al., 2004). In particular, Ahsberg et al. (2000b) reported that female shiftworkers reported higher levels of total and physical fatigue on the SOFI. Although the nursing workforce is predominantly female, the percentage of male registered nurses has grown in recent years (Spratley et al., 2001). Thus, it is important to continue to consider gender differences in fatigue levels within this population.

Effects of fatigue on performance

The effects of fatigue on aspects of performance in previous studies of healthcare workers have been mixed (Caldwell, 2001; Flin et al., 2003; Howard et al., 2002; Krueger, 1994; Landrigan et al., 2004; Owens, 2001). Performance on tasks requiring high levels of vigilance, tasks of long duration, or tasks requiring newly learned procedural skills appear more vulnerable to the effects of fatigue (Owens, 2001). Within this study, performance on the tasks requiring endurance and holistic motor control (Box Placement and Force Fluctuation), as well as those requiring more complex cognitive processing (Code Substitutions and Logical Relations), were also more sensitive to changes in fatigue levels.

With regard to the physical performance measures, only physical fatigue had a significant effect on any of the measures (Table 11). The physical demands within the study were likely insufficient to induce peripheral physical fatigue. Thus, those measures that had larger intrinsic motivational components (Box Placement, Force Fluctuation), and thus may have been more susceptible to central physical fatigue, were more vulnerable to effects of physical fatigue.

For the mental performance measures, RT measures were more frequently (and negatively) affected by increases in physical fatigue, while score measures were negatively affected by changes in both physical and mental fatigue levels (Table 12). Two measures were significantly affected by fatigue levels; logical relations reaction time was negatively affected by physical fatigue, and the Code Substitution RT measure was positively affected by mental fatigue. This significant improvement in performance in the high mental fatigue conditions compared to the low mental fatigue conditions may be explained by considering the role of arousal in mental performance. The relationship between mental demands, arousal, and human performance is

generally thought to be an inverted U-shaped curve (Selye, 1976; Welford, 1973; Yerkes et al., 1908). At low levels of demand or fatigue, there is insufficient arousal, motivation, and engagement in the task leading to decrements in accuracy, response time, and organization of task strategy (Welford, 1973). In contrast, high mental demands and resulting mental fatigue levels are also associated with performance decrements due to insufficient attentional resources and changes in arousal regulation and information flow (Grandjean, 1968; Welford, 1973). The levels of mental demands and associated mental fatigue within this study may have been shifted on this inverted U curve; thus, in the low mental fatigue conditions, the participants may have had insufficient arousal compared to the high mental fatigue conditions, leading to improvements in performance in the high mental fatigue conditions.

Additionally, the Logical Relations, Code Substitution and Memory Search tasks, which require more complex rule- and knowledge-based levels of cognitive processing (Rasmussen, 1983), were most negatively affected by fatigue across conditions. Cognitive tasks that require memory, learning, logical reasoning, mathematical processing, pattern recognition, and decision-making have also been shown to be more impaired by fatigue and sleep loss in other industries compared to tasks that require simple cognition (Babkoff et al., 1985; Krueger, 1989, 1994; Ryman et al., 1985). The performance decrements in these measures due to induced fatigue are critical and relevant in nursing, as nurses' tasks frequently require critical thinking and cognitively complex processing such as decision-making, diagnosing, and evaluating (Page, 2004). It is also worth noting that standard deviations on most of the physical and mental performance measures (Tables 11 and 12) were high compared to the means, emphasizing substantial interindividual variability. The current sample size was also somewhat small, and large individual differences in the responses to fatigue could have masked what may be relatively subtle effects of fatigue on performance.

One of the primary initial hypotheses was that there would be significant interaction and crossover effects of mental fatigue on physical performance and of physical fatigue on mental performance. However, mental fatigue did not significantly affect any of the physical performance measures. As noted earlier, this may be attributable to a failure in adequately manipulating mental workload to induce two statistically (and substantially) distinct levels of

mental fatigue, as well as the relatively lower mental fatigue levels induced compared to those reported by registered nurses (Chapter 2). Increases in mental demands in existing studies have been associated with decreases in measures of physical performance, such as increased muscle activity and increased muscle contraction force variability (e.g., Davis et al., 2002; Leyman et al., 2004; Lorist et al., 2002; Lundberg et al., 2002; Van Cott, 1994). Thus, the relationship between mental fatigue and physical performance deserves further attention.

While mental fatigue levels did not significantly affect any of the physical performance measures, physical fatigue levels did negatively affect mental performance, particularly reaction time measures. When humans are physically fatigued, their reaction times and accuracy will decrease during cognitive tasks (Lorist et al., 2002). Slowed reaction times have been shown to impair performance and lead to errors in healthcare work environments (Krueger, 1994). Additionally, results from several studies indicate that fatigued medical residents will frequently sacrifice efficiency in performing tasks to preserve accuracy (Craig et al., 1985; Krueger, 1994; Owens, 2001). In critical situations, though, where both speed and accuracy are required, this strategy is often insufficient and medical errors may occur (Craig et al., 1985; Howard et al., 2002; Krueger, 1994; Owens, 2001). The significant effects of physical fatigue levels on mental performance measures in this study further highlight the importance of a multidimensional definition of fatigue when considering the relationship between occupational fatigue and performance.

Limitations and future directions

This study has several limitations that should be acknowledged. First, fatigue is a construct that has been traditionally difficult to define and measure. There are likely many individual, environment, and work factors that influence the development of fatigue in workers. It was impossible, though, to control for all of these factors, and thus confounding factors may have been present that could also account for variations in fatigue levels and performance across experimental conditions. The experiment took place across several rooms and hallways in an academic building and factors such as increased traffic in the hallways could not be controlled. This lack of control may have introduced variability across participants and experimental sessions, which may have decreased the power of the study. However, this lack of control of

distractions or environmental factors in the experimental setting was likely more representative of an actual clinical work environment.

In addition, participants were relatively young, healthy adults (~21 years old) compared to the U.S. nursing workforce, which is aging and will have an average projected age of 45.5 years by 2010 (Buerhaus et al., 2000). Further, participants in the current study had no previous nursing work experience. While the experimental tasks were designed so as not to require any nursing knowledge or experience, the fatigue levels induced and resulting performance changes in these “novice” participants may not represent those that would occur in working nurses. In particular, the levels of mental fatigue were lower than those reported by registered nurses. However, the participants may be representative of younger registered nurses just entering the workforce. As turnover rates and shortages of skilled workers are substantial challenges within nursing (ANA, 2001; Page, 2004; Sochalski, 2002), understanding fatigue and performance in these novice nurses may be critical for recruitment and retention.

There was also a potential confounding effect of task completion time. Due to the design of the study, which varied task demands while holding constant the overall set of tasks to be completed, the conditions involving high levels of physical and mental demands took significantly longer to complete. This was done in an effort to control for motivational issues that might arise if participants had to work for a set amount of time but did not complete the same number of tasks. During the sessions, participants were not informed as to how long they had been working, and when completing the subjective fatigue measures participants were instructed to respond based on how they felt after completing the set of work tasks. Thus, their reported fatigue levels are likely based on the task demands rather than the amount of time they worked.

Regardless of the levels of mental and physical demand, the work tasks were performed for only 1-2 hours, clearly shorter than the 8 - 12 hour shifts common in nursing. As such, the levels of fatigue induced may not have been representative of those found in actual nursing work environments. Specifically, the physical fatigue levels after completing 1.5-2 hours of simulated nursing tasks in the current study were comparable to those reported by registered nurses at the end of full work shifts (~8-12 hours) in Chapter 2. Mental fatigue levels in the current study, in

contrast, were notably lower than those reported by registered nurses in Chapter 2. This difference in the induced levels of mental and physical fatigue may be attributable to high or low mental and physical demands in the simulated tasks compared to actual nursing work, or to differences in the rate of development of these two dimensions of fatigue. General fatigue symptoms and performance decrements in nurses are more severe after 12-hour shifts compared to 8-hour shifts (Josten et al., 2003; Szczurak et al., 2007), and fatigue-related symptoms change over the course of nursing work shifts, with the greatest increases occurring in the second half of a shift (Soh et al., 1996). Here, performance and fatigue levels were assessed upon completion of the work tasks, and this design may have allowed for some recovery from induced fatigue prior to these measures being collected. An attempt was made to minimize differences in this recovery across conditions, by collecting the performance and fatigue measures in a consistent order at the beginning and end of each session, and also by ensuring that the time between task completion and performance and fatigue measures was consistent across sessions. Future research should examine the relationships between sub-dimensions of fatigue and performance over a longer work period, and with measurement points throughout the work tasks, to determine more accurately the rate of fatigue development and associated performance changes.

Performance measures used here were chosen to assess specific dimensions of physical and mental performance that were intended to represent skills needed in nursing tasks; however, they may not have been representative of actual performance in a clinical setting. Further, effect sizes for all of the performance measures were relatively small ($.0001 < \eta^2 < .14$), indicating that they may not have been sensitive to the manipulations of mental and physical fatigue levels. The largest effect sizes were associated with the significant effects presented earlier in Tables 11 and 12; specifically, the effect of physical fatigue on Box Placement Time was 0.14, the effect of mental fatigue on Code Substitution RT was 0.08, the physical fatigue by mental fatigue interaction effect on 2-Choice Reaction Time Score was 0.06, and the physical fatigue effect on Logical Relations RT was 0.06. Additionally, most of these measures targeted aspects of physical and mental performance in isolation from each other. Applied performance in work-settings is often a combination of both physical and mental performance dimensions with participants completing multiple tasks simultaneously. Potential dual-task performance implications were not considered in this study. Future research should incorporate a broader set

of performance measures embedded within actual work tasks wherever possible. The increasing prevalence of medical simulators in medical education and healthcare facilities worldwide may provide opportunities for measuring performance during clinically relevant tasks and scenarios without compromising patient care.

Finally, the current study was concerned primarily with performance as it relates to patient safety and medical errors. However, in addition to high numbers of medical errors, the healthcare industry also has relatively high rates of occupational injuries and illnesses. Evidence exists linking long work hours, sleep deprivation, and fatigue to worker injuries, particularly among nurses and medical trainees (Fisman et al., 2007; Lipscomb et al., 2004; Trinkoff et al., 2006; Trinkoff et al., 2001). Fatigue resulting from long work hours and physically demanding work is associated with numerous behavioral changes, such as haste, distraction, inattention, reduced motivation and willingness to exert effort, decreased perception of performance limitations, and failure to check equipment, all of which might have implications for both patient and nurse safety (Caldwell, 2001; Flin et al., 2003; Frzovic et al., 2000; Howard et al., 2002; *Implications of fatigue on patient and nurse safety*, 2005; Krueger, 1994). Specifically, these changes could affect how nurses perform work tasks, or their willingness to take short-cuts (e.g., performing patient-handling tasks without assistance), which could increase injury risk. Additional research is needed to measure these behavioral consequences of fatigue related to both patient and provider safety.

Conclusions

The performance of nurses has implications for both patient and provider safety. Fatigue has been identified as a factor that influences performance across work contexts; however, findings on whether mental and physical dimensions of fatigue have significant effects on aspects of mental and physical performance are mixed. This study was able to successfully induce mental fatigue, total fatigue, and two distinct levels of physical fatigue in participants. Results indicate that mental fatigue significantly affected one measure of mental performance. Physical fatigue, though, had a significant negative effect on multiple measures of both physical and mental performance. Thus, a multidimensional view of fatigue that considers both direct effects between mental fatigue and mental performance and physical fatigue and physical performance,

as well as crossover effects between dimensions of fatigue and performance, is relevant when quantifying effects of fatigue on performance. Future work should build on these findings and incorporate longer work times, increased mental demands, and clinically-relevant embedded task-based performance measures in order to define further the causal relationships between fatigue and performance. By understanding these relationships we may ultimately be able to predict when fatigue-related performance decrements will occur and develop appropriate interventions.

Chapter 4: Total fatigue as a mediator in relationships between distinct dimensions of fatigue and performance: A structural equation modeling approach among registered nurses

Abstract

Background: While fatigue has been linked to performance decrements in a number of professions, including nursing, relationships between mental and physical dimensions of fatigue and total fatigue, as well as the effects of fatigue on performance, have not been fully defined.

Objectives: A quantitative model was developed that relates mental and physical dimensions of fatigue to total fatigue and evaluates direct and indirect effects of dimensions of fatigue on dimensions of performance.

Methods: Data from a previous survey of registered nurses quantifying perceived levels of mental, physical, and total fatigue, and performance were used to estimate the model using structural equation modeling techniques. Initial hypothesized and alternate models were evaluated for fit, and a final model was cross-validated with a subset of the data sample.

Results: The initial, alternate, and validated models all had adequate fit ($GFI \geq .95$) to the data. Pathways in the initial and validated models revealed that total fatigue as a construct does exist and is directly affected by mental and physical fatigue. There were also direct effects between mental fatigue and mental performance and between physical fatigue and physical performance. However, the pathway between total fatigue and mental performance was not significant, suggesting that total fatigue may not play a mediating role in the relationship between dimensions of fatigue and performance. This lack of a mediating role was further supported by the alternate model, which included significant direct effect pathways between mental fatigue and physical performance and between physical fatigue and mental performance.

Conclusions: The final model provides quantitative estimates of the strength of the relationships between perceived dimensions of fatigue and performance in registered nurses. It can be used to implement fatigue interventions and evaluate their effectiveness at reducing fatigue levels and mitigating the negative effects of fatigue on performance.

Keywords: structural equation modeling, total fatigue, mental fatigue, physical fatigue, performance, nursing

Introduction

The overall goal or mission of health care organizations is to serve a community by providing quality medical care to patients in a safe and efficient manner. However, the prevalence of medical errors and the importance of accountability for medical outcomes have been cited as serious challenges for healthcare organizations in achieving this mission (Kohn et al., 1999; Van Cott, 1994). An increased emphasis on medical errors and the overall quality of services within this industry point to a need for further research to expand our understanding of factors that might influence the performance of healthcare workers.

Human performance is critical in any work system and is generally considered to be a function of the speed and accuracy a human maintains while working on a task (Sanders et al., 1993; Wickens et al., 2000). If the demands placed on a worker completing a task in a specific environment approach the limits of that worker's capacities or available attentional resources, performance decrements will occur in the form of reduced efficiency and increased error rates (Wickens et al., 2000). Much research has been performed investigating the factors, both intrinsic and extrinsic, that lead to decreases in worker performance. Fatigue is one such intrinsic factor, and which has been implicated both indirectly and directly in numerous industries as a cause of human error (Akerstedt, 2000; Caldwell, 2001; Caldwell et al., 2002; Miller, 2005; Moss et al., 1981; Muecke, 2005; Peters et al., 1999). Further, fatigue in the healthcare domain has been frequently noted as a contributing factor to medical errors (Caldwell, 2001; Craig et al., 1985; Flin et al., 2003; Howard et al., 2002; Krueger, 1994; Landrigan et al., 2004; Owens, 2001)

While fatigue has been linked to performance in several occupational sectors, the causal mechanisms linking fatigue and performance have not been fully defined. Extant research on fatigue and performance in healthcare indicates that certain tasks or aspects of performance are more susceptible to fatigue-related decrements. Specifically, performance on tasks requiring vigilance, more complex procedural skills, or a combination of both physical speed and accuracy have been shown to be most vulnerable (Craig et al., 1985; Krueger, 1994; Owens, 2001). Further, most studies on the relationship between fatigue and performance have focused on specific aspects of fatigue within certain work tasks; for example, sleep deprivation in medical

residents (Butterfield, 1988; Eastridge et al., 2003; Samkoff & Jacques, 1991; Strunk et al., 1991), or physical fatigue in laparoscopic surgeons (Berguer, 1998; Berguer et al., 1997; Uhrich et al., 2002). Existing research has not considered a broader definition of fatigue, accounting for the main and interactive effects of multiple dimensions of fatigue on performance. As the occupational tasks of many healthcare workers (e.g., nurses, surgeons, or residents) consist of both physical and mental activities, a broader fatigue construct, namely “total fatigue” (see below), should be further defined and modeled to better understand the relationships between fatigue and performance.

Part of the difficulty in establishing the relationship between fatigue and performance in healthcare workers has been the lack of a clear consensus on a definition for occupational fatigue (Ahsberg, 2000; Akerstedt et al., 2004; Friedberg et al., 1998; Hockey, 1983; Soh et al., 1996). It is generally agreed that fatigue is a multicausal, multidimensional state, which arises in workers in response to exposures to excessive activity and psychological demands, and which over time can lead to decreased capacity and an increased risk for error (De Vries et al., 2003; Ream et al., 1996; Soh et al., 1996; Tiesinga et al., 1996). The inherent multidimensional aspect of this definition leads to a construct of “total fatigue”, which is comprised of distinct dimensions of fatigue (De Vries et al., 2003). However, the exact dimensions included in definitions of total fatigue have varied across the contexts or populations being considered (e.g., Ahsberg et al., 2000a; De Vries et al., 2003; Tiesinga et al., 1996). For healthcare workers, specifically nurses, who are consistently exposed to both mental and physical demands, it is likely that both mental fatigue and physical fatigue dimensions are present, can influence performance, and should be considered (Page, 2004; Trinkoff et al., 2001). Therefore, for the purposes of this research, the following definition is used:

Total fatigue is a state comprised of at least two dimensions: mental fatigue and physical fatigue. Mental and physical fatigue dimensions are present in nurses exposed to excessive mental and physical demands through their work tasks and schedules. These fatigue dimensions contribute to a state of total fatigue, which over time can result in these workers not being able to function at their normal capacity and can lead to an increased risk for injury or medical error.

Many existing studies of occupational fatigue and performance have addressed dimensions of total fatigue in isolation (Berguer, 1998; Berguer et al., 1997; Boksem et al., 2006; Lorist et al., 2000; Soh et al., 1996; Uhrich et al., 2002; van der Linden et al., 2003a; van der Linden et al., 2003b). Such isolation, however, does not allow for consideration of potential interactions or indirect effects of the different dimensions of fatigue on dimensions of performance (e.g., mental performance or physical performance). In contrast, dual-task studies, involving simultaneous mental and physical demands, have shown consistent interactive effects on mental and physical aspects of behavior and performance (e.g., Davis et al., 2002; Leyman et al., 2004; Lorist et al., 2002; Lundberg et al., 2002). Given this apparent complexity, and to understand better the mechanisms involved, a model would be of use, and which simultaneously considers both physical and mental fatigue dimensions and their direct and indirect effects on total fatigue and performance.

Indeed, a number of fatigue models exist, and numerous researchers have incorporated some component of fatigue into performance models. These range from conceptual models of fatigue to quantitative models using structural equation techniques to express the relationship between fatigue and various performance, work, and personal variables. For example, conceptual models of fatigue have been used to examine the relationship between fatigue and performance, work, and personal life factors (Papp et al., 2004; Sonnentag et al., 2006). Conceptual models have also been developed relating workload, arousal, and motivation to the development of fatigue in workers (Boksem et al., 2006; Finkelman, 1994; Macdonald, 2003; Schellekens et al., 2000).

Quantitative models relating fatigue and performance have also been developed. The Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) model (Miller, 2005) integrates circadian rhythms, cognitive performance recovery rates, and cognitive performance effects to model performance as it relates to mission safety under varying fatigue conditions. Using this model, principles of operational risk management are used to predict the timing and severity of fatigue episodes that might occur after exposure to fatigue risk factors during military operations; a goal of this is to manage fatigue-related impacts on overall safety and performance (Miller, 2005). The SAFTE model, however, is based largely on aspects of sleep deprivation and sleep quality as risk factors for fatigue. In this context, fatigue is viewed primarily as a consequence of

prolonged wakefulness or sleep deprivation rather than as a response to excessive work demands. While nurses and other healthcare workers are often sleep deprived and experience circadian rhythm disruptions, the focus of the current research is not on sleep deprivation and its associated consequences. Although the role of sleepiness as a potential moderator between task demands and fatigue levels is relevant and cannot be ignored, sleepiness is a distinct construct from total fatigue (Krueger, 1989; Lavidor et al., 2003; Shen et al., 2006). The current research is differentiated from much previous research by focusing on the relationship between work-induced (due to high task demands) fatigue and performance decrements.

Structural equation modeling (SEM) has been widely used to quantify the relationships between fatigue and diverse personal or work-related outcomes. SEM is a statistical method used to estimate the relationships between directly observed subjective or objective variables and their underlying constructs, as well as between various latent factors within a model (Hoyle, 1995; Schumacker et al., 2004). It allows for quantitative modeling of relationships between complex constructs, making it particularly well suited for research involving humans where many constructs of interest cannot be measured directly. For example, Byström et al. (2004) used SEM to examine how perceived fatigue impacts the relationship between workload and musculoskeletal symptoms among blue-collar assembly workers. Different dimensions of perceived fatigue were found to have different influences on the relationship between workload and musculoskeletal symptoms. SEM has also been used to model the relationship between work characteristics and diverse outcome variables, including intrinsic work motivation and emotional exhaustion, dimensions which are often considered components of total or emotional fatigue (Houkes et al., 2003).

Although a number of conceptual and quantitative models exist in the literature, a simple yet comprehensive model does not yet exist that relates dimensions of fatigue to total fatigue and evaluates the direct and indirect effects of dimensions of fatigue on dimensions of performance. Thus, the overall aim of this study was to develop such a quantitative model to assess the relationships between dimensions of fatigue and performance; this was done in a nursing context because nurses provide a majority of direct patient care in healthcare organizations and are thus closely linked to medical error. Further, nurses regularly perform a variety of mentally and

physically demanding tasks and report that they are both mentally and physically fatigued (Chapter 2). A set of six initial hypotheses were used to develop the model, based on previous research related to the multi-dimensionality of occupational fatigue and the interactive effects of mental and physical demands on performance during dual-task scenarios:

1. Mental fatigue will have a direct positive effect on total fatigue.
2. Physical fatigue will have a direct positive effect on total fatigue.
3. Mental fatigue will have a direct negative effect on mental performance.
4. Physical fatigue will have a direct negative effect on physical performance.
5. Total fatigue will have a direct negative effect on mental performance.
6. Total fatigue will have a direct negative effect on physical performance.

Structural equation analyses methods were used to test these hypotheses, to determine whether total fatigue exists as a distinct construct related to mental and physical fatigue, and identify if total fatigue plays a mediating role in the interactions between mental and physical dimensions of fatigue and performance. The final, validated model is expected to: 1) facilitate estimates of the likelihood of changes in performance based on measured levels of fatigue; and 2) guide interventions to eliminate or mitigate the adverse effects of fatigue on worker performance and safety in healthcare systems.

Methods

Overview

Data used in the current modeling efforts were obtained from a previous survey study investigating perceived levels of fatigue and performance in registered nurses (Chapter 2). In that study, 1006 registered nurses – all of whom were currently employed in a hospital, community or public health setting, ambulatory care, or nursing home/extended care facility – completed a set of surveys regarding their perceptions of fatigue and performance. Nurses were recruited through convenience sampling in cooperation with several nursing organizations and publications. A majority of respondents were female (94.2%), Caucasian (85.9%), and married (67.8%). Most respondents worked in an acute care setting (80.5%) and over half (57.7%) worked over 11 hours per shift on average. Additional demographic and work environment descriptors of the sample are provided in Chapter 2 of this document.

In the survey, eight instruments were compiled to form a “Fatigue in Nursing Survey Set” (FNSS). Results from four of these were used here to estimate the structural equation model, and which measured perceived mental fatigue, physical fatigue, total fatigue, and performance. These four instruments are described briefly here, and for additional detail the reader is referred to Chapter 2 of this document.

Fatigue: Subscales from the Swedish Occupational Fatigue Inventory (SOFI) were used to measure mental, physical and total fatigue dimensions (Ahsberg, 2000; Ahsberg et al., 1997). Specifically, the four items from the Physical Discomfort (PD) scale and the four items from the Physical Exertion (PE) scale were used to measure physical fatigue; the four items from the Lack of Motivation (LoM) scale were used to measure mental fatigue; and the four items from the Lack of Energy scale (LoE) were used to measure total fatigue. All subscales from the SOFI have been previously tested with multiple worker populations and found to be both reliable and able to discriminate between fatigue from mental versus physical work. Acceptable to good reliability was found for the inventory within the present study (Cronbach’s alphas = 0.76-0.88; Chapter 2).

The Fatigue-Related Symptoms Questionnaire (F-RSQ) was included to measure mental and physical fatigue dimensions (Yoshitake, 1978). In this instrument, 16 symptoms commonly associated with fatigue are grouped into two categories in order to obtain scores for mental and physical fatigue. Participants are asked to indicate whether or not they are experiencing each symptom at any specific moment and a percentage score is calculated for each dimension of fatigue. The F-RSQ has been used to measure mental and physical fatigue in nurses (Soh et al., 1996) and is sensitive to fatigue levels resulting from varying work task demands (Chen et al., 2003; Murata et al., 1991; Yoshitake, 1978).

The Fatigue Scale (FAS) was used to measure total fatigue (De Vries et al., 2003; Michielsen et al., 2003; Michielsen et al., 2004). The FAS includes 10 items that relate to different aspects of fatigue and are averaged to arrive at an overall total fatigue score. This scale has good reliability and content validity for measuring fatigue in a general or worker population (De Vries et al.,

2003; Michielsen et al., 2003; Michielsen et al., 2004). In the current study, acceptable reliability was found (Cronbach's $\alpha = 0.72$; Chapter 2).

Performance: Aspects of physical and mental performance were measured using new a Nursing Performance Instrument (NPI; Chapter 2). The NPI consists of nine items that describe different aspects of performance during nursing work tasks. Of the nine items, four relate to general performance standards, two (questions 5 and 7) relate to mental performance specifically, and three (questions 1, 4, and 8) relate to physical performance specifically. Mental performance items encompass perceptions of changes in concentration, alertness, communication, monitoring, arithmetic, and documentation aspects of mental performance during nursing tasks. Physical performance items relate to functional physical capacity, fine motor coordination, and safe patient handling aspects of physical performance. Cronbach's α values for the five mental and physical performance items ranged from 0.78 to 0.80 (Chapter 2).

Model Specification

SEM is a statistical method that allows for simultaneous estimation of the strength and direction of relationships between variables in a hypothesized theoretical model. One advantage of SEM is that it allows for simultaneous estimation of both direct and indirect relationships between a number of independent and dependent variables. Further, it can quantify the relationships between variables that are not directly measured and accounts for measurement error in variables that are measured. SEM also allows for analysis of group differences, interaction and main effects, and can be used to test causal hypotheses. SEM is intended to be a confirmatory method, in that models to be estimated should be specified *a priori*. For a summary of the theoretical basis of SEM, as well as general guidelines for performing SEM analyses, the reader is referred to texts by Hoyle (1995) and Schumacker et al. (2004).

A conceptual SEM (Figure 1) was initially developed relating mental fatigue, physical fatigue, total fatigue, mental performance, and physical performance. Quantitative parameters describing the magnitude and direction of relationships between variables in the model were then estimated using SEM estimation and analysis methodologies. As summarized earlier, total fatigue is generally recognized to be a broad and incompletely defined construct, encompassing at least

two underlying dimensions (physical and mental fatigue). From this, the conceptual model was generated based on the set of six initial hypotheses listed in the Introduction.

Full SEMs consist of two parts or sub-models, a measurement model and a structural model. The measurement model describes the relationships between observed (or indicator) variables and unmeasured (or latent) variables in the model. Latent variables are constructs in the model that are not directly measured, but rather are inferred from an associated set of indicator variables. In depicting SEMs, latent variables are shown using circles and indicator variables are shown using squares. Each of the latent variables has arrows pointing to, typically, two to five observed variables. These arrows illustrate which observed variables are hypothesized to be related to that particular latent variable, or that construct within the model. These relationships are the same as those found in a confirmatory factor analysis; the latent variables are the underlying factor and the observed variables are the items hypothesized to load on that factor. In the current model, the observed variables were all obtained from instrument scores or individual items within the FNSS. In addition to relating observed variables to latent variables, the measurement model is also used to establish a scale for the latent variables within the model. As latent variables are not directly measured, they initially do not have an associated measurement scale. However, in order to estimate the relationships between latent variables or between measurement variables and latent variables within the model, a scale must be defined for each latent variable. To this end, the factor loading between one observed variable associated with each latent variable was fixed to one, effectively assigning the measurement scale of that particular observed variable to the latent variable. The observed variables used to assign the scales were chosen based on Cronbach's Alpha measures of reliability (Tables 2 and 3, Chapter 2). For each latent variable, the associated observed variable with the highest reliability was used to establish the scale.

The structural model component of the SEM specifies the directional relationships between latent variables in the model. In the present hypothesized structural model (Figure 8), mental fatigue and physical fatigue were depicted as exogenous latent variables, in that they are not dependent on any other latent variables in the model. Total fatigue, mental performance, and physical performance are endogenous latent variables and were hypothesized as being dependent

on (directly affected by) at least one other latent variable. Structural paths between these five latent variables were specified using arrows to indicate the direction of the hypothesized relationship.

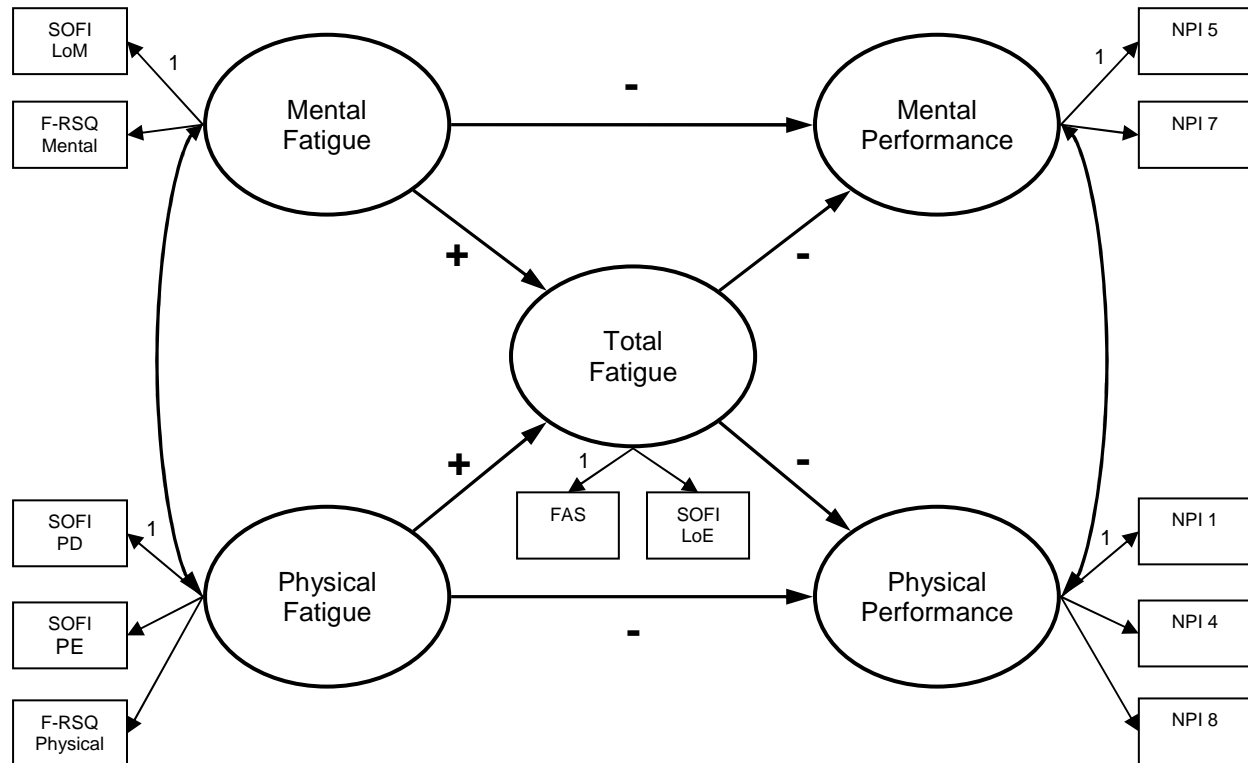


Figure 8. Initial conceptual model relating mental, physical, and total fatigue to mental and physical performance. The direction of hypothesized relationships is indicated with + and - signs. Indicator variables for each of the five latent variables comprise the measurement model and are also included in the conceptual model. Paths set to equal 1, in order to establish a scale for latent variables are shown in the model.

Analyses

All observed variables used in the model (scales and items from survey instruments in the FNSS) were first assessed for normality. The SOFI PE, LoM, and LoE scales, the F-RSQ Mental and Physical scales, and the FAS had non-normal distributions and were transformed using Box-Cox transformations. Correlations between survey measures were obtained using Spearman's rank correlation coefficient (r_s).

For the current analysis, the data were randomly split into two samples, a primary model *development sample* and a separate model *validation sample*. Listwise deletion, which excludes

an entire participant if any of their observed variables is missing, was used for missing data in order to maintain consistent sample sizes within the correlation and covariance matrices. This resulted in two samples each with $N = 352$. Covariance matrices for all direct measures in the model were calculated for each sample. LISREL modeling software with maximum-likelihood estimation (LISREL 8.72, Scientific Software International, Inc., Lincolnwood, IL) was used in all SEM analyses.

Estimation and analysis of the SEM followed a two-step approach (Anderson et al., 1988). First, a confirmatory factor analysis was performed to evaluate the fit of the measurement model by determining which sets of observed variables shared common variance-covariance characteristics and related to the latent variables within the model (Hoyle, 1995; Schumacker et al., 2004). Standardized factor loadings between indicator variables and their associated latent variable were evaluated for significance using a two-tailed t -test (critical value = ± 1.96). All statistical tests were considered significant at $p < .05$. Squared multiple correlation values (R^2) were used to determine the proportion of variance in the indicator variables explained by the model.

To evaluate the overall fit of the measurement model, a set of fit indices encompassing a variety of aspects of fit were used (Bollen et al., 1993; Hair et al., 1995). Absolute fit was evaluated using a chi-squared (χ^2) test, relative chi-square (χ^2/df), the goodness of fit index (GFI), adjusted goodness of fit index (AGFI), and standardized root mean square residual (RMR) indices. These indices are all based on predicted versus observed covariances (Schumacker et al., 2004). The comparative fit index (CFI), incremental fit index (IFI), normed fit index (NFI), and non-normed fit index (NNFI) were used to evaluate model fit relative to a null (independent) model. Model parsimony was evaluated using the parsimony fit Index (PFI) and the root mean square error of approximation (RMSEA). Values for these indices were compared to published standards for minimum, acceptable, and good fit (Byrne, 1994; Chau, 1997; Dilalla, 2000; Hair et al., 1995; Hoyle, 1995; Maxim, 1999; Schumacker et al., 2004; Sumer, 2003). A Critical N (CN) statistic was used as a *post-hoc* indication of the adequacy of the sample size for the chi-square measure of model fit (Schumacker et al., 2004).

Once satisfactory fit was achieved for the measurement model, an *initial structural model* was estimated. Structural path coefficients relating latent variables in the model were evaluated for significance using a two-tailed *t*-test. Values of squared multiple correlation coefficients (R^2) were used to determine the proportion of variance in the latent variables explained by the model. The set of goodness of fit indices used for the measurement model was also used to evaluate fit in the structural model.

Based on the initial fit of the structural model and the significance of estimated parameters, a *modified model* was generated by eliminating observed variables or altering structural relationships between latent variables to achieve a better fit. Each iteration of the model was reviewed using a chi-squared difference test ($\Delta\chi^2 / \Delta df$) and the Akaike Information Criterion (AIC) to determine whether it was a significant improvement over previous models (Burnham et al., 2004; Schumacker et al., 2004). The final model was then validated using the separate validation sample.

In addition to the initial conceptual model, an *alternate model* was proposed to evaluate whether mental fatigue had a direct effect on physical performance, and physical performance had a direct effect on mental performance, without the presence of total fatigue as a mediating variable. This alternate model was also estimated using the initial data set. In this model, the Total Fatigue dependent latent variable was removed entirely from the model and direct structural paths were added between Mental Fatigue and Physical Performance and between Physical Fatigue and Mental Performance. All other measurement variable paths, structural paths, and latent variable correlations remained the same.

Results

Measurement Model

Correlations and covariances between direct measures within the measurement model are summarized in Table 13. In the measurement model, all loadings between indicator and latent variables were significant (Table 14), and R^2 values for the indicator variables ranged from 0.03 for NPI 4 to 0.79 for SOFI – PD. Overall, the measurement model showed acceptable fit to the

data ($\chi^2 = 74.2$, $df = 44$, $p = .003$). The model achieved a good fit for a majority of the fit indices (Table 15). Based on Hoelter's Critical N (CN = 319.4), the sample size was adequate for the Chi-Square test. Thus, the measurement model was deemed satisfactory and analysis proceeded to evaluation of the structural model.

Table 13. Correlations (r_s) and covariances among model direct measures (upper, correlation values; lower, covariance values).

	SOFI PE	SOFI PD	SOFI LoM	SOFI LoE	F-RSQ Phys.	F-RSQ Mental	FAS	NPI 1	NPI 4	NPI 5	NPI 7	NPI 8
SOFI PE	1 (1.52)											
SOFI PD	0.52 (0.96)	1 (2.20)										
SOFI LoM	0.35 (0.66)	0.42 (0.96)	1 (2.40)									
SOFI LoE	0.39 (0.68)	0.58 (1.22)	0.49 (1.04)	1 (2.00)								
F-RSQ Physical	0.37 (1.96)	0.57 (3.63)	0.24 (1.56)	0.32 (2.00)	1 (18.47)							
F-RSQ Mental	0.30 (1.81)	0.37 (2.67)	0.43 (3.27)	0.43 (2.90)	0.35 (7.19)	1 (23.69)						
FAS	0.36 (0.06)	0.42 (0.08)	0.36 (0.07)	0.45 (0.08)	0.34 (0.19)	0.41 (0.26)	1 (0.02)					
NPI 1	-0.29 (-0.53)	-0.46 (-1.01)	-0.32 (-0.75)	-0.38 (-0.79)	-0.37 (-2.31)	-0.35 (-2.59)	-0.30 (-0.06)	1 (2.25)				
NPI 4	-0.15 (-0.18)	-0.16 (-0.23)	-0.15 (-0.21)	-0.09 (-0.11)	-0.15 (-0.63)	-0.17 (-0.76)	-0.11 (-0.01)	0.20 (0.28)	1 (0.95)			
NPI 5	-0.17 (-0.31)	-0.26 (-0.55)	-0.38 (-0.87)	-0.33 (-0.66)	-0.19 (-1.16)	-0.42 (-3.02)	-0.24 (-0.05)	0.47 (1.05)	0.19 (0.27)	1 (2.18)		
NPI 7	-0.21 (-0.35)	-0.28 (-0.56)	-0.37 (-0.83)	-0.33 (-0.65)	-0.22 (-1.31)	-0.37 (-2.94)	-0.28 (-0.05)	0.50 (1.06)	0.17 (0.23)	0.62 (1.30)	1 (2.03)	
NPI 8	-0.08 (-0.11)	-0.07 (-0.12)	-0.21 (-0.43)	-0.13 (-0.24)	-0.12 (-0.65)	-0.19 (-1.21)	-0.14 (-0.02)	0.14 (0.28)	0.21 (0.26)	0.25 (0.47)	0.21 (0.40)	1 (1.68)

PE = physical exertion, PD = physical discomfort, LoM = lack of motivation, LoE = lack of energy

Table 14. Squared multiple correlations (R^2) for indicator variables and path coefficients* between indicator and latent variables in measurement model.

Indicator Variable	R^2	Mental Fatigue	Physical Fatigue	Total Fatigue	Mental Performance	Physical Performance
SOFI – LoM	0.45	1.00 / 0.67 [#]				
F-RSQ Mental	0.45	3.14 / 0.67 (0.30) 10.40				
SOFI – PD	0.79		1.00 / 0.89 [#]			
SOFI – PE	0.35		0.55 / 0.59 (0.05) 10.93			
F-RSQ Physical	0.41		2.01 / 0.64 (0.17) 11.96			
FAS	0.29			1.00 / 0.54 [#] 13.64 / 0.73 (1.51) 9.06		
SOFI - LoE	0.54					
NPI 5	0.56				1.00 / 0.75 [#] 1.10 / 0.86 (0.09) 12.41	
NPI 7	0.73					
NPI 1	0.49					1.00 / 0.70 [#]
NPI 4	0.03					0.16 / 0.18 (0.05) 3.05
NPI 8	0.04					0.26 / 0.21 (0.07) 3.55

*Path coefficient data presented as: Unstandardized parameter / standardized parameter
(Standard error of the unstandardized parameter)
 t -value (all were significant)

[#] Unstandardized path coefficients for these indicator variables were set equal to 1 in order to establish a scale for the underlying latent variable. There are no associated t -values for these paths, as they were pre-specified within the model.

Table 15. Goodness of fit indices for the measurement, initial, modified, alternate, and validated models. The second column indicates contemporary criteria for acceptable fit.

Index	Criteria	Measurement	Initial	Modified	Alternate	Validated
Degrees of freedom	-	44	46	47	29	46
Chi-square statistic	-	74.2	77.8	85.4	53.5	105.4
Chi-square statistic/ <i>df</i>	≤ 3.00	1.69	1.69	1.82	1.84	2.29
Goodness of fit index (GFI)	≥ 0.90	0.97	0.96	0.96	0.97	0.95
Adjusted goodness of fit index (AGFI)	≥ 0.90	0.94	0.94	0.94	0.94	0.92
Parsimony goodness of fit index (PGFI)	≥ 0.50	0.54	0.57	0.58	0.51	0.56
Root mean square error of approx. (RMSEA)	≤ 0.08	0.04	0.04	0.05	0.05	0.06
Comparative fit index (CFI)	≥ 0.90	0.99	0.99	0.98	0.98	0.97
Normed fit index (NFI)	≥ 0.90	0.97	0.97	0.96	0.96	0.96
Non-normed fit index (NNFI)	≥ 0.90	0.98	0.98	0.98	0.97	0.96
Incremental fit index (IFI)	≥ 0.90	0.99	0.99	0.98	0.98	0.97
Standardized root mean square residual (RMR)	≤ 0.05	0.04	0.04	0.04	0.04	0.05

Initial Model SEM Analysis

Overall, the structural model showed acceptable fit to the data ($\chi^2 = 77.81$, $df = 46$, $p = .002$), and the model achieved a good fit on a majority of the fit indices (Table 15). All structural path coefficients in the initial model (Figure 9) were significant, except for the path between Total Fatigue and Mental Performance (t -value = 1.65, $p = 0.10$). All paths had the same sign as in the hypothesized model (Figure 8), again excepting the path between total fatigue and mental performance; this had a positive sign, indicating that higher levels of total fatigue led to higher levels of mental performance. Based on R^2 values, 91% of the variance in Total Fatigue, 69% of the variance in Mental Performance, and 74% of the variance in Physical Performance was explained by the independent latent variables in the model (Mental Fatigue and Physical Fatigue). Standardized path coefficients (Figure 9) indicated that Mental Fatigue had a larger positive direct effect (0.63) on Total Fatigue than Physical Fatigue (0.41). Mental Fatigue also had a larger negative direct effect on Mental Performance (-1.44) than Physical Fatigue on Physical Performance (-0.44). The direct positive effect of Total Fatigue on Mental Performance was larger in magnitude (0.74) than the direct negative effect of Total Fatigue on Physical Performance (-0.46).

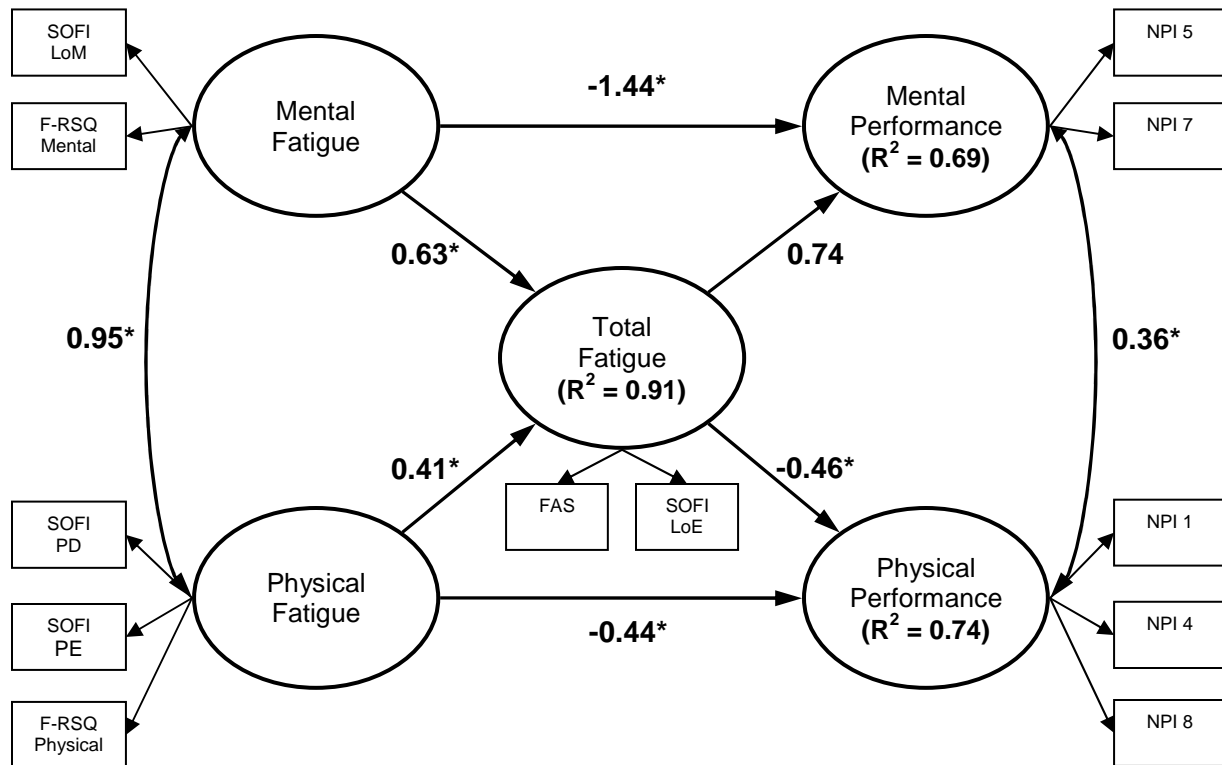


Figure 9. Initial SEM ($n = 352$), with standardized path coefficients and squared multiple correlations (R^2) shown for the dependent latent variables. * = significant at $p < .05$

Model Modification and Comparisons

The initial model had acceptable fit and modification indices suggested that correlating measurement errors between F-RSQ Mental and SOFI PD indicator variables would have the largest effect on overall model fit. This correlation was not clearly justifiable, however, based on the study design and the specific direct measures. Aside from the modification indices, however, the structural path between Total Fatigue and Mental Performance was not significant. Thus, the model was modified to eliminate this path and re-estimated to evaluate fit.

Fit indices for the modified model also indicated an overall acceptable fit, which was generally comparable to or worse than the fit for the original hypothesized model (Table 15). The p -value for the modified model was lower (0.0005 vs. 0.002), and the relative chi-squared value for the modified model was higher (1.82 vs. 1.69), than in the initial model, indicating that the modified

model did not have significantly better fit. A decision was thus made to use the initial model as the final model.

The estimated alternate model showed acceptable fit to the data ($\chi^2 = 53.5$, $df = 29$, $p = .004$). Compared to the initial hypothesized model, fit indices for the alternate model were equivalent or slightly worse (Table 15). The GFI index was an exception as it showed a slight improvement in the alternate model (from 0.96 to 0.97). The AIC value for the alternate model was lower than for the initial model (105.5 vs. 141.8), indicating a better fit for the alternate model (Burnham et al., 2004). However, the relative chi-square value was higher in the alternate model (1.84 vs. 1.69), indicating worse fit than for the initial model.

All structural paths in the alternate model were significant (Figure 10). Standardized path coefficients revealed that mental fatigue has a negative direct effect on both mental performance and physical performance and the effect is larger in magnitude for mental performance (-1.01) than physical performance (-0.38). Physical fatigue, in contrast, has a negative direct effect on physical performance (-0.60) and a positive direct effect on mental performance (-0.38). Squared multiple correlation values for Mental Performance and Physical Performance were 0.69 and 0.83, respectively. Thus, this model accounted for more of the variance in Physical Performance as compared to the initial model ($R^2 = 0.74$).

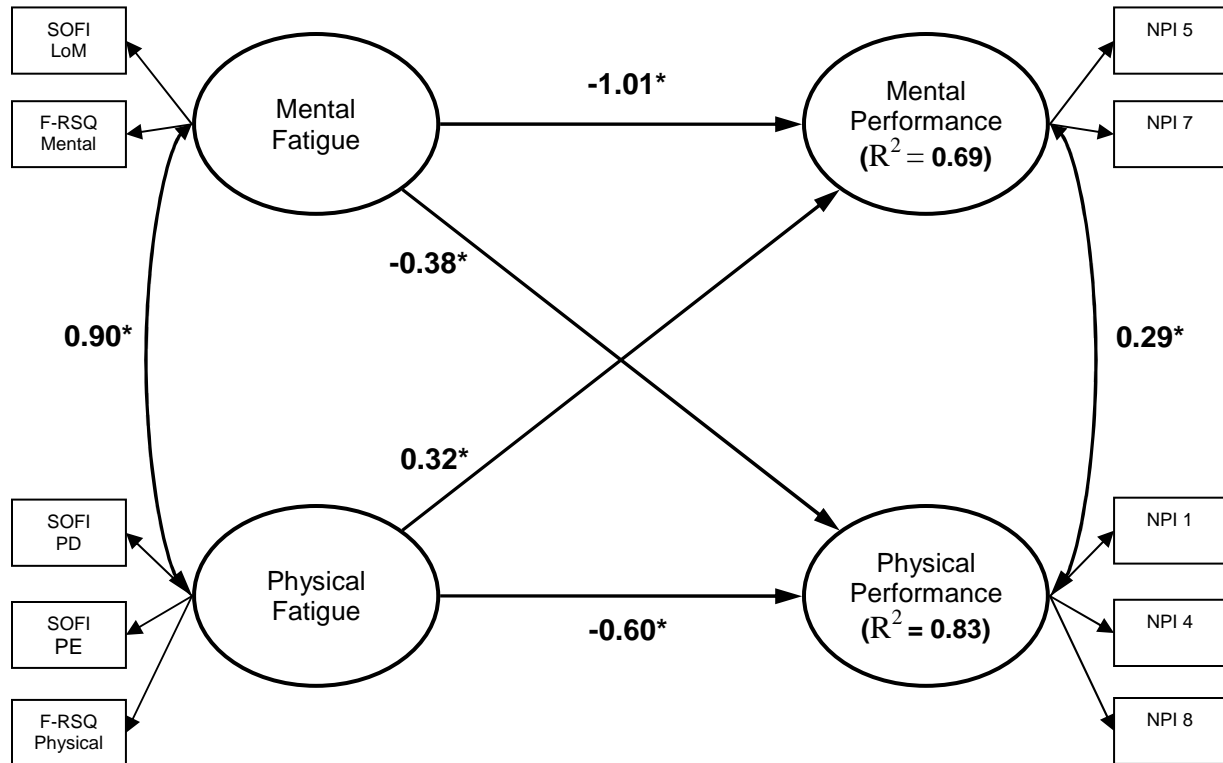


Figure 10. Alternate SEM ($n = 352$), showing standardized path coefficients and R^2 for dependent latent variables. * = significant at $p < .05$

Model Validation

Since neither the modified or alternate models resulted in substantially or consistently better fits, and all pathways related to total fatigue in the initial model were significant, the initial estimated SEM (Figure 9) was subject to validation, which was done using the second half of the original data set. Overall, the final model showed acceptable fit to the data ($\chi^2 = 105.41$, $df = 46$, $p = .000$, but the fit was generally worse than the model estimated with the initial data set (Table 15). Absolute fit indices largely indicated acceptable fit ($\chi^2/df < 3$; GFI > 0.90 ; and standardized RMR < 0.05 ; AGFI > 0.9). The comparative fit indices (CFI, IFI, NFI and NNFI) indicated adequate fit for the model relative to the independent model. Model parsimony was also adequate based on the PGFI and RMSEA values.

In the final model with the validated data set, two of the structural path coefficients in the model were not significant: 1) the path between Total Fatigue and Mental Performance (t -value = 1.08,

$p = .28$), as in the original model; and, 2) the path between Mental Fatigue and Mental Performance (t -value = -1.72, $p = .09$). With one exception, all paths had the same sign as in the hypothesized model (Figure 8). The exception was the non-significant path between total fatigue and mental performance, which had a positive sign (indicating that higher levels of total fatigue lead to higher levels of mental performance). R^2 values for the dependent latent variables were similar to those in the initial model using the development sample for Total Fatigue (0.91), but lower for Mental Performance (0.51) and Physical Performance (0.52). Standardized path coefficients (Table 16) for the final model showed that: 1) mental fatigue had a larger direct effect (0.76) on total fatigue than did physical fatigue (0.25); 2) the negative direct effect of mental fatigue on mental performance (-1.58) was mitigated by a positive indirect effect (0.72); and 3) the direct effect of physical fatigue on physical performance (-0.29) was lower in magnitude than the direct effect of mental fatigue on mental performance (-1.58). The standardized path coefficients in the initial model (estimated with the development sample) had the same signs and showed the same relationships between constructs as in the final model. However, the coefficients in the final model were generally larger in magnitude than in the initial model with the exception of the effects of physical fatigue on total fatigue and physical performance.

Table 16. Standardized direct, indirect, and total effects of fatigue dimensions on performance as determined by the SEM. Coefficients are presented as initial / final model estimates.

	Total Fatigue	Mental Performance			Physical Performance		
	Direct Effect	Direct Effect	Indirect Effect	Total Effect	Direct Effect	Indirect Effect	Total Effect
Mental Fatigue	0.63 / 0.76	-1.44 / -1.58	0.47 / 0.72	-0.97 / -0.86	-	-0.29 / -0.37	-0.29 / -0.37
Physical Fatigue	0.41 / 0.25	-	0.30 / 0.24	0.30 / 0.24	-0.44 / -0.29	-0.19 / -0.12	-0.63 / -0.41
Total Fatigue	-	0.74 / 0.95	-	0.74 / 0.95	-0.46 / -0.49	-	-0.46 / -0.49

Discussion

The purpose of this study was to estimate and refine a structural equation model relating dimensions of fatigue, total fatigue, and performance of registered nurses. Survey data from 1001 registered nurses was split into two samples for the purposes of initial model estimation and model refinement, and model validation. The initial hypothesized conceptual model was estimated and found to have adequate to good overall fit. An alternate model, in which the construct of total fatigue was removed, was also estimated and found to have adequate fit. Finally, a validation data set was used to re-estimate the initial conceptual model and yielded a final structural equation model with adequate fit to the data.

The initial conceptual model was based on six hypotheses describing direct and indirect effects of fatigue on performance. From the statistical significance of the structural paths in both the initial and final models, four of these hypotheses were supported (Table 17). One hypothesis, that mental fatigue will have a direct effect on mental performance, was supported by the initial but not by the validation model; however, the effect in the final model using the validation data set was suggestive ($p < .10$). Splitting the data set into initial and validation data sets in order to validate the final model may have resulted in an underpowered model leading to this instability in path significance. It is generally recommended that SEM samples contain at least 10 observations per estimated parameter (measurement and structural paths) in the model (Schumacker et al., 2004). Larger sample sizes are recommended (> 500) to prevent instability in final models, especially when cross-validating a model (Boomsma, 1983; Hu et al., 1992; MacCallum et al., 1992). The remaining hypothesis, of a direct effect of total fatigue on mental performance, was not supported by either model.

Table 17. Evaluation of model hypotheses.

Hypothesis	<i>t</i> -Values*		Remarks
	Development Sample	Validation Sample	
Direct effect of mental fatigue on total fatigue	5.26	4.95	Supported
Direct effect of physical fatigue on total fatigue	3.60	2.05	Supported
Direct effect of mental fatigue on mental performance	-2.88	-1.72	Supported?
Direct effect of physical fatigue on physical performance	-2.77	-2.04	Supported
Direct effect of total fatigue on mental performance	1.65	1.08	<i>Rejected</i>
Direct effect of total fatigue on physical performance	-2.40	-3.22	Supported

* *t*-test critical value = ± 1.96 ($p < .05$); non-significant values shown in *italics*

Relationships between the model constructs can be evaluated further based on the signs and magnitudes of the path coefficients describing direct and indirect effects (Table 16). In the final validation model, both mental fatigue and physical fatigue had positive direct effects on total fatigue. Further, the standardized path coefficients indicated that mental fatigue has a higher direct effect (0.76) on total fatigue than does physical fatigue (0.25). These standardized path coefficients represent the amount of change that would occur in the dependent variable given a one-unit change in the independent variable.

The model supports a view of total fatigue as a separate construct defining a nurse's overall fatigue state, and which is based on direct effects from at least the physical and mental dimensions. This is consistent with previous literature indicating that occupational fatigue has multiple dimensions that may vary in magnitude across different work environments, but also that there is a general underlying total fatigue factor relating to all other dimensions (Ahsberg, 2000; De Vries et al., 2003; Kinsman et al., 1976). Specifically, a review of six measures of perceived occupational fatigue (De Vries et al., 2003) revealed that, while many questionnaires were designed and intended to measure specific fatigue dimensions separately, factor analyses have frequently revealed the presence of an additional general fatigue factor that accounts for a large proportion of the variance across dimension-specific items. When analyzing the fatigue dimensions within the Swedish Occupational Fatigue Inventory, Ahsberg (2000a) reported a similar fatigue structure with multiple dimensions all relating to a general fatigue dimension.

While a total fatigue construct likely exists, its role in performance relative to specific fatigue dimensions has not been established. It was hypothesized here that total fatigue played a mediating role between dimensions of fatigue and performance and that its presence would help explain the effects of mental fatigue on physical performance and of physical fatigue on mental performance. However, both the initial and the validated models indicated that the structural path between total fatigue and mental performance was not significant. In addition, an alternate model was estimated for this study, which did not include total fatigue as a separate construct. Though this model had a slightly worse fit than the initial model (Table 15), the difference was not substantial. This suggests that although total fatigue exists as a construct it may not play a role as a mediator between dimensions of fatigue and performance. Rather, the alternate model indicates there are significant direct effects between mental fatigue and physical performance and physical fatigue and mental performance that occur independent of total fatigue.

While the models do not clearly support a mediating role of total fatigue in performance, “crossover” effects of mental and physical fatigue on mental and physical performance in the alternate model were significant. However, the signs of these effects were not consistent. Physical fatigue had a positive direct effect on mental performance while mental fatigue had a negative direct effect on physical performance. This difference may be accounted for by considering the potential roles of motivation, arousal levels, and attention as moderators between fatigue and performance (Finkelman, 1994). Changes in central nervous system arousal, for example, have been associated with an increase in cognitive performance following physical activity (Hillman et al., 2003; Kamijo et al., 2004; Kamijo et al., 2007; Magnie et al., 2000; Polich et al., 1995). In contrast, the roles of expectancy of work demands, motivation, and cognitive resources in physical performance may help explain the observed negative effect of mental fatigue on perceived physical performance. Since physical work requires cognitive resources, increasing levels of mental fatigue may impact availability of those resources and lead to a decrement in physical performance (Bertram et al., 1990; Collins et al., 2003; van der Linden et al., 2003b).

However, in a separate laboratory study conducted as part of this dissertation (Chapter 3), wherein levels of mental and physical fatigue were induced through varying work task demands

and changes in mental and physical task performance were measured, mental fatigue did not clearly have negative effects on physical performance. Moreover, physical fatigue did negatively impact multiple measures of mental performance, which also contradicts the model effects in the current models. These differences in the crossover relationships between dimensions of fatigue and performance may be attributed to differences in performance measurement. During the laboratory study, performance was based on objective measures of speed, accuracy, and neuromuscular control. In contrast, performance measures within the model were based on nurses' perceptions of factors associated with mental and physical performance during their work tasks (due to the large sample size required for SEM methods, obtaining objective measures of performance was not feasible during the survey). This difference, between objectively measured and subjectively perceived performance attributes, likely contributes to the inconsistency in the direction of relationships between mental fatigue and physical performance and between physical fatigue and mental performance. As fatigue has also been associated with decreased perception of performance limitations, it is important to continue to build on the perception-based relationships within the model, by conducting additional controlled studies investigating fatigue and performance using a combination of both subjective and objective measures.

There are additional potential limitations within this study that should be acknowledged. SEM outcomes were dependent on perceptions related to fatigue and performance from a specific sample of registered nurses (Chapter 2). Any biases in the study sample will also be present in the model, potentially affecting its external validity. Demographic characteristics of the study sample, however, had a similar distribution to previous surveys of registered nurses, indicating that the sample is likely representative of a larger registered nurse population within the United States (ANA, 2001; Spratley et al., 2001; Trinkoff et al., 2006). However, these results may not be generalizable to healthcare workers other than registered nurses or other work sectors.

The model developed in this study does not explicitly consider an emotional fatigue dimension that may be present in nurses. In contrast to mental fatigue, changes in emotion as a consequence or dimension of fatigue have not been commonly studied in fatigue research (Zohar et al., 2005). Further, while emotional fatigue has been cited as a dimension in total fatigue, it is

most commonly referenced as a component of burnout. Burnout is a phenomenon related to both emotional and mental fatigue, and which has been described in the literature as a state of physical, emotional, and mental exhaustion arising after prolonged involvement in emotionally demanding situations (Collins et al., 2003). Burnout has been acknowledged as a large problem in healthcare workers, especially nurses, and which has potential negative consequences for patient safety, the personal well-being of these workers, and the current shortage of nurses (Sullivan et al., 2002; Tyler et al., 1991). Although burnout may affect performance during nursing tasks, it is extremely difficult to measure or quantify and thus was not included in the initial definition and model of total fatigue for this study.

Additionally, factors not explicitly considered in the conceptual model that guided this research (e.g., psychosocial, individual, environmental) may be critical to the relationships between fatigue and performance. Model relationship may be over-simplified by not including these factors within the model, yet existing research findings are mixed on the role of these factors related to fatigue and performance in work settings. For example, Finkelman (1994) found that five factors were associated with perceived or actual determinants of fatigue, namely: information-processing demands, job control, job performance, pay rate, and physical demands. Dawson et al. (2001), however, suggested that psychosocial factors do not affect fatigue levels directly but rather they interact with fatigue to influence performance in workers.

While the role of psychosocial and other work task and work environment factors in influencing the relationship between fatigue and performance is potentially important and has not yet been fully defined, these factors are often inconsistently defined within the literature and are difficult to measure or manipulate in an experimental setting. Thus, a decision was made initially to develop a simplified model that focuses solely on the dimensions of fatigue and their role on performance of nurses. The goal of this simplified model was to better understand and define the construct of total fatigue. Future research should build on the current model to incorporate other relevant personal or work environment factors, as well as additional dimensions of fatigue that may be present in nurses (e.g., emotional fatigue or burnout).

Finally, while SEM does allow for causal inferences to be made relative to the relationships between independent and dependent variables in a model, causality can only be demonstrated when the three criteria of association, isolation, and directionality are met (Hoyle, 1995; Schumacker et al., 2004). SEM is generally able to meet the criteria of association and isolation, and in fact it offers some advantage over other multivariate analysis methods relevant to isolation because it accounts for measurement error (Hoyle, 1995). Directionality, however, cannot be assumed and is not formally tested in SEM models. Rather, assumptions regarding directionality are typically based on existing theory or previous research, or based on the experimental manipulation of the independent model variables (Hoyle, 1995; Schumacker et al., 2004). In order to provide support for causality within the model, a separate study conducted as part of this dissertation (Chapter 3) manipulated workload experimentally to induce levels of both mental and physical fatigue and measured resulting effects on mental and physical performance. Results from this experiment indicated that higher levels of physical fatigue led to significantly lower levels of performance (as assessed by several measures of both physical and mental performance). Moreover, mental fatigue had a significant effect on one measure of mental performance. These results lend support to causal inferences related to structural paths within the model. Additional controlled experimental research, though, is needed to establish further support for causality between mental and physical dimensions of fatigue and performance.

Conclusions

A model relating the mental and physical dimensions of fatigue and performance in registered nurses was estimated using structural equation modeling techniques and was found to have acceptable to good fit using two separate data samples. The resulting model supported the existence of a total fatigue construct that is directly affected by mental and physical fatigue levels. However, the role of total fatigue as a mediating variable between dimensions of fatigue and performance was not clearly supported. The final model also provides quantitative path coefficients defining the strength of relationships between mental and physical dimensions of fatigue, total fatigue, and mental and physical performance. Thus, by quantifying fatigue levels using simple surveys, we can begin to understand related changes in perceived performance, or ability to perform. The model can also be used to implement interventions and evaluate their

effectiveness at reducing fatigue levels and mitigating the negative effects of fatigue on performance. Future research should build on the developed model to incorporate additional psychosocial and individual factors that might influence both the levels of fatigue in nurses and other workers, as well as the effects of occupational fatigue on performance.

Chapter 5: Conclusions and Recommendations

High rates of medical errors and worker injuries are well-documented within the healthcare sector. As the largest group of healthcare providers, and one which is critical to the delivery of patient care across healthcare organizations, nurses, in particular, play a critical role in the quality and safety of healthcare services.

In any given context within the healthcare domain, the specific causal or most critical factor(s) leading to safety or quality performance decrements may vary. Numerous studies have sought to improve worker performance by focusing on a specific task, healthcare specialty, or environmental factor (Clarke et al., 2006; Emam et al., 2002; Howard et al., 2002; Salas et al., 2005; Squires et al., 2005). While many of these studies have demonstrated a reduction in errors or injuries, they are narrowly focused and may only be valid in a specific context (Clarke et al., 2006). Few studies, however, have considered potential pervasive factors that might influence performance across workers, tasks, and contexts.

Fatigue is one such pervasive factor, and which has been linked to stress, safety, and performance decrements in numerous work environments (Goode, 2003; Leung et al., 2006; Leung et al., 2004; Lorist et al., 2000; Miller, 2005; Ochoa et al., 1998; Schellekens et al., 2000). Previous investigations of the relationship between fatigue and performance in healthcare have focused on specific components of fatigue; for example, sleep deprivation in medical trainees, physical fatigue in laparoscopic surgeons, or burnout in nurses. A more comprehensive definition of fatigue encompassing multiple dimensions (e.g., mental fatigue and physical fatigue) has not been considered, but is warranted since nurses perform tasks consisting of diverse physical and mental activities.

Fatigue is a common complaint amongst nurses (Bosh et al., 1987; Zboril-Benson, 2002) and has been associated with increased potential for both patient error and personal harm to nurses across healthcare work environments (Geiger-Brown et al., 2004; Lipscomb et al., 2004; Rogers, A. et al., 2004; Rogers, A. E. et al., 2004a; Rogers, A. E. et al., 2004b). However, the levels of fatigue in nurses from diverse healthcare work environments have not been quantified and associations between demographic and work environment factors (e.g., shift length, hours worked per week,

and shift schedule) have not been consistently demonstrated. Further, the casual mechanisms linking total fatigue, its dimensions, and changes in performance have not yet been clearly defined.

As such, the role of fatigue in nursing deserves further attention. Measuring fatigue levels in nurses may help us to better understand work demands and associated performance, safety, and satisfaction consequences. Further, understanding differences in fatigue levels across nursing work environments may allow for improved design of work variables to reduce fatigue levels and mitigate negative effects of fatigue on performance. Finally, by determining causal relationships between fatigue and nursing performance, patient outcomes, as well as nurse safety, can be improved.

The current research was conducted to address several of these needs by measuring and modeling dimensions of total fatigue (mental fatigue and physical fatigue), and identifying their effects (both direct and indirect) on mental and physical aspects of performance in nursing. The entire body of work was motivated and guided by an initial conceptual model which proposed both a definition of total fatigue within nursing, as well as causal pathways between dimensions of fatigue and performance (Figure 1).

Summary of outcomes

All three phases of this research were guided by and intended to evaluate hypotheses specified within the conceptual model presented in Chapter 1 (Figure 1). A survey study quantified levels of mental, physical, and total fatigue, as well as acute and chronic fatigue states, in registered nurses from a range of healthcare work environments (Chapter 2). The survey sample was similar to those published in earlier studies with the exception of the age and experience distributions. The current sample was slightly older and reported less experience than previous samples; however, these differences likely reflect aging and turnover trends within the larger registered nurse populations.

Compared to a range of other occupations, registered nurses reported relatively high levels of mental, physical, and total fatigue. Although reported levels of mental fatigue were significantly

higher than levels of physical fatigue, which fits with existing research describing the high mental demands in nursing, the physical fatigue levels, and in particular the physical discomfort levels, were higher than in other occupations. Moreover, the high rates of overexertion and occupational injuries amongst this population warrant the continued inclusion of physical fatigue in definitions and measures of fatigue in registered nurses. Thus, inclusion of these dimensions within the conceptual model (Figure 1) is warranted for this population.

Differences in fatigue dimensions and states across demographic and work environment variables were also identified. A number of demographic and work environment variables (e.g., shift length, hours worked per week, and shift schedule) were associated with significant differences in perceived fatigue levels. In particular, increased hours worked per week and longer shift lengths were related to increased levels of physical, total, acute, and chronic fatigue. Differences in mental, physical, total, acute, and chronic fatigue levels were found across nurses working different shift schedules. These findings are important contributions to the ongoing discussion within healthcare systems and the nursing community regarding the prevalence of extended work shifts, and the design of shift schedules, and potential impacts on performance, safety, and satisfaction.

Finally, mental, physical, and total fatigue, as well as acute and chronic fatigue, measures were all negatively correlated with measures of performance. Specifically, mental fatigue measures were most strongly negatively correlated with performance measurement items that related to changes in concentration, mood, and mental energy, and the implications for patient monitoring, medication administration, and documentation tasks. Physical fatigue measures, in contrast, were most strongly correlated with a measure of muscle strength, endurance, and physical abilities during nursing tasks. Thus, dimensions of fatigue were more strongly associated with similar dimensions of performance. Further, performance measures that related to particular practice guidelines were least correlated with fatigue dimensions and states, indicating that performance guidelines which specifically govern clinical practice may, in some instances, mitigate the negative effects of fatigue. The significant negative correlations between fatigue dimensions and performance support the pathways between these constructs within the conceptual model (Figure 1).

A laboratory study was conducted to determine causal pathways between mental and physical dimensions of fatigue and performance during simulated nursing work tasks (Chapter 3). In this study, increased levels of mental, physical, and total fatigue were induced following the completion of simulated nursing tasks. Increasing mental demands associated with the tasks, led to larger changes in perceived mental fatigue, although these differences were not significant. Higher physical demands associated with the tasks, though, did lead to a statistically significant increase in measures of physical fatigue. Overall, the experiment was able to manipulate changes in levels of mental and physical fatigue, by varying mental and physical task demands.

The high and low levels of mental and physical fatigue did affect measures of mental and physical performance as well. Physical fatigue had a significant negative effect on measures of both physical and mental performance, while mental fatigue had a significant positive effect on a measure of mental performance. The direct effects between mental fatigue and mental performance and physical fatigue and physical performance, as well as the crossover effect between physical fatigue and mental performance, further support a multidimensional approach (Figure 1) to quantifying and defining the relationship between fatigue and performance in nurses.

Data and findings from both the survey and laboratory studies were used to estimate an initial conceptual (Figures 1, 8, and 9) and alternate structural equation model (Figure 10) relating dimensions of fatigue and performance in registered nurses (Chapter 4). A final model was then cross-validated using a separate sample. The final model supported the existence of a separate construct of total fatigue in nurses that is directly affected by mental and physical fatigue levels. This structural relationship is an important contribution to our understanding and definition of total fatigue in nursing, and potentially in other mentally and physically demanding occupations.

The model was also used to investigate the mediating role of total fatigue in the relationship between mental and physical dimensions of fatigue and performance. The pathway between total fatigue and mental performance in the initial and final models, though, was not significant. Moreover, in an alternate model, direct pathways between mental fatigue and physical performance and between physical fatigue and mental performance were significant. These

findings suggest that although total fatigue exists as a construct in nurses, it may not play a role as a mediator between fatigue and performance. Rather, there are direct effects between dimensions of fatigue and performance that occur independent of total fatigue.

In the final and alternate models, mental fatigue had a significant negative effect on physical performance and physical fatigue had a significant positive effect on mental performance. These findings contradict the relationships found in the laboratory study (Chapter 3), in which physical fatigue negatively affected measures of mental performance and mental fatigue did not have a significant effect on physical performance measures. These differences may be attributable to differences in performance measurement between the two studies. The laboratory study used objective measures of mental and physical capacity, namely, speed, accuracy, and motor control during mental and physical tasks. The structural equation model was estimated using nurses' perceptions of aspects associated with mental and physical performance during their work tasks. Both studies, however, did support causal pathways between dimensions of fatigue and performance in nurses. Additional research is needed to further clarify the direction of effects between fatigue and clinically relevant measures of nursing performance.

Results from all three phases generally support the constructs and pathways specified within the conceptual model guiding the research (Figure 1). Specifically, results from Phases 1 indicate that both mental and physical fatigue dimensions should be included when defining, measuring, and modeling the relationships between fatigue and performance in nurses. Further, negative correlations between perceptions of fatigue and performance in this study indicate that pathways between fatigue and performance constructs within the model are warranted. Results from Phase 2 lend support for directionality in the fatigue and performance relationships specified in Figure 1. Specifically, the experimental design allows for causal inferences about the effects of fatigue dimensions on measures of mental and physical performance. Finally, in Phase 3, the pathways in the model were quantitatively estimated and evaluated for statistical significance using structural equation modeling.

Recommendations for future research

While findings from the present research have contributed to our overall understanding of total fatigue and the relationship between fatigue and performance in nursing, there are a number of areas that deserve further attention. Additional work is needed to define total fatigue, and to identify measures of fatigue and performance that are clinically relevant and can be used to quantify levels of fatigue and performance during healthcare work tasks. Further, the causal mechanisms between fatigue and performance should be clarified, and other relevant variables that might mediate or moderate these relationships should be considered. Finally, individual, task, and environmental variables that might influence both levels of fatigue in nurses as well as the effects of fatigue on performance should be formally evaluated. Simultaneous consideration of these factors using a systems design or macroergonomic approach will provide guidance as to where interventions might be effective in reducing fatigue and mitigating negative effects on performance in this work context.

Defining and measuring fatigue and performance

Defining fatigue

Although fatigue is a complex construct that has not yet been clearly defined independent of context (Ahsberg, 2000; Akerstedt et al., 2004; Friedberg et al., 1998; Hockey, 1983; Soh et al., 1996), a definition of total fatigue in nursing has been proposed and supported by findings from the current research:

Total fatigue is a state comprised of at least two dimensions: mental fatigue and physical fatigue. Mental and physical fatigue dimensions are present in nurses exposed to excessive mental and physical demands through their work tasks and schedules. These fatigue dimensions contribute to a state of total fatigue, which over time can result in these workers not being able to function at their normal capacity and can lead to an increased risk for injury or medical error.

Further, fatigue in nursing consists of both acute and chronic states that can alter motivation and alertness and lead to a decreased capacity to perform (De Vries et al., 2003). Although levels of acute fatigue are higher (31%) than levels of chronic fatigue in nurses (Chapter 2), chronic fatigue levels are moderate (~50%) and thus measures of fatigue within this population should continue to consider fatigue states as well as fatigue dimensions.

The current research and definition of total fatigue does not incorporate an emotional fatigue dimension or the potential role of burnout. Changes in emotion as a consequence or dimension of fatigue have not been commonly studied in fatigue research. Zohar et al. (2005) did investigate how sleep-deprivation and fatigue impact the intensity of medical residents' emotional responses to goal-disruptive (machine malfunction, interrupting phone calls or questions, or medication unavailability) or goal-enhancing (performing a little-practiced task, managing a complex case, or watching a senior physician perform a novel task) events. They hypothesized that a decline in available cognitive-energy resources following sleep loss would lead to problems regulating emotional responses and coping with negative events or capitalizing on positive events. Results from their study indicated that emotional reactions to negative events were amplified and reactions to positive events were mitigated following sleep deprivation (Zohar et al., 2005).

While emotional fatigue has been cited as a dimension in total fatigue, it is most commonly referenced as a component of burnout. Burnout is a phenomenon related to both emotional and mental fatigue, and which has been described in literature as a state of physical, emotional and mental exhaustion arising after prolonged involvement in emotionally demanding situations (Collins et al., 2003). Burnout has been acknowledged as a large problem in healthcare workers, especially nurses, and one which has potential negative consequences for patient safety, the personal well-being of these workers, and the current shortage of nurses (Sullivan et al., 2002; Tyler et al., 1991). Future work should quantify levels of emotional fatigue in nurses and determine the effects of emotional fatigue on total fatigue. Moreover, potential causal links between emotional fatigue and performance should be evaluated.

Measuring fatigue

In addition to being difficult to define, fatigue is also difficult to measure. Traditionally, fatigue has been acknowledged to have both physiological and psychological components, measurable through objective and subjective assessments, respectively. Several methods for fatigue assessment have been developed, but have generally either focused objectively on a single dimension or accounted subjectively for multiple dimensions (Ahsberg, 2000; Tiesinga et al., 1996). However, given the multidimensional definition of total fatigue in nurses presented

above, at least mental and physical fatigue, and possibly emotional fatigue, dimensions should be accounted for in assessments. A multidimensional approach to measuring total fatigue should also incorporate subjective, physiological, and behavioral measures to allow for simultaneous measure of both the quality and intensity of fatigue (Ahsberg, 2000; Annett, 2002).

Subjective measures of fatigue include a variety of questionnaires, diaries, or interviews on perceptions of fatigue (De Vries et al., 2003). Questionnaires are often used because they are less time consuming than other measures and can address various conceptual models or definitions of fatigue (De Vries et al., 2003). Although many questionnaires were originally designed based on the unidimensional definition of fatigue, instruments such as the Swedish Occupational Fatigue Inventory (Ahsberg et al., 1997), the Checklist Individual Strength (Vercoelen et al., 1994), and the Fatigue Scale (Chalder et al., 1993) contain items that relate to multiple components of fatigue. The Occupational Fatigue Exhaustion Recovery scale takes a different approach by considering the three fatigue states (chronic, acute, and recovery) that occur in workers (Winwood et al., 2006a; Winwood et al., 2005). Existing multidimensional questionnaires that quantify occupational fatigue levels do not account for emotional fatigue, though, and thus new measures may be needed to quantify this fatigue dimension in nurses and other healthcare workers.

A number of previously validated scales are available to assess workers' perceptions of their fatigue levels. As many existing models of fatigue incorporate a person's motivation or willingness to exert effort, it is important that subjective measures be used to measure fatigue. Nurses, however, are placed under conditions of increasing sleep deprivation and work demands that negatively impact their ability to perceive their own fatigue; given this, their responses to a subjective questionnaire may not adequately reflect their physiological status and capabilities (Baldwin et al., 2004; Caldwell, 2001). Thus, measurement of fatigue in these workers should incorporate both objective and subjective components (Leung et al., 2004).

Objective measures are traditionally physiological or performance-based, emphasizing measurable consequences of fatigue (De Vries et al., 2003). Existing objective measures of fatigue are often based on indirect physiological responses to fatigue. Electromyography

(EMG), for example, has been used to measure muscle activation level in facial muscles during mental tasks. Facial EMG measures were found to be sensitive to differences in fatigue complaints among participants (Veldhuizen et al., 2003). Movement-related cortical potential (MRCP) has also been shown to be sensitive to varying levels of perceived fatigue in workers. Results from one experiment, which measured electroencephalographic (EEG) signals during a repetitive tapping task, demonstrated that participants with higher levels of perceived fatigue (measured using a subjective questionnaire) had different rates of change in MRCPs (Dirnberger et al., 2004).

Physiological measures (such as higher systolic blood pressure) can also be used to detect changes in effort or exertion during a task. It has been proposed that fatigue can be considered an outcome of effort or energy expenditure (Macdonald, 2003). As demands during a task increase, a worker's available resources for performing the task decrease and workload increases. The increasing workload and diminishing attentional resources lead to workers perceiving themselves to be more fatigued (DeLuca, 2005; Gopher et al., 1986; Macdonald, 2003). Effort during a task can also be measured from heart rate and the amount of urinary adrenaline (Schellekens et al., 2000). Physiological measures obtained through actigraphs (electronic device worn around the wrist and consisting of an accelerometer which is used to measure movement/activity) and heart rate monitors have also been shown to be related to work performed and fatigue in workers (Kecklund et al., 2001; Soh et al., 1996). Physical measures such as maximum voluntary muscle contraction have been shown to detect muscle fatigue in workers in non-healthcare industries (Christensen, 1986; Fleming et al., 1997; Nussbaum, 2003; Nussbaum et al., 2001), while manual dexterity tests have been shown to be sensitive to fatigue in healthcare workers (Owens, 2001; Samkoff et al., 1991).

One of the challenges to using objective measures of fatigue in nurses relates to potential interference with patient care. Many of the objective measurement methods require placement of equipment on the nurse or in the clinical treatment environment. Technologies that are obtrusive or restrict nurse movement, and would thus interfere with patient-handling or other physical nursing work tasks, would not be feasible. There are also concerns related to sterility of equipment within healthcare environments. Additionally, medical environments frequently

include medical technologies used for patient assessment and monitoring; signal interference between fatigue measurement tools and clinical equipment is a potential concern.

There has been limited investigation of the relationship between objective physiological or behavioral assessments of specific dimensions of fatigue and subjective perceptions as measured through a multidimensional instrument. One study showed that performance decrements on tasks such as psychomotor vigilance lag behind subjective perceptions of fatigue by approximately 24 hours in conditions of extended sleep deprivation (Dinges et al., 1997). Thus, subjective perceptions of fatigue may be a warning sign of future performance decrements. Whenever possible fatigue measures should be integrated into work shifts in order to identify rates of change of fatigue levels during work tasks, and also to prevent recover or recall biases that may be present in post-work measures. By including both objective and subjective measures when quantifying fatigue in nurses, we can also gain a better understanding of the development of total fatigue and its underlying dimensions (Annett, 2002).

Defining performance

Human performance is critical in any work system. Generally, those in human factors view human performance as a function of the speed and accuracy a human maintains while working toward a goal (Sanders et al., 1993; Wickens et al., 2000). In healthcare workers, the goal is often patient related (Karsh et al., 2006). If the demands placed on a worker completing a task in a specific environment approach the limits of that worker's capacities or available attentional resources, performance decrements will occur in the form of reduced efficiency and increased error rates (Wickens et al., 2000).

Karsh et al. (2006) describe a input-transformation-output model of healthcare professional performance. In this model, aspects of the work environment that might influence performance (patient and provider factors, task demands, technology, etc.) are treated as inputs. These inputs are then transformed through processes that require physical, cognitive, or social/behavioral performance. These performance dimensions are broken down based on types of activities being performed. For example, physical performance consists of activities or tasks such as carrying, lifting, walking or manipulating, whereas cognitive performance includes sensing,

communicating, and learning. Social-behavioral performance activities include motivation, cost-benefit analysis, and decision-making. The outputs from the model are performance outputs such as changes in physical or mental state and ultimately patient and employee safety. Fatigue is listed both as an input and as an output in the model. It is listed as an input associated with the state of the healthcare provider relative to physical performance. In contrast, as an output it is associated with the larger category related to the mental state of the provider and/or the patient. However, the authors also describe the interconnections between types of performance and the importance of considering all aspects of performance simultaneously. System inputs may have both direct and indirect implications for multiple transformation processes and outputs.

Within nursing several models of performance have been generated (Haussmann et al., 1976; Jelinek, 1967; Koerner, 1981; Schwirian, 1978). These models differ from human factors definitions of fatigue in that they relate performance to subcategories of nursing practice rather than aspects of human capacity (e.g., mental, physical). Specifically, the Six-Dimension Scale of Nursing Performance, one of the most widely accepted and used measures of nurse performance, consists of six subscales of performance: Leadership, Critical Care, Teaching/Collaboration, Planning/Evaluation, Interpersonal Relations/Communication, and Professional Development (Schwirian, 1978). Springer et al. (1998) developed a behavioral based view of nursing performance; in this definition, performance was quantified based on expectations for how a nurse would behave during clinical tasks.

Future work should seek to develop a model of performance in nursing that relates traditional human factors definitions of performance to clinically relevant aspects of nursing practice. Performance should be defined such that it is directly measurable but also relevant to actual nursing work tasks. Further, the model should address performance as it relates to medical errors and nurse safety, as these are critical areas of concern within nursing and the healthcare industry as a whole.

Measuring performance

In defining performance above, many of the existing measures of performance were alluded to. Specifically, aspects of mental and physical capacity during artificial or simulated tasks (e.g.,

Chapter 3) have been used to quantify performance changes that would likely also be present during actual nursing work tasks (Gaba et al., 2002; Owens, 2001; Samkoff et al., 1991; Weinger et al., 2002). Subjective assessments of nursing behaviors or clinical competency have also been employed, and these measures are frequently used in organizational performance appraisals (Hausmann et al., 1976; Jelinek, 1967; Schwirian, 1978; Springer et al., 1998). Performance measures that are direct measures of patient care, safety, or adherence to practice guidelines have not been widely used. Incident reports, patient records, and other internal documents within healthcare organizations have been used to track adverse events and associated errors, although these measures can be unreliable due to underreporting or inaccurate documentation (Gaba et al., 2003; Mattke et al., 2004; Ramsey, 2005; Stone et al., 2006).

Clinical simulators may offer a solution to many of the challenges associated with measuring both performance and fatigue in healthcare workers, including nurses. Human patient simulators, computerized mannequins that can be remotely programmed and controlled to present symptoms and respond to clinical treatments in an almost indefinite range of clinical practice scenarios, have been used in medical and nursing education contexts for the past 15-25 years (Nehring et al., 2004). Increases in the fidelity and sophistication of these simulators, along with decreases in prices, have led to their integration into entire medical simulation environments in healthcare facilities (Bradley, 2006). Medical simulators have been shown to be valuable tools for both medical education and training purposes, as well as performance measurement and discriminating between different levels of clinical practice (Devitt et al., 2001; Gaba et al., 1988; Nehring et al., 2004). They allow for objective and subjective assessment of clinically relevant performance, of both individuals and medical treatment teams, and future research related to fatigue and performance in nursing should utilize these technologies in order to more completely and accurately understand implications of fatigue on clinical practice and medical errors.

Additional factors associated with fatigue and performance

As occupational fatigue has been defined as “the manifestation of a decrement in performance” (Leung et al., 2004, p. 233) that occurs as a result of work demands exceeding a worker’s perceived or actual physical or mental capabilities over an extended period of time (Akerstedt et

al., 2004; Leung et al., 2004), correlations between dimensions of workload, fatigue, and performance might be expected. However, previous research on the longitudinal relationships between subjective fatigue, workload, and performance in shift workers has found that these relationships may vary over time (Baulk et al., 2007). Specifically, the relationship between workload and fatigue has been found to increase as fatigue increases (Baulk et al., 2007). Although the laboratory study (Chapter 3) in the current work did manipulate task demands in order to induce mental and physical fatigue, workload itself was not explicitly measured or considered in quantifying fatigue or the causal effects of fatigue on performance in either the laboratory setting or the final structural equation model. Thus, there is a need for additional research to determine the directional relationships between workload, fatigue, and performance.

The role of psychosocial factors in the development of fatigue and potential consequences for performance is also not clearly established in literature. A number of previous research studies have investigated the role of psychosocial factors in nursing satisfaction and burnout (Aiken, 2001; Begat et al., 2005; Piko, 2006). Psychosocial factors can positively influence nursing satisfaction, stress, and emotional exhaustion levels and ultimately self-reported job performance (AbuAlRub, 2004; Adams et al., 2006; Piko, 2006). Psychosocial factors and associated work stress and satisfaction levels have also been linked low back pain in nurses (Yip, 2001). While relationships between psychosocial factors, fatigue, and performance as it relates to both patient and nurse safety, have been established in previous literature, the specific causal pathways between these constructs have not been clearly established. Whether psychosocial factors are solely stressors that influence the development of fatigue, or whether they play a role as moderators influencing the effects of fatigue on performance, has yet to be determined. Future research is needed to describe, and where possible, quantify the causal mechanisms or pathways between workload, psychosocial factors, fatigue, and performance.

Additional individual or work environment variables may also be associated with levels of fatigue and the effects of fatigue on performance in nurses. Gender differences in both perceived levels of fatigue and resulting changes in physical and mental performance were present in the current laboratory study. Other demographic factors, such as age, personality type, education, and years of experience may also play a role in fatigue levels in this population. Physical

fatigue, in particular, may become an increasing concern as the nursing population continues to age. Future studies should continue to measure the role of these factors in quantifying and modeling fatigue and performance.

Work environment variables, specifically shift length, work hours per week, and shift schedule, must also be incorporated into any future research related to fatigue and performance in nursing. Although there has been a great deal of research related to shift lengths and schedules in nursing, and implications for performance, safety, and satisfaction, results are mixed. These discrepancies may be due to these factors being considered in isolation from one another and in specific nursing work contexts. The effects of extended shift lengths on fatigue and ultimately performance, though, maybe depend on the shift schedule. Further, they may also demand on the specific task demands and psychosocial factors present within that type of healthcare work environment. A broader approach is needed, which aims to simultaneously consider multiple aspects of nursing work design (e.g., shift length, shift schedule, staffing ratios, patient ratios, physical and mental workload). to truly understand fatigue and performance in this population, and to ultimately design effective interventions which can reduce fatigue and ultimately improve performance. Such an approach should also involve nurses to identify which task and environmental variables they perceive to be affecting their levels of fatigue and performance.

Final conclusions

The current research provides an increased understanding of fatigue levels in registered nurses across work environments, as well as the underlying causal mechanisms between dimensions of fatigue and performance decrements. The findings and the final structural equation model support a definition of total fatigue in nurses that includes both mental and physical dimensions of fatigue. Further, both acute and chronic fatigue states are present and should be considered in quantifying fatigue in this population. Future work should quantify the levels of emotional fatigue in nurses and contribution of this dimension to total fatigue.

Differences in fatigue levels across work environments point to the importance of continued research related to variables such as shift length, hours worked per week, and shift schedule, which can be manipulated through work design and interventions. Identifying factors, and

combinations of factors, that contribute to increased levels of fatigue will aid in the development of interventions to reduce levels of fatigue and mitigate negative effects of fatigue on performance. Further research is needed to solicit feedback from nurses on additional task and environmental variables that are associated with increased levels of fatigue.

Causal effects between mental and physical dimensions of fatigue and mental and physical performance measures were demonstrated in a laboratory study. Further, direct and indirect effects of fatigue dimensions on perceived performance were quantified in a structural equation model. Research is needed to build upon these findings by investigating the effects of fatigue on performance during actual clinical practice; medical simulators may be a viable tool for such efforts. As well, the role of additional variables, such as workload, psychosocial factors, and individual differences, in mediating or moderating the causal pathways between fatigue and performance should be explored.

Overall, the findings from this research, including the final validated model, contribute to the body of knowledge in the field of human factors and industrial engineering, as well as the health care industry as a whole. Our understanding of the construct of total fatigue and underlying dimensions of fatigue has been expanded. Further, the demonstration of causal effects of dimensions fatigue on dimensions of performance provides motivation for continuing to quantify fatigue levels in this population with ultimate goals of being able to predict fatigue-related performance decrements, and designing interventions to reduce or eliminate the contributions of fatigue to the occurrence of medical errors.

References

- Aaronson, LS, Pallikkathayil, L, & Crighton, F. (2003). A qualitative investigation of fatigue among healthy working adults. *Western Journal of Nursing Research*, 25(4), 419-433.
- AbuAlRub, RF. (2004). Job stress, job performance, and social support among hospital nurses. *J Nurs Scholarsh*, 36(1), 73-78.
- Adams, RE, Boscarino, JA, & Figley, CR. (2006). Compassion fatigue and psychological distress among social workers: A validation study. *Am J Orthopsychiatry*, 76(1), 103-108.
- Ahsberg, E. (2000). Dimensions of fatigue in different working populations. *Scand J Psychol*, 41(3), 231-241.
- Ahsberg, E, Gamberale, F, & Gustafsson, K. (2000a). Perceived fatigue after mental work: An experimental evaluation of a fatigue inventory. *Ergonomics*, 43(2), 252 - 268.
- Ahsberg, E, Gamberale, F, & Kjellberg, A. (1997). Perceived quality of fatigue during different occupational tasks - development of a questionnaire. *International Journal of Industrial Ergonomics*, 20, 121-135.
- Ahsberg, E, Kecklund, G, Akerstedt, T, & Gamberale, F. (2000b). Shiftwork and different dimensions of fatigue. *International Journal of Industrial Ergonomics*, 26(4), 457-465.
- Aiken, LH. (2001). An international perspective on hospital nurses' work environments: The case for reform. *Policy, Politics, & Nursing Practice*, 2(4), 255-263.
- Aiken, LH, Clarke, SP, Sloane, DM, & Sochalski, J. (2001). Cause for concern: Nurses' reports of hospital care in five countries. *LDI Issue Brief*, 6(8), 1-4.
- Akerstedt, T. (2000). Consensus statement: Fatigue and accidents in transport operations. *Journal of Sleep Research*, 9, 395.
- Akerstedt, T, Knutsson, A, Westerholm, P, Theorell, T, Alfredsson, L, & Kecklund, G. (2004). Mental fatigue, work and sleep. *J Psychosom Res*, 57(5), 427-433.
- ANA. (2001). Nursingworld.Org health and safety survey. Retrieved April 1, 2007, from <http://www.nursingworld.org/surveys/hssurvey.pdf>
- Anderson, J, & Gerbing, D. (1988). Structural equation modeling in practice: A review and recommended two-step approach. *Psychological Bulletin*, 103(3), 411-423.
- Ando, S, Ono, Y, Shimaoka, M, Hiruta, S, Hattori, Y, Hori, F, et al. (2000). Associations of self estimated workloads with musculoskeletal symptoms among hospital nurses. *Occup Environ Med*, 57(3), 211-216.
- Annett, J. (2002). Subjective rating scales: Science or art? *Ergonomics*, 45(14), 966-987.
- Astrand, I. (1960). Aerobic capacity in men and women with special reference to age. *Acta Physiol Scand*, 49(Suppl), 169.

- Babkoff, H, Thorne, DR, Sing, HC, Genser, SG, Taube, SL, & Hegge, FW. (1985). Dynamic changes in work/rest duty cycles in a study of sleep deprivation. *Behavior Research Methods, Instruments, and Computers*, 17, 604-613.
- Baldwin, DC, Jr., & Daugherty, SR. (2004). Sleep deprivation and fatigue in residency training: Results of a national survey of first- and second-year residents. *Sleep*, 27(2), 217-223.
- Barnekow-Bergkvist, M, Aasa, U, Angquist, KA, & Johansson, H. (2004). Prediction of development of fatigue during a simulated ambulance work task from physical performance tests. *Ergonomics*, 47(11), 1238-1250.
- Battersby, D, & Hemmings, L. (1991). Clinical performance of university nursing graduates. *The Australian Journal of Advanced Nursing*, 9(1), 30-34.
- Baulk, S, Kandelaars, K, Lamond, N, Roach, G, Dawson, D, & Fletcher, A. (2007). Does variation in workload affect fatigue in a regular 12-hour shift system? *Sleep and Biological Rhythms*, 5, 74-77.
- Begat, I, Ellefsen, B, & Severinsson, E. (2005). Nurses' satisfaction with their work environment and the outcomes of clinical nursing supervision on nurses' experiences of well-being -- a norwegian study. *J Nurs Manag*, 13(3), 221-230.
- Berguer, R. (1997). The application of ergonomics in the work environment of general surgeons. *Reviews on Environmental Health*, 12(2), 99-106.
- Berguer, R. (1998). Surgical technology and the ergonomics of laparoscopic instruments. *Surgical Endoscopy*, 12, 458-462.
- Berguer, R, Rab, GT, Abu-Ghaida, H, Alarcon, A, & Chung, J. (1997). A comparison of surgeons' posture during laparoscopic and open surgical procedures. *Surgical Endoscopy*, 11, 139-142.
- Berguer, R, Smith, WD, & Chung, YH. (2001). Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery. *Surgical Endoscopy*, 15, 1204-1207.
- Bertram, DA, Hershey, CO, Opila, DA, & Quirin, O. (1990). A measure of physician mental work load in internal medicine ambulatory care clinics. *Medical Care*, 28(5), 458-467.
- Bertram, DA, Opila, DA, Brown, JL, Gallagher, SJ, Schifeling, RW, Snow, IS, et al. (1992). Measuring physician mental workload: Reliability and validity assessment of a brief instrument. *Med Care*, 30(2), 95-104.
- Beynon, C, & Reilly, T. (2001). Spinal shrinkage during a seated break and standing break during simulated nursing tasks. *Appl Ergon*, 32(6), 617-622.
- Blosser, F. (2006). Niosh update: Niosh, ao hp sign healthcare workplace agreement. Retrieved April 1, 2007, from <http://www.cdc.gov/niosh/updates/upd-10-17-06.html>
- Bogner, MS (Ed.). (1994). *Human error in medicine*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.
- Boksem, MA, Meijman, TF, & Lorist, MM. (2006). Mental fatigue, motivation and action monitoring. *Biol Psychol*, 72(2), 123-132.

- Bollen, KA, & Long, JS. (1993). *Testing structural equation models*. Newbury Park, CA: Sage Publications.
- Boomsma, A. (1983). *On the robustness of lisrel against small sample size and nonnormality*. Amsterdam: Sociometric Research Foundation.
- Borg, G. (1970). Perceived exertion as an indicator of somatic stress. *Scand J Rehab Med*, 1970(2-3), 92-98.
- Borg, G. (1982). Psychological basis of physical exertion. *Medicine and Science in Sports and Exercise*, 14, 377-381.
- Borg, G. (1998). *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinestics Books.
- Bosh, LHM, & De Lange, WAM. (1987). Shift work in health care. *Ergonomics*, 30, 773-791.
- Bradley, P. (2006). The history of simulation in medical education and possible future directions. *Med Educ*, 40(3), 254-262.
- Browne, B, Van Susteren, T, Onsager, D, Simpson, D, Salaymeh, B, & Condon, R. (1994). Influence of sleep deprivation on learning among surgical house staff and medical students. *Surgery*, 115, 604-610.
- Buerhaus, P, Staiger, D, & Auerbach, D. (2000). Implications of an aging registered nurse workforce. *Journal of the American Medical Association*, 283(22), 2948-2954.
- Bureau of Labor Statistics. (2005). Total recordable cases -- injuries and illnesses, 2005. Retrieved April 6, 2007, from <http://www.bls.gov/iif/oshwc/osh/os/ostb1619.pdf>
- Burnham, K, & Andersen, D. (2004). Multimodal inference: Understanding aic and bic in model selection. *Sociological Methods Research*, 33, 261-304.
- Byrne, BM. (1994). *Structural equation modelling with eqs and eqs/windows: Basic concepts, applications, and programming*. Thousand Oaks, CA: Sage Publications.
- Caldwell, JA. (2001). The impact of fatigue in air medical and other types of operations: A review of fatigue facts and potential countermeasures. *Air Medical Journal*, 25-32.
- Caldwell, JA, & Gilreath, SR. (2002). A survey of aircrew fatigue in a sample of u.S. Army aviation personnel. *Aviation, Space, and Environmental Medicine*, 73(5), 472-479.
- Carayon, P, Alvarado, C. J. and Hundt, A. Schoofs. (2007). Work design and patient safety. *Theoretical Issues in Ergonomics Science*, 8(5), 395 - 428.
- Carayon, P, & Gurses, AP. (2005). A human factors engineering conceptual framework of nursing workload and patient safety in intensive care units. *Intensive Crit Care Nurs*, 21(5), 284-301.
- Chalder, T, Berelowitz, G, Pawlikowska, T, Watts, L, Wessely, S, Wright, D, et al. (1993). Development of a fatigue scale. *J Psychosom Res*, 37(2), 147-153.
- Chau, PYK. (1997). Reexamining a model for evaluating information center success using a structural equation modelling approach. *Decision Sciences*, 28(2), 309-334.

- Chen, M, Chen, C, Yeh, W, Huang, J, & Mao, I. (2003). Heat stress evaluation and worker fatigue in a steel plant. *AIHA Journal*, 64(3), 352-359.
- Chen, SM, & McMurray, A. (2001). "Burnout" In intensive care nurses. *J Nurs Res*, 9(5), 152-164.
- Cholewicki, J, Polzhofer, GK, & Radebold, A. (2000). Postural control of trunk during unstable sitting. *J Biomech*, 33(12), 1733-1737.
- Christensen, H. (1986). Muscle activity and fatigue in the shoulder muscles during repetitive work. *European Journal of Applied Physiology*, 54, 596-601.
- Clark, BC, Collier, SR, Manini, TM, & Ploutz-Snyder, LL. (2005). Sex differences in muscle fatigability and activation patterns of the human quadriceps femoris. *Eur J Appl Physiol*, 94(1-2), 196-206.
- Clarke, SP, & Aiken, LH. (2006). More nursing, fewer deaths. *Qual Saf Health Care*, 15(1), 2-3.
- Colligan, MJ, Frocht, IJ, & Tasto, DL. (1979). Frequency of sickness absence and worksite clinic visits among nurses as a function of shift. *J Environ Pathol Toxicol*, 2(5), 135-148.
- Collins, S, & Long, A. (2003). Too tired to care? The psychological effects of working with trauma. *Journal of Psychiatric and Mental Health Nursing*, 10, 17-27.
- Cook, D, Nagelkirk, P, Peckerman, A, Poluri, A, Mores, J, & Natelson, B. (2005). Exercise and cognitive performance in chronic fatigue syndrome. *Medicine and Science in Sports and Exercise*, 37(9), 1460-1467.
- Craig, A, & Condon, R. (1985). Speed-accuracy trade-off and time of day. *Acta Psychol (Amst)*, 58, 115-122.
- Davis, KG, Marras, WS, Heaney, CA, Waters, TR, & Gupta, P. (2002). The impact of mental processing and pacing on spine loading. *Spine*, 27, 2645-2653.
- Dawson, D, & Fletcher, A. (2001). A quantitative model of work-related fatigue: Background and definition. *Ergonomics*, 44(2), 144-163.
- De Vries, J, Michielsen, HJ, & Van Heck, GL. (2003). Assessment of fatigue among working people: A comparison of six questionnaires. *Occup Environ Med*, 60(Suppl I), i10-i15.
- DeLuca, J (Ed.). (2005). *Fatigue as a window to the brain*. Cambridge: The MIT Press.
- DeMoss, C, McGrail, M, Jr., Haus, E, Crain, AL, & Asche, SE. (2004). Health and performance factors in health care shift workers. *J Occup Environ Med*, 46(12), 1278-1281.
- Denis, S, Shannon, H, Wessel, J, Stratford, P, & Weller, I. (2007). Association of low back pain, impairment, disability, & work limitations in nurses. *Journal of Occupational Rehabilitation*, 17, 213-226.
- Devitt, JH, Kurrek, MM, Cohen, MM, & Cleave-Hogg, D. (2001). The validity of performance assessments using simulation. *Anesthesiology*, 95, 36-42.

- DiDomenico, A. (2003). *An investigation on subjective assessments of workload and postural stability under conditions of joint mental and physical demands*. Unpublished Dissertation, Virginia Polytechnic Institute and State University, Blacksburg.
- DiDomenico, A., & Nussbaum, M. (2005). Interactive effects of mental and postural demands on subjective assessment of mental workload and postural stability. *Safety Science*, 43(2005), 485-495.
- Dilalla, LF. (2000). Structural equation modeling: Uses and issues. In H. E. A. Tinsley & S. D. Brown (Eds.), *Handbook of applied multivariate statistics and mathematical modeling* (pp. 439-464). New York, NY: Academic Press.
- Dimick, JB, Swoboda, SM, Pronovost, PJ, & Lipsett, PA. (2001). Effect of nurse-to-patient ratio in the intensive care unit on pulmonary complications and resource use after hepatectomy. *Am J Crit Care*, 10(6), 376-382.
- Dinges, D, Pack, F, Williams, K, Gillen, K, Powell, J, Ott, G, et al. (1997). Cumulative sleepiness, mood disturbance, and psychomotor vigilance performance decrements during a week of sleep restricted to 4-5 hours per night. *Sleep*, 20(4), 267-277.
- Dirnberger, G, Duregger, C, Trettler, E, Lindinger, G, & Lang, W. (2004). Fatigue in a simple repetitive motor task: A combined electrophysiological and neuropsychological study. *Brain Res*, 1028(1), 26-30.
- Dundon, JM, Cirillo, J, & Semmler, JG. (2008). Low-frequency fatigue and neuromuscular performance after exercise-induced damage to elbow flexor muscles. *J Appl Physiol*, 105(4), 1146-1155.
- Edell-Gustafsson, UM, Kritz, EI, & Bogren, IK. (2002). Self-reported sleep quality, strain and health in relation to perceived working conditions in females. *Scand J Caring Sci*, 16(2), 179-187.
- Emam, TA, Frank, TG, Hanna, GB, & Cuschieri, A. (2001). Influence of handle design on the surgeon's upper limb movements, muscle recruitment, and fatigue during endoscopic suturing. *Surgical Endoscopy*, 15, 667-672.
- Emam, TA, Hanna, G, & Cuschieri, A. (2002). Ergonomic principles of task alignment, visual display, and direction of execution of laparoscopic bowel suturing. *Surgical Endoscopy*, 16, 267-271.
- Estryn-Behar, M, Kaminski, M, Peigne, E, Maillard, MF, Pelletier, A, Berthier, C, et al. (1990). Strenuous working conditions and musculo-skeletal disorders among female hospital workers. *Int Arch Occup Environ Health*, 62(1), 47-57.
- Farmer, JH, & Freund, RJ. (1975). Variable selection in the multivariate analysis of variance (manova). *Communications in Statistics - Simulation and Computation*, 4(1), 87-98.
- Faucett, J. (2005). Integrating 'psychosocial' factors into a theoretical model for work-related musculoskeletal disorders. *Theoretical Issues in Ergonomics Science*, 6(6), 531-550.
- Finkelman, J. (1994). A large database study of the factors associated with work-induced fatigue. *Human Factors*, 36(2), 232-243.

- Fisman, DN, Harris, AD, Rubin, M, Sorock, GS, & Mittleman, MA. (2007). Fatigue increases the risk of injury from sharp devices in medical trainees: Results from a case-crossover study. *Infection Control and Hospital Epidemiology*, 28(1), 10-17.
- Fleischman, E, & Hempel, W. (1954). A factor analysis of dexterity tests. *Personnel Psychology*, 715-732.
- Fleming, SL, Jansen, CW, & Hasson, SM. (1997). Effect of work glove and type of muscle action on grip fatigue. *Ergonomics*, 40(6), 601-612.
- Flin, R, Fletcher, G, McGeorge, P, Sutherland, A, & Patey, R. (2003). Anaesthetists' attitudes to teamwork and safety. *Anaesthesia*, 58, 233-242.
- Frey, R, Decker, K, Reinfried, L, Klosch, G, Saletu, B, Anderer, P, et al. (2002). Effect of rest on physicians' performance in an emergency department, objectified by electroencephalographic analyses and psychometric tests. *Neurologic Critical Care*, 30(10), 2322-2329.
- Friedberg, F, & Jason, LA. (1998). *Understanding chronic fatigue syndrome* (1 ed.). Washington, DC: American Psychological Association.
- Frzovic, D, Morris, ME, & Vowels, L. (2000). Clinical tests of standing balance: Performance of persons with multiple sclerosis. *Arch Phys Med Rehabil*, 81(2), 215-221.
- Gaba, DM, & DeAnda, A. (1988). A comprehensive anesthesia simulation environment: Re-creating the operating room for research and training. *Anesthesiology*, 69(3), 387-394.
- Gaba, DM, & Howard, SK. (2002). Fatigue among clinicians and the safety of patients. *N Engl J Med*, 347(16), 1249-1255.
- Gaba, DM, Singer, SJ, Sinaiko, AD, Bowen, JD, & Ciavarelli, AP. (2003). Differences in safety climate between hospital personnel and naval aviators. *Human Factors*, 45(2), 173-185.
- Gamberale, F. (1972). Perceived exertion, heart rate, oxygen uptake and blood lactate in different work operations. *Ergonomics*, 15, 545-554.
- Gander, P, Merry, A, Millar, M, & Weller, J. (2000). Hours of work and fatigue-related error: A survey of new zealand anesthetists. *Anaesth Intensive Care*, 28, 178-183.
- Ganong, WL, Ganong, JM, & Harrison, ET. (1976). The 12-hour shift: Better quality, lower cost. *J Nurs Adm*, 6(2), 17-29.
- Garland, GA. (1996). Self report of competence. A tool for the staff development specialist. *J Nurs Staff Dev*, 12(4), 191-197.
- Gawande, AA, Zinner, MJ, Studdert, DM, & Brennan, T, A. (2003). Analysis of errors reported by surgeons at three teaching hospitals. *Surgery*, 133, 614-621.
- Geiger-Brown, J, Trinkoff, AM, Nielsen, K, Lirtmunlikaporn, S, Brady, B, & Vasquez, E. (2004). Nurses' perception of their work environment, health, and well-being: A qualitative perspective (i.). *AAOHN J*, 52(1), 16-22.
- Ghiselli, E. (1973). The validity of aptitude tests in personnel selection. *Personnel Psychology*, 26(4), 461-477.

- Gillespie, A, & Curzio, J. (1996). A comparison of a 12-hour and eight-hour shift system. *Nurs Times*, 92(39), 36-39.
- Gold, DR, Rogacz, S, Bock, N, Tosteson, TD, Baum, TM, Speizer, FE, et al. (1992). Rotating shift work, sleep, and accidents related to sleepiness in hospital nurses. *Am J Public Health*, 82(7), 1011-1014.
- Goode, J. (2003). Are pilots at risk of accidents due to fatigue? *Journal of Safety Research*, 34, 309-313.
- Gopher, D, & Donchin, E. (1986). Workload - an examination of the concept. In K. R. Boff, L. Kaufman & J. P. Thomas (Eds.), *Handbook of perception and human performance* (pp. 41.41-41.49). New York: Wiley & Sons, Inc.
- Gouttebauge, V, Wind, H, Kuijer, PP, & Frings-Dresen, MH. (2004). Reliability and validity of functional capacity evaluation methods: A systematic review with reference to blankenship system, ergos work simulator, ergo-kit and isernhagen work system. *Int Arch Occup Environ Health*, 77(8), 527-537.
- Grandjean, E. (1968). Fatigue: Its physiological and psychological significance. *Ergonomics*, 11(5), 427-436.
- Gravenstein, J, Cooper, J, & Orkin, F. (1990). Work and rest cycles in anesthesia practice. *Anesthesiology*, 72, 734-742.
- Guillot, A, Haguenaue, M, Dittmar, A, & Collet, C. (2005). Effect of a fatiguing protocol on motor imagery accuracy. *European Journal of Applied Physiology*, 95, 186-190.
- Hair, JFJ, Anderson, RE, Tatham, RL, & Black, WC. (1995). *Multivariate data analysis with readings* (4th ed.). Englewood Cliffs, NJ: Prentice-Hall.
- Hancock, P, Harris, W, & Harris, S. (2001). Information processing changes following extended stress. *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting*, 45, 901-905.
- Harris, W, Goernert, P, Nelson, K, Netsch, S, & Scheel, M. (1996). *Daytime cognitive performance and fatigue change*. Mankato, MN: Mankato State University, Department of Psychology, Engineering Psychology and Human Performance Laboratory.
- Hausmann, RK, & Hegyvary, ST. (1976). Monitoring the quality of nursing care. *Aust Nurses J*, 5(8), 29-32, 36.
- Hillman, CH, Snook, EM, & Jerome, GJ. (2003). Acute cardiovascular exercise and executive control function. *International Journal of Psychophysiology*, 48, 307-314.
- Hockey, R (Ed.). (1983). *Stress and fatigue in human performance* (1 ed.). New York: John Wiley & Sons.
- Holding, DH. (1983). Fatigue. In G. R. J. Hockey (Ed.), *Stress and fatigue in human performance* (pp. 145-167). New York: John Wiley and Sons Ltd.
- Houkes, I, Janssen, PPM, de Jonge, J, & Bakker, AB. (2003). Specific determinants of intrinsic work motivation, emotional exhaustion and turnover intention: A multisample

- longitudinal study. *Journal of Occupational and Organizational Psychology*, 76, 427-450.
- Howard, SK, Rosekind, MR, Katz, JD, & Berry, AJ. (2002). Fatigue in anesthesiology. Implications and strategies for patient and provider safety. *Anesthesiology*, 97(5), 1281-1294.
- Hoyle, RH (Ed.). (1995). *Structural equation modeling*. Thousand Oaks: SAGE Publications.
- Hu, L, Bentler, PM, & Kano, Y. (1992). Can test statistics in covariance structure analysis be trusted? *Psychological Bulletin*, 112, 351-362.
- Huberty, C, & Olejnik, S. (2006). *Applied manova and discriminant analysis* (2nd ed.). Hoboken, NJ: Wiley-Interscience.
- Implications of fatigue on patient and nurse safety*. (2005.): American Nurses Association.
- Isernhagen, SJ, Hart, DL, & Matheson, LM. (1999). Reliability of independent observer judgments of level of lift effort in a kinesiophysical functional capacity evaluation. *Work*, 12(2), 145-150.
- Janowitz, IL, Gillen, M, Ryan, G, Rempel, D, Trupin, L, Swig, L, et al. (2006). Measuring the physical demands of work in hospital settings: Design and implementation of an ergonomics assessment. *Appl Ergon*, 37(5), 641-658.
- Jason, LA, Jordan, KM, Richman, JA, Rademaker, AW, Huang, CF, McCready, W, et al. (1999). A community-based study of prolonged fatigue and chronic fatigue. *Journal of Health Psychology*, 4, 9-26.
- Jelinek, RC. (1967). A structural model for the patient care operation. *Health Serv Res*, 2(3), 226-242.
- Johnson, LJ, & Miller, M. (2001). Functional testing: Approaches and injury management integration. *Work*, 16(1), 7-11.
- Jordan, J, Harris, W, Goernert, P, & Roberts, J. (1996). The effect of active noise reduction technology on noise induced pilot fatigue and associated cognitive performance decrements. *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*, 40, 67-71.
- Josten, EJ, Ng, ATJE, & Thierry, H. (2003). The effects of extended workdays on fatigue, health, performance and satisfaction in nursing. *J Adv Nurs*, 44(6), 643-652.
- Kamath, MV, & Fallen, EL. (1993). Power spectral analysis of heart rate variability: A noninvasive signature of cardiac autonomic function. *Critical Reviews in Biomedical Engineering*, 21, 245-311.
- Kamijo, K, Nishihira, Y, Hatta, A, Kaneda, T, Wasaka, T, Kida, T, et al. (2004). Differential influences of exercise intensity on information processing in the central nervous system. *European Journal of Applied Physiology*, 92, 305-311.

- Kamijo, K, Nishihira, Y, Higashiura, T, & Kuroiwa, K. (2007). The interactive effect of exercise intensity and task difficulty on human cognitive processing. *Int J Psychophysiol*, 65(2), 114-121.
- Kandolin, I. (1993). Burnout of female and male nurses in shiftwork. *Ergonomics*, 36(1-3), 141-147.
- Kane, R, & Reeves, D. (1997). Computerized test batteries. In A. Horton (Ed.), *The neuropsychology handbook: New edition*. New York: Springer.
- Karasek, R, Brisson, C, Kawakami, N, Houtman, I, Bongers, P, & Amick, B. (1998). The job content questionnaire (jcq): An instrument for internationally comparative assessments of psychosocial job characteristics. *Journal of Occupational Health Psychology*, 3(4), 322-355.
- Karsh, BT, Holden, RJ, Alper, SJ, & Or, CK. (2006). A human factors engineering paradigm for patient safety: Designing to support the performance of the healthcare professional. *Qual Saf Health Care*, 15 Suppl 1, i59-65.
- Kaufman, H. (1987). Teaching surgeons to operate--principles of psychomotor skills training. *Acta Neurochirurgica*, 87(1-2), 1-7.
- Kecklund, G, Ekstedt, M, Akerstedt, T, Dahlgren, A, & Samuelson, B. (2001). The effects of double-shifts (15.5 hours) on sleep, fatigue, and health. *J. Human Ergol.*, 30, 53-58.
- Kilborn, A. (1971). Physical training in women. *Scand J Clin Lab Invest*, 28(suppl), 119.
- Kinsman, R, & Weiser, P. (1976). Subjective symptomatology during work and fatigue. In E. Simonson & P. Weiser (Eds.), *Psychological aspects and physiological correlates of work and fatigue* (pp. 336-405). Springfield: CC Thomas.
- Knibbe, JJ, & Friele, RD. (1996). Prevalence of back pain and characteristics of the physical workload of community nurses. *Ergonomics*, 39(2), 186-198.
- Koerner, BL. (1981). Selected correlates of job performance of community health nurses. *Nurs Res*, 30(1), 43-48.
- Kohn, LT, Corrigan, JM, & Donaldson, MS. (1999). *To err is human: Building a safer health system*. Washington, DC: National Academy Press.
- Kroll, P, Machado, L, Happy, C, Leong, S, & Chen, B. (2000). The relationship between five measures of trunk strength. *Journal of Back and Musculoskeletal Rehabilitation*, 14(2000), 89-97.
- Krueger, GP. (1989). Sustained work, fatigue, sleep loss and performance: A review of the issues. *Work & Stress*, 3(2), 129-141.
- Krueger, GP. (1994). Fatigue, performance and medical error. In M. S. Bogner (Ed.), *Human error in medicine* (pp. 311-326). Hillsdale: L. Erlbaum Associates.
- Lagerstrom, M, Wenemark, M, Hagberg, M, & Hjelm, EW. (1995). Occupational and individual factors related to musculoskeletal symptoms in five body regions among swedish nursing personnel. *Int Arch Occup Environ Health*, 68(1), 27-35.

- Lamberg, L. (2002). Long hours, little sleep. Bad medicine for physicians-in-training? *JAMA*, 287(3), 303-307.
- Landrigan, CP, Rothschild, JM, Cronin, JW, Kaushal, R, Burdick, E, Katz, JT, et al. (2004). Effect of reducing interns' work hours on serious medical errors in intensive care units. *N Engl J Med*, 351(18), 1838-1848.
- Lavidor, M, Weller, A, & Babkoff, H. (2003). How sleep is related to fatigue. *British Journal of Health Psychology*, 8, 95-105.
- Lee, H, Granata, KP, & Madigan, ML. (2008). Effects of trunk exertion force and direction on postural control of the trunk during unstable sitting. *Clinical Biomechanics*, 23(2008), 505-509.
- Lerner, D, Amick, B, Rogers, W, Malspeis, S, Bungay, K, & Cynn, D. (2001). The work limitations questionnaire. *Medical Care*, 39(1), 72-85.
- Leung, A, Chan, C, Ng, J, & Wong, P. (2006). Factors contributing to officers' fatigue in high-speed maritime craft operations. *Applied Ergonomics*, 37, 565-576.
- Leung, AW, Chan, CC, & He, J. (2004). Structural stability and reliability of the swedish occupational fatigue inventory among chinese vdt workers. *Appl Ergon*, 35(3), 233-241.
- Lewittes, L, & Marshall, V. (1989). Fatigue and concerns about quality of care among ontario interns and residents. *Cmaj*, 140.
- Leyman, ELC, Mirka, GA, Kaber, DB, & Sommerich, CM. (2004). Cervicobrachial muscle response to cognitive load in a dual-task scenario. *Ergonomics*, 47, 625-645.
- Lin, D, Nussbaum, MA, Seol, H, Singh, NB, Madigan, ML, & Wojcik, LA. (2009). Acute effects of localized muscle fatigue on postural control and patterns of recovery during upright stance: Influence of fatigue location and age. *Eur J Appl Physiol*, 106(3), 425-434.
- Lindborg, C, & Davidhizar, R. (1993). Is there a difference in nurse burnout on the day or night shift? *The Health Care Supervisor*, 11(3), 47-52.
- Lipscomb, J, Trinkoff, A, Brady, B, & Geiger-Brown, J. (2004). Health care system changes and reported musculoskeletal disorders among registered nurses. *Am J Public Health*, 94(8), 1431-1435.
- Lipscomb, JA, Trinkoff, AM, Geiger-Brown, J, & Brady, B. (2002). Work-schedule characteristics and reported musculoskeletal disorders of registered nurses. *Scand J Work Environ Health*, 28(6), 394-401.
- Lorist, MM, Kernell, D, Meijman, TF, & Zijdwind, I. (2002). Motor fatigue and cognitive task performance in humans. *J Physiol*, 545(Pt 1), 313-319.
- Lorist, MM, Klein, M, Nieuwenhuis, S, De Jong, R, Mulder, G, & Meijman, TF. (2000). Mental fatigue and task control: Planning and preparation. *Psychophysiology*, 37(5), 614-625.
- Lowe, M, Harris, W, Kane, R, Banderet, L, Levinson, D, & Reeves, D. (2007). Neuropsychological assessment in extreme environments. *Archives of Clinical Neuropsychology*, 22(Supplement 1), 89-99.

- Lundberg, U, Forsman, M, Zachau, G, Eklof, M, Palmerud, G, Melin, B, et al. (2002). Effects of experimentally induced mental and physical stress on motor unit recruitment in the trapezius muscle. *Work & Stress*, 16, 166-178.
- Luttmann, A, Jager, M, Sokeland, J, & Laurig, W. (1996). Electromyographical study on surgeons in urology. II. Determination of muscular fatigue. *Ergonomics*, 39(2), 298-313.
- MacCallum, RC, Roznowski, M, & Necowitz, LB. (1992). Model modifications in covariance structure analysis: The problem of capitalization on chance. *Psychol Bull*, 111(3), 490-504.
- Macdonald, W. (2003). The impact of job demands and workload on stress and fatigue. *Australian Psychologist*, 38(2), 102-117.
- Magnie, MN, Berman, S, Martin, F, Madany-Lounis, M, Suisse, G, Muhammad, W, et al. (2000). P300, n400, aerobic fitness, and maximal aerobic exercise. *Psychophysiology*, 37(369-377).
- Marcora, SM, Staiano, W, & Manning, V. (2009). Mental fatigue impairs physical performance in humans. *J Appl Physiol*, 106(3), 857-864.
- Matheson, L, Isernhagen, S, & Hart, D. (2002). Relationships among lifting ability, grip force, and return to work. *Physical Therapy*, 82(3), 249-256.
- Mattke, S, Needleman, J, Buerhaus, P, Stewart, M, & Zelevinsky, K. (2004). Evaluating the role of patient sample definitions for quality indicators sensitive to nurse staffing patterns. *Med Care*, 42(2 Suppl), II21-33.
- Maxim, PS. (1999). *Quantitative research methods in the social sciences*. New York, NY: Oxford University Press.
- McCloskey, J, & McCain, B. (1988). Variables related to nurse performance. *IMAGE: Journal of Nursing Scholarship*, 20(4), 203-207.
- McKee, M, & Black, N. (1992). Does the current use of junior doctors in the united kingdom affect the quality of medical care? *Soc Sci Med*, 34, 549-558.
- McKenney, S. (2000). Working with industry: Matching the work and worker. *Work*, 15(2), 121-124.
- McKinley, A. (2005). Health care providers and facilities: Health facilities--2005. End of year issue brief. *Issue Brief Health Policy Track Serv.*, 1-10.
- Meshkati, N. (1988a). Heart rate variability and mental workload assessment. In P. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 101-115). Amsterdam: Elsevier.
- Meshkati, N. (1988b). Toward development of a cohesive model of workload. In P. Hancock & N. Meshkati (Eds.), *Human mental workload* (pp. 305-314). Amsterdam: Elsevier.
- Michielsen, HJ, De Vries, J, & Van Heck, GL. (2003). Psychometric qualities of a brief self-rated fatigue measure: The fatigue assessment scale. *J Psychosom Res*, 54(4), 345-352.

- Michielsen, HJ, De Vries, J, Van Heck, GL, Van de Vijver, FJR, & Sijtsma, GJ. (2004). Examination of the dimensionality of fatigue: The construction of the fatigue assessment scale (fas). *European Journal of Psychological Assessment*, 20(1), 39-48.
- Mientjes, MI, & Frank, JS. (1999). Balance in chronic low back pain patients compared to healthy people under various conditions in upright standing. *Clin Biomech (Bristol, Avon)*, 14(10), 710-716.
- Miller, JC. (2005). *Operational risk management of fatigue effects*. Brooks City-Base, Texas: United States Air Force Research Laboratory.
- Missenard, O, Mottet, D, & Perrey, S. (2008). Muscular fatigue increases signal-dependent noise during isometric force production. *Neurosci Lett*, 437(2), 154-157.
- Moss, T, & Sills, D. (1981). The three mile island nuclear accident: Lessons and implications. In (pp. 341). New York, New York: Academy of Sciences.
- Muecke, S. (2005). Effects of rotating night shifts: Literature review. *J Adv Nurs*, 50(4), 433-439.
- Murata, K, Araki, S, Kawakami, N, Saito, Y, & Hino, E. (1991). Central nervous system effects and visual fatigue in vdt workers. *International Archives of Occupational and Environmental Health*, 63(2), 109-113.
- Nachemson, AL. (1985). Advances in low-back pain. *Clin Orthop Relat Res*(200), 266-278.
- Narumi, J, Miyazawa, S, Miyata, H, Suzuki, A, Kohsaka, S, & Kosugi, H. (1999). Analysis of human error in nursing care. *Accident Analysis & Prevention*, 31(6), 625-629.
- Nehring, WM, & Lashley, FR. (2004). Current use and opinions regarding human patient simulators in nursing education: An international survey. *Nurs Educ Perspect*, 25(5), 244-248.
- Nindl, BC, Leone, CD, Tharion, WJ, Johnson, RF, Castellani, JW, Patton, JF, et al. (2002). Physical performance responses during 72 h of military operational stress. *Med Sci Sports Exerc*, 34(11), 1814-1822.
- Nunnally, J. (1978). *Psychometric theory*. New York: McGraw-Hill.
- Nussbaum, MA. (2003). Postural stability is compromised by fatiguing overhead work. *AIHAJ*, 64(1), 56-61.
- Nussbaum, MA, Clark, LL, Lanza, MA, & Rice, KM. (2001). Fatigue and endurance limits during intermittent overhead work. *AIHAJ*, 62, 446-456.
- Oberg, T, Sandsjo, L, & Kadefors, R. (1994). Subjective and objective evaluation of shoulder muscle fatigue. *Ergonomics*, 37(8), 1323-1333.
- Ochoa, FJ, Ramalle-Gomara, E, Lisa, V, & Saralegui, I. (1998). The effect of rescuer fatigue on the quality of chest compressions. *Resuscitation*, 37(1998), 149-152.
- Owens, JA. (2001). Sleep loss and fatigue in medical training. *Current Opinion in Pulmonary Medicine*, 7, 411-418.

- Page, A (Ed.). (2004). *Keeping patients safe - transforming the work environment of nurses*. Washington: The National Academies Press.
- Panjabi, MM. (1992). The stabilizing system of the spine. Part ii. Neutral zone and instability hypothesis. *J Spinal Disord*, 5(4), 390-396; discussion 397.
- Papp, KK, Stoller, EP, Sage, P, Aikens, JE, Owens, J, Avidan, A, et al. (2004). The effects of sleep loss and fatigue on resident-physicians: A multi-institutional, mixed-method study. *Academic Medicine*, 79(5), 394-406.
- Patterson, ES, Roth, EM, & Render, ML. (2005, 2005). *Handoffs during nursing shift changes in acute care*. Paper presented at the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando.
- Peters, RD, Wagner, E, Alicandri, E, Fox, JE, Thomas, M, & Thorne, D. (1999). Effects of partial and total sleep deprivation on driving performance. *Public Roads*, 62(4).
- Piko, BF. (2006). Burnout, role conflict, job satisfaction and psychosocial health among hungarian health care staff: A questionnaire survey. *Int J Nurs Stud*, 43(3), 311-318.
- Polich, J, & Kok, A. (1995). Cognitive and biological determinants of p300: An integrative review. *Biological Psychology*, 41, 103-146.
- Prieto, TE, Myklebust, JB, Hoffmann, RG, Lovett, EG, & Myklebust, BM. (1996). Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Trans Biomed Eng*, 43(9), 956-966.
- Punnett, L. (1987). Upper extremity musculoskeletal disorders in hospital workers. *J Hand Surg [Am]*, 12(5 Pt 2), 858-862.
- Ramsey, G. (2005). Nurses, medical errors, and the culture of blame. *Hastings Cent Rep*, 35(2), 20-21.
- Rasmussen, J. (1983). Skills, rules, knowledge: Signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man and Cybernetics*, 13(257-266).
- Ream, E, & Richardson, A. (1996). Fatigue: A concept analysis. *Int J Nurs Stud*, 33(5), 519-529.
- Reeves, D, Kane, R, & Winter, K. (1996). *Anam v3. 11a/96 users manual: Clinical and neurotoxicology subsets (scientific report ncrf-sr-96-01)*. San Diego, CA: National Cognitive Recovery Foundation.
- The registered nurse population: Findings from the 2004 national sample survey of registered nurses. (2004). Retrieved May 30, 2009, from <http://bhpr.hrsa.gov/healthworkforce/rnsurvey04/default.htm>
- Rogers, A, Hwang, W, & Scott, L. (2004). The effects of work breaks on staff nurse performance. *Journal of Nursing Administration*, 34(11), 512-519.
- Rogers, AE. (2004). Study shows 12-hour shifts increase errors. *Healthcare Benchmarks and Quality Improvement*, 105-106.

- Rogers, AE, Hwang, W, & Scott, LD. (2004a). The effects of work breaks on staff nurse performance. *Journal of Nursing Administration*, 34(11), 512-519.
- Rogers, AE, Hwang, W, Scott, LD, Aiken, LH, & Dinges, DF. (2004b). The working hours of hospital staff nurses and patient safety. *Health Affairs*, 23, 202-221.
- Ruggiero, JS. (2003). Correlates of fatigue in critical care nurses. *Res Nurs Health*, 26(6), 434-444.
- Ryman, DH, Naitoh, P, & Englund, CE. (1985). Decrements in logical reasoning performance under conditions of sleep loss and physical exercise: The factor of sentence complexity. *Percept Mot Skills*, 61(3 Pt 2), 1179-1188.
- Salas, E, Wilson, KA, Burke, CS, & Priest, HA. (2005). Using simulation-based training to improve patient safety: What does it take? *Jt Comm J Qual Patient Saf*, 31(7), 363-371.
- Samkoff, JS, & Jacques, CHM. (1991). A review of studies concerning effects of sleep deprivation and fatigue on residents' performance. *Academic Medicine*, 66(11), 687-693.
- Sammer, G. (1998). Heart period variability and respiratory changes associated with physical and mental load: Non-linear analysis. *Ergonomics*, 41(5), 746-755.
- Sanders, MS, & McCormick, EJ. (1993). *Human factors in engineering and design* (Seventh ed.). New York: McGraw-Hill, Inc.
- Sawyer, J, & Bennett, A. (2006). Comparing the level of dexterity offered by latex and nitrile safeskin gloves. *Annals of Occupational Hygiene*, 50(3), 289-296.
- Schellekens, JM, Sijtsma, GJ, Vegter, E, & Meijman, TF. (2000). Immediate and delayed after-effects of long lasting mentally demanding work. *Biol Psychol*, 53(1), 37-56.
- Schumacker, RE, & Lomax, RG. (2004). *A beginner's guide to structural equation modeling* (2nd ed.). Mahwah, New Jersey: Lawrence Erlbaum Associates.
- Schwirian, P. (1978). Evaluating the performance of nurses: A multidimensional approach. *Nursing Research*, 27(6), 347-351.
- Scott, LD, Rogers, AE, Hwang, W-T, & Zhang, Y. (2006). Effects of critical care nurses' work hours on vigilance and patients' safety. *American Journal of Critical Care*, 15(1), 30-37.
- Selye, H. (1976). [stress without distress]. *Brux Med*, 56(5), 205-210.
- Sexton, JB, Thomas, EJ, & Helmreich, RL. (2000). Error, stress, and teamwork in medicine and aviation: Cross sectional surveys. *Bmj*, 320, 745-749.
- Shen, J, Barbera, J, & Shapiro, CM. (2006). Distinguishing sleepiness and fatigue: Focus on definition and measurement. *Sleep Med Rev*, 10(1), 63-76.
- Slota, GP, Granata, KP, & Madigan, ML. (2008). Effects of seated whole-body vibration on postural control of the trunk during unstable seated balance. *Clin Biomech (Bristol, Avon)*, 23(4), 381-386.
- Smedley, J, Egger, P, Cooper, C, & Coggon, D. (1997). Prospective cohort study of predictors of incident low back pain in nurses. *Bmj*, 314(7089), 1225-1228.

- Smith, DR, Sato, M, Miyajima, T, Mizutani, T, & Yamagata, Z. (2003). Musculoskeletal disorders self-reported by female nursing students in central japan: A complete cross-sectional survey. *Int J Nurs Stud*, 40(7), 725-729.
- Sochalski, J. (2002). Nursing shortage redux: Turning the corner on an enduring problem. *Health Affairs*, 21(5), 157-164.
- Soh, T, & Crumpton, LL. (1996). *An evaluation of fatigue indicators while performing nursing tasks*. Paper presented at the Industrial Engineering Research, Norcross, GA.
- Song, S, Jason, LA, & Taylor, RR. (1999). The relationship between ethnicity and fatigue in a community-based sample. *Journal of Gender, Culture, and Health*, 4(4), 255-268.
- Sonnentag, S, & Zijlstra, FRH. (2006). Job characteristics and off-job activities as predictors of need for recovery, well-being and fatigue. *Journal of Applied Psychology*, 91(2), 330-350.
- Sosnoff, JJ, & Newell, KM. (2006). Information processing limitations with aging in the visual scaling of isometric force. *Exp Brain Res*, 170(3), 423-432.
- Spratley, E, Johnson, A, Sochalski, J, Fritz, M, & Spencer, W. (2001). *The registered nurse population. Findings from the national sample survey of registered nurses*. Rockville, MD: Health Resources and Services Administration.
- Springer, P, Payne, K, & Petermann, B. (1998). Rating nursing performance based on behaviors. *Journal of Nursing Administration*, 28(1), 39-45.
- Squires, M, Biesiada, D, Fanizza, R, Stationwala, A, MacLean, J, & Strapp, AM. (2005). New approaches to improving patient safety: Strategy, technology and funding. *Healthc Q*, 8(3), 120-122, 124.
- Stone, PW, Yunling, D, Cowell, R, Amsterdam, N, Helfrich, TA, Linn, RW, et al. (2006). Comparison of nurse, system and quality patient care outcomes in 8-hour and 12-hour shifts. *Medical Care*, 44, 1099-1106.
- Stubbs, DA, Buckle, P., Hudson, M.P., Rivers, P.M. and Worringham, C.J. (1983). Back pain in the nursing profession. I. Epidemiology and pilot methodology. *Ergonomics*, 26, 755-765.
- Sullivan, C, & Reading, S. (2002). Nursing shortages: Let's be flexible. *Collegian*, 9(4), 24-28.
- Sumer, N. (2003). Personality and behavioral predictors of traffic accidents: Testing a contextual mediated model. *Accident Analysis & Prevention*, 35(6), 949-964.
- Suzuki, K, Ohida, T, Kaneita, Y, Yokoyama, E, & Uchiyama, M. (2005). Daytime sleepiness, sleep habits and occupational accidents among hospital nurses. *J Adv Nurs*, 52(4), 445-453.
- Szczurak, T, Kaminska, B, & Szpak, A. (2007). Estimation of the psychological load in the performance of nurses' work based on subjective fatigue symptoms. *Advances in Medical Sciences*, 52(Suppl. 1), 102-104.

- Takala, EP, Korhonen, I, & Viikari-Juntura, E. (1997). Postural sway and stepping response among working population: Reproducibility, long-term stability, and associations with symptoms of the low back. *Clin Biomech (Bristol, Avon)*, 12(7-8), 429-437.
- Tanaka, M, Nussbaum, M, & Ross, S. (2009). *Determining the threshold of stability during unstable sitting*. Paper presented at the ASME 2009 Summer Bioengineering Conference, Lake Tahoe, CA.
- Taylor, B, & Barling, J. (2004). Identifying sources and effects of carer fatigue and burnout for mental health nurses: A qualitative approach. *Int J Ment Health Nurs*, 13(2), 117-125.
- Tiesinga, LJ, Dassen, TW, & Halfens, RJ. (1996). Fatigue: A summary of the definitions, dimensions, and indicators. *Nurs Diagn*, 7(2), 51-62.
- Tiffin, J. (1948). The purdue pegboard: Norms and studies of reliability and validity. *Journal of Applied Psychology*, 32, 234-247.
- Torgen, M, Winkel, J, Alfredsson, L, & Kilbom, A. (1999). Evaluation of questionnaire-based information on previous physical work loads. Stockholm music 1 study group. Musculoskeletal intervention center. *Scand J Work Environ Health*, 25(3), 246-254.
- Tourangeau, AE, Cranley, LA, & Jeffs, L. (2006). Impact of nursing on hospital patient mortality: A focused review and related policy implications. *Qual Saf Health Care*, 15(1), 4-8.
- Treanor, HL. (2000). Health risks and the health care professional. *Medicine, Health Care and Philosophy*, 3, 251-255.
- Trinkoff, A, Geiger-Brown, J, Brady, B, Lipscomb, J, & Muntaner, C. (2006). How long and how much are nurses now working? *The American Journal of Nursing*, 106(4), 60-71.
- Trinkoff, AM, Lipscomb, JA, Geiger-Brown, J, & Brady, B. (2002). Musculoskeletal problems of the neck, shoulder, and back and functional consequences in nurses. *Am J Ind Med*, 41(3), 170-178.
- Trinkoff, AM, & Storr, CL. (1998). Work schedule characteristics and substance use in nurses. *Am J Ind Med*, 34(3), 266-271.
- Trinkoff, AM, Storr, CL, & Lipscomb, JA. (2001). Physically demanding work and inadequate sleep, pain medication use, and absenteeism in registered nurses. *J Occup Environ Med*, 43(4), 355-363.
- Tyler, PA, Carroll, D, & Cunningham, SE. (1991). Stress and well-being in nurses: A comparison of the public and private sectors. *Int. J. Nurs. Stud.*, 28(2), 125-130.
- Uhrich, ML, Underwood, A, Standeven, JW, Soper, NJ, & Engsberg, JR. (2002). Assessment of fatigue, monitor placement, and surgical experience during simulated laparoscopic surgery. *Surgical Endoscopy*, 16, 635-639.
- Underwood, AB. (1975). What a 12-hour shift offers. *Am J Nurs*, 75(7), 1176-1178.
- Van Cott, H. (1994). Human errors: Their causes and reduction. In M. S. Bogner (Ed.), *Human error in medicine* (pp. 53-65). Hillsdale, New Jersey: Lawrence Erlbaum Associates.

- van der Linden, D, Frese, M, & Meijman, TF. (2003a). Mental fatigue and the control of cognitive processes: Effects on perseveration and planning. *Acta Psychol (Amst)*, 113(1), 45-65.
- van der Linden, D, Frese, M, & Sonnentag, S. (2003b). The impact of mental fatigue on exploration in a complex computer task: Rigidity and loss of systematic strategies. *Human Factors*, 45(3), 483-494.
- Varghese, M, Saha, P, & Atreya, N. (1994). A rapid appraisal of occupational workload from a modified scale of perceived exertion. *Ergonomics*, 37(3), 485-491.
- Veldhuizen, IJ, Gaillard, AW, & de Vries, J. (2003). The influence of mental fatigue on facial emg activity during a simulated workday. *Biol Psychol*, 63(1), 59-78.
- Vercoulen, JHMM, Swanink, CMA, Fennis, JFM, Galama, JMD, van der Meer, JWM, & Bleijenberg, G. (1994). Dimensional assessment of chronic fatigue. *Journal of Psychosomatic Research*, 38(5), 383-392.
- Weinger, M, & Ancoli-Israel, S. (2002). Sleep deprivation and clinical performance. *Journal of the American Medical Association*, 287, 955-957.
- Welford, AT. (1973). Stress and performance. *Ergonomics*, 16(5), 567-580.
- Wickens, CD, & Hollands, JG. (2000). *Engineering psychology and human performance* (Third ed.). Upper Saddle River, NJ: Prentice Hall.
- Winter, D. (2004). *Biomechanics and motor control of human movement* (3rd ed.). Hoboken, New Jersey: Wiley.
- Winwood, PC, Lushington, K, & Winefield, AH. (2006a). Further development and validation of the occupational fatigue exhaustion recovery (ofer) scale. *J Occup Environ Med*, 48(4), 381-389.
- Winwood, PC, Winefield, AH, Dawson, D, & Lushington, K. (2005). Development and validation of a scale to measure work-related fatigue and recovery: The occupational fatigue exhaustion/recovery scale (ofer). *J Occup Environ Med*, 47(6), 594-606.
- Winwood, PC, Winefield, AH, & Lushington, K. (2006b). Work-related fatigue and recovery: The contribution of age, domestic responsibilities and shiftwork. *J Adv Nurs*, 56(4), 438-449.
- Wolf, LD, Potter, P, Sledge, JA, Boxerman, SB, Grayson, D, & Evanoff, B. (2006). Describing nurses' work: Combining quantitative and qualitative analysis. *Human Factors*, 48(1), 5-14.
- Wu, A, Folkman, S, McPhee, S, & Lo, B. (1991). Do house officers learn from their mistakes? *JAMA*, 265, 2089-2094.
- Yarnold, PR, & Bryant, FB. (1994). Student jenkins activity survey (sjas). In J. Fischer & K. Corcoran (Eds.), *Measures for clinical practice* (2nd ed., Vol. 2, pp. 637-641). New York, NY: The Free Press.

- Yerkes, RM, & Dodson, JD. (1908). The relation of strength of stimulus to rapidity of habit formation. *Journal of Comparative Neurological Psychology*, 18, 459-482.
- Yip, Y. (2001). A study of work stress, patient handling activities and the risk of low back pain among nurses in hong kong. *J Adv Nurs*, 36(6), 794-804.
- Yoshitake, H. (1978). Three characteristic patterns of subjective fatigue symptoms. *Ergonomics*, 21(3), 231-233.
- Zboril-Benson, LR. (2002). Why nurses are calling in sick: The impact of health-care restructuring. *Can J Nurs Res*, 33(4), 89-107.
- Zijdewind, I, van Duinen, H, Zielman, R, & Lorist, MM. (2006). Interaction between force production and cognitive performance in humans. *Clin Neurophysiol*, 117(3), 660-667.
- Zohar, D, Tzischinsky, O, Epstein, R, & Lavie, P. (2005). The effects of sleep loss on medical residents' emotional reactions to work events: A cognitive-energy model. *Sleep*, 28(1), 47-54.

APPENDICES

APPENDIX A: FATIGUE IN NURSING SURVEY SET – INSTRUCTIONS AND DEMOGRAPHIC DATA

The following survey consists of several sets of questions intended to measure your perceptions about your work environment, fatigue, and work performance. The results will be used in a research study being conducted in the Industrial and Systems Engineering Department at Virginia Tech. Participating in this study is completely voluntary. By completing the survey and submitting your responses, you are implying consent to participate in this research. All of your responses are anonymous and will be viewed only by the research team. The entire survey should take approximately 15-20 minutes to complete.

Please complete the following survey set as close to the completion of a work shift as possible.

Background Information:

1. Gender:

☐ Female

☐ Male

2. Age:

☐ Under 20 years old

☐ 51 - 60

☐ 21 - 30

☐ 61 - 65

☐ 31 - 40

☐ 66 or older

☐ 41 - 50

3. Please choose the race, ethnicity, or national group you most identify with:

☐ African-American

☐ Multiracial

☐ Asian-American

☐ Native American

☐ Caucasian

☐ Native Hawaiian or Other Pacific Islander

☐ Foreign national

☐ Other

☐ Hispanic

4. Marital status

☐ Single

☐ Separated

- ☐ Married ☐ Other
☐ Divorced

5. Number of dependents (e.g., children, elderly relatives, etc.):

- ☐ 0
☐ 1 - 2
☐ 3 - 4
☐ More than 4

6. How many hours of sleep do you get, on average, per night?

- ☐ 8 - 9 ☐ 5 - 6
☐ 7 - 8 ☐ Less than 5
☐ 6 - 7 ☐ More than 9

7. What is your highest educational degree?

- ☐ 2 year associates ☐ Masters
☐ 3 year degree ☐ Ph.D.
☐ 4 year baccalaureate ☐ Other

8. Years working as a registered nurse:

- ☐ Less than 1 ☐ 16 - 20
☐ 1 - 5 ☐ 21 - 25
☐ 6 - 10 ☐ More than 25
☐ 11 - 15

9. Which of the following best describes the type of setting in which you work?

- ☐ Acute care hospital

- ☐ Doctor's office, public health clinic, free-standing ambulatory care center
- ☐ Psychiatric facility
- ☐ Educational setting
- ☐ Long term care facility
- ☐ Homes of patients
- ☐ Correctional facility
- ☐ Other

10. Years working in current setting:

- ☐ Less than 1 ☐ 16 - 20
- ☐ 1 - 5 ☐ 21 - 25
- ☐ 6 - 10 ☐ More than 25
- ☐ 11 - 15

11. How much of your work time is spent in direct patient care activities?

- ☐ 76 - 100% ☐ Less than 25%
- ☐ 51- 75% ☐ No patient care
- ☐ 26 – 50%

12. On average, how many hours per week do you work per week in nursing jobs?

- ☐ Less than 20 ☐ 61 - 80
- ☐ 21 - 40 ☐ More than 80
- ☐ 41 - 60

13. Do you have any jobs besides your main nursing job or do you do any other work for pay?

☐ Yes

☐ No

If yes, please list:

14. On average, how many hours do you work per week in all jobs combined?

☐ Less than 20

☐ 61 - 80

☐ 21 - 40

☐ More than 80

☐ 41 - 60

15. Which of the following best describes the schedule you USUALLY work at your main nursing job? (Please select only one.)

☐ Regular daytime schedule

☐ 3 shift rotation-days / evenings / nights

☐ Regular night shift

☐ Irregular schedule arranged by employer

☐ Regular evening shift

☐ Irregular schedule arranged by employee

☐ 2 shift rotation-days / evenings

☐ Other

16. What is the usual length of your shift at your main nursing job?

☐ 8 hours

☐ Less than 8 hours

☐ 10 hours

☐ More than 12 hours

☐ 12 hours

APPENDIX B: NURSING PERFORMANCE INSTRUMENT

Please rate the extent to which you agree with the following statements. Circle a number from 1-6: “Strongly Disagree” to “Strongly Agree” which best indicates your response.

	Strongly Disagree	Disagree	Slightly Disagree	Slightly Agree	Agree	Strongly Agree
During a work shift, changes in my muscle strength, endurance, or physical energy affect my ability to perform physical tasks associated with my job (e.g., carry items, perform patient handling tasks, walk/drive from patient to patient, etc.)	1	2	3	4	5	6
I sometimes find it necessary to take short-cuts in patient care	1	2	3	4	5	6
I always apply the “5 rights” principle when administering medications	1	2	3	4	5	6
Throughout a work shift I am able to perform fine motor tasks (e.g., inserting an IV, catheter insertion, medication preparation, etc.) without difficulty	1	2	3	4	5	6
During a work shift, changes in my concentration or alertness affect my ability to perform patient monitoring, medication administration, and documentation tasks.	1	2	3	4	5	6
I am always able to carry out safe nursing practice	1	2	3	4	5	6
During a work shift, changes in my mood, mental energy, or attentiveness affect my ability to communicate clearly and effectively (e.g., express my opinions, understand what others are saying, etc.) with other nurses, physicians, clinicians, patients or family members	1	2	3	4	5	6
I always follow existing facility guidelines for safe patient handling (e.g., use of lift devices, two person lifts, etc.)	1	2	3	4	5	6
I am sometimes forced to modify my standards to get the work done	1	2	3	4	5	6

APPENDIX C: LABORATORY STUDY PARTICIPANT DEMOGRAPHICS

Participant	Gender	Age	Ethnicity	Height (in)	Weight (lb)	Hours of sleep/night
1	M	21	Asian-American	74	245	6-7
2	M	20	Caucasian	71	173	7-8
3	M	20	Caucasian	68	155	5-6
4	M	23	Asian-American	68	152	7-8
5	M	22	Caucasian	73	206	5-6
6	M	24	Asian-American	71	178	5-6
7	M	20	Caucasian	74	175	6-7
8	M	22	Caucasian	73.5	201	7-8
9	F	21	Asian-American	63	126	7-8
10	F	20	Caucasian	67	131	7-8
11	F	20	Caucasian	67.5	150	7-8
12	F	20	Hispanic	62	138	6-7
13	F	24	Caucasian	65	115	7-8
14	F	23	Caucasian	64	126	7-8
15	F	21	Asian-American	68	173	5-6
16	F	20	Caucasian	68	135	8-9

APPENDIX D: LABORATORY STUDY INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants in Research Projects Involving Human Subjects

Title of Project: Measuring the effects of fatigue on performance

Investigator(s): Linsey Barker and Dr. Maury Nussbaum, Faculty Advisor

I. Purpose

The purpose of this project is to examine fatigue and performance during simulated nursing work tasks. Specifically, we are interested in determining how changing task demands will affect performance on mental and physical work tasks. The results of the study will help us to further understand how fatigue can impact performance and safety.

II. Procedures

It is important for you to understand that we are not evaluating you or your abilities in any way. You are helping us to collect data that will be used to understand how work demands affect fatigue and performance in nursing work tasks. Therefore, we ask that you perform normally and be as honest as possible in your responses to questions. The information and feedback that you provide is very important to this project. The experiment will consist of one orientation session (less than one hour) and one to four experimental sessions with each experimental session lasting approximately 3 to 4 hours.

During the course of this experiment you will be asked to perform the following tasks:

- 1) Read and sign an Informed Consent Form (this form)
- 2) Fill out a brief demographic form
- 3) Perform one to four experimental sessions of several simulated nursing tasks

During each experimental session you will complete the following tasks/procedures:

1. At the start of the session, a heart rate monitor will be affixed to your chest. This heart rate monitor includes both a chest strap and receiver worn on your wrist. A same-gender individual will assist you in positioning the chest strap.
2. Fill out several surveys related to your perceptions of fatigue and complete a set of physical and mental assessments
3. Complete a series of simulated nursing work tasks with high and low mental and physical demands. Simulated work tasks will include: fine motor skills tasks (sorting beads by color, using yarn to sew a pattern on a cardboard template), filling out paperwork, mathematical activities, walking up and down up to 3 flights of stairs, and pushing a hospital bed down a 40 meter pathway. You will be provided specific instructions on

how to complete each task. You will perform these tasks in a repeated sequence for approximately 2-3 hours, or until you feel high levels of exertion.

4. While completing the work tasks, you will be asked to regularly rate your level of perceived exertion using a 10 point scale. This scale will be demonstrated to you during the orientation session and you will have an opportunity to practice providing exertion ratings.
5. Upon completing the work tasks, fill out several surveys related to your perceptions of fatigue and complete a set of physical and mental assessments

Each experimental session will last approximately 3-4 hours; 1 hour for completing surveys and mental and physical assessments, and 2-3 hours for completing work tasks.

All of the experimental sessions will take place within the Industrial Ergonomics and Biomechanics Laboratory, in the Department of Industrial and Systems Engineering.

III. Risks and Benefits

There are minimal risks to you as a participant in this study as follows.

1. You may experience minor muscle strain or fatigue as a result of performing the experimental tasks.
2. You may experience some muscle soreness, 1-2 days after the experiment.

Participants in a study are considered volunteers, regardless of whether they receive payment for their participation. Under Commonwealth of Virginia law, workers compensation does not apply to volunteers. Should you be injured during your participation in this study, neither the researchers or the University have money set aside to pay for medical treatment, and any costs associated with treatment would be at your own expense. Appropriate health insurance is strongly recommended to cover these types of expenses.

This research project will help quantify the effects of fatigue on performance. Understanding these effects may benefit both nurses and the patients they provide care for. While this research may yield such benefits, no promise or guarantee of benefits will be made to participants. Participants may contact the investigators listed at the end of the Consent Form to inquire about the results and conclusions of this research.

IV. Extent of Anonymity and Confidentiality

Your personal information and identity will be kept in the strictest of confidence. No names will appear on questionnaires or surveys, and a coding system will be used to associate your identity with questionnaire answers and data. The list associating names with answers will be destroyed one month after completion of data collection. All information will be collected in a file and locked when not being used, and only the investigators have access to the data. It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

V. Informed Consent

You will receive two informed consent forms to be signed before beginning the experiment; one for your record and one for the experimenter's record.

VI. Compensation

If you meet all of the inclusion criteria, you will be compensated for your participation at a rate of \$10 per hour for a maximum of 20 hours, or a maximum of \$200 total. You will be paid at the end of this study in cash. Should you choose to withdraw from the study prior to completing all experimental sessions, you will be paid for the hours you have participated in the study up to the point of your withdrawal.

VII. Freedom to Withdraw

You are free to withdraw from this study at any time without penalty or reason stated, and no penalty or withholding of compensation will occur for doing so. If you choose to withdraw, you will be compensated for the portion of time of the study for which you participated.

Furthermore, you are free not to answer any question or respond to experimental situations without penalty. There may be circumstances under which the investigator may determine that the experiment should not be continued. In this case, you will be compensated for the portion of the project completed.

VIII. Approval of Research

The Department of Industrial and Systems Engineering has approved this research, as well as the Institutional Review Board (IRB) for Research Involving Human Participants at Virginia Tech.

IX. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1. To read and understand all instructions.
2. To work under the conditions specified by the experimenter to the best of my ability.
3. To answer questions, surveys, etc. honestly and to the best of my ability
4. To inform the investigator of any discomforts I experience immediately.
5. Be aware that I am free to ask questions at any point.

X. Participant's Permission

I have read the Consent Form and conditions of this project and the answers I have included within the declaration of physical health are factual. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent to participate with the understanding that I may discontinue participation at any time if I choose to do so:

Participant's Signature

Date

Experimenter's Signature

Date

The research team for this experiment is led by Dr. Maury Nussbaum. He may be contacted at the following address and phone number:

Dr. Maury A. Nussbaum
Professor
Department of Industrial and Systems Engineering
250 Durham Hall
Blacksburg, VA 24061
(540) 231-6053

In addition, if you have any detailed questions regarding your rights as participant in University Research, you may contact the following individual:

Dr. David Moore
Chair, Virginia Tech Institutional Review Board
for the Protection of Human Subjects
Office of Research Compliance
2000 Kraft Drive, Suite 2000 (0497)
Blacksburg, VA 24060
(540) 231-4991

APPENDIX E: LABORATORY STUDY ARITHMETIC AND DISTRACTION QUESTIONS

Arithmetic Questions - Low Mental Demand Sessions

(X: random number between 1 and 20; Y: random number between 1 and 20)

1. The patient needs **X** of the blue pill and **Y** of the green pill. How many pills total will the patient be taking?
2. John needs his blood pressure taken **X** times a day. Mary needs her blood pressure taken **Y** times a day. What is the total number of times you will take both John's and Mary's blood pressure?
3. There are **X** people on the first hall that are in need of assistance. There are **Y** people in the second hall that need assistance. How many people are there that you need to assist?
4. There are **X** people that arrived today with a broken arm. There are **Y** people that arrived today with a broken leg. How many people will you need to cast today?
5. Stitches are required for **X** people in waiting room one and for **Y** people in waiting room two. How many people combined are in need of stitches?
6. There are **X** doctors on call and **Y** nurses, how many people are on staff?
7. There are **X** patients on floor seven, and **Y** patients on floor four. How many patients are there on those two floors?
8. If **X** ambulances come in the morning, and **Y** come in the afternoon, how many arrive that day?
9. If Bill needs **X** ccs of one drug and Dave needs **Y** ccs of another, what is the total amount of medication that you will administer to these two patients? -- **23**
10. If the doctor discharges **X** patients from the ICU and **Y** patients from the emergency room, how many patients are discharged?

Arithmetic Questions - High Mental Demand Sessions

(X: random number between 4 and 9; Y: random number between 11 and 50)

1. Ann Smith, a patient of yours, needs her medication of **Y** milligrams **X** times throughout the day. What is the total dosage in milligrams that Ann will receive?
2. **Y** accidents will occur today with **X** people from each accident. How many people will be arriving at the ER?
3. If **Y** patients have been released today on each of the **X** floors of the building, what is the total number of patients released today?
4. If **X** beds are in each room and there are **Y** rooms. How many bed sheets need to be changed?
5. A patient needs a dosage of **Y** mg of medication **X** times every day. How many milligrams will the patient take per day?

6. There are **X** doctors on call and **7** nurses, how many patients will each doctor have to see if there are **Y** patients?
7. If there are **X** hospitals in the area and **Y** ambulances how many ambulances go to each hospital?
8. If **X** doctors have **12** interns each and there are **Y** rooms how many rooms does each doctor have to cover?
9. If there are **Y** nurses and **X** amount of shifts how many nurses will be on each shift?
10. If there are **Y** nurses and **X** hours worked per nurse how many hours are worked per day?

Distraction Questions – during medication administration in high Mental Demand sessions

1. What is one patient name?
2. What floor did you just go to get the medicine?
3. What are the letters of the pills you just picked up?
4. What task is next?
5. What is the total amount of milligrams for the drug you have in your hand?
6. What are the three things that you must remember for each patient?
7. How many patients are you responsible for?
8. How many drugs are there to administer?
9. How many task cycles have you completed?
10. How many weights are on the bed?
11. Which patient did you have to type notes for?
12. How many times do you push the bed per cycle?
13. How many task cycles do you do per session?
14. Where do you have to go for the next set of pills?
15. How many things are you carrying around this session?
16. How many side rails are there on the bed?
17. How many cycles of the box placement task do you do at the start and end of each session?
18. How many patient rooms are there?

APPENDIX F: LABORATORY STUDY NURSING TREATMENT NOTES

Patient: Lin Yang, Treatment Notes 13:54

Mid-day assessment indicated that the patient was Ox4 but still complaining of insomnia and difficulty sleeping. Tests indicated PERLLA. 50 ccs of dexmedetomidine was administered via central line to aid in sleeping/rest. A pain assessment revealed he was not experiencing any localized pains but was still complaining of general discomfort and some numbness in his posterior. The patient asked when the DHT could be removed. The last BM was at 0845. Family members were educated on the tube and digestive concerns when it is removed.

Patient: Anne Klein, Treatment Notes 14:02

Mid-day nursing assessment began with GCS. Patient scored 10 overall – 4 on eyes, 3 on verbal and 3 on motor. A follow up motor assessment was performed and APPP plus PWD. Oral examination revealed TML. The speech-language pathologist was in the room and educating caregiver on results of swallow study. Patient is not ambulatory and bed-based fall prevention alarms were checked and re-activated. Patient requested a change of gown and nursing tech was called to perform sponge bath and gown change.

Patient: John Smith, Treatment Notes 14:49

Mr. Smith is complaining of trouble breathing and CP. An EKG was brought in to more closely monitor cardiovascular activity. Aspirin per oral was administered. Pulse oxygen levels were sufficient at 80% oxygen. Patient complained about oxygen tubes and numbing ointment was provided to help with pain sensation in nasal cavities. A circulation exam revealed APPP indicating that the SCD is functioning. The patient should be ambulatory within the next 24-48 hours but will need to wear SCD when in bed even post-discharge.

Patient: David Lee, Treatment Notes 15:00

Patient has not had a BM in 36 hours and has fever (100.8 F). Physical exam indicated BSx4. A NGT was inserted. During insertion, the patient gagged as the tube approached the pharynx. Water was administered per oral and the patient was able to swallow and allow the tube to pass. Proper insertion was tested with pH paper which indicated a pH of 5.2. Lubiprostone and Naproxin were administered via the NGT and follow-up reviews of pain and bowel activity were ordered.

Patient: Arthur Evans, Treatment Notes 15:11

Patient was combative and visibly distressed. Sedative administered via ETT. Physical exam revealed PERLLA and a GCS score of 9. Patient gestured that he was experiencing localized pain in his head and left hip surgical wound. A check of the skin revealed that skin around the wound was PWD but skin on the sacrum was red and irritated indicating a pressure sore due to immobility. Increased rotation of the patient in bed was ordered and antibiotic ointment was applied to the wound.

Patient: Jane Gardner, Treatment Notes 15:27

Ms. Gardner has been coughing all day and complained of SOB. Her pulse oxygen is 100 on 90% oxygen. The bed was raised to 60 degrees to aid in airway maintenance. Physical exam

revealed PERRLA, TML and patient was Ox4. Patient also reported blood in her urine; a 50ml urine sample was collected and sent to laboratory for testing. Blood was also drawn, the patient's veins are starting to collapse from multiple IVs; a central line may be warranted to provide consistent access.

Patient: David Lee, Treatment Notes 15:44

Patient was Ox4 but still complaining of insomnia and difficulty sleeping. Tests indicated PERRLA. Additional 100 ccs of dexmedetomidine administered via central line to aid in sleeping/rest. Pain assessment revealed he was not experiencing localized pains but still complaining of general discomfort and some numbness in his posterior. Physical exam revealed skin on posterior is PWD and there are no signs of shearing or pressure wounds. The patient's DHT was removed. Food per oral will be slowly reintroduced following dietician's treatment plan.

Patient: Anne Klein, Treatment Notes 15:58

Assessment began with GCS. Patient scored 10 overall – 4 eyes, 3 verbal and 3 motor. Follow-up motor assessment was performed and APPP plus PWD. Oral examination revealed TML. Caregiver education performed on GCS and implications for home care following discharge. 50 ccs of urine present in Foley catheter bag with good clarity and color. Blood sugar tested and within normal ranges (109). Patient indicated she was feeling lightheaded and dizzy at times and bed was lowered to 15 degrees. Blood pressure steady at 134/86.